CITY OF SAN LEANDRO
"METRICOM'S RICOCHET NETWORK: ALTERNATIVE NEW WIRELESS TECHNOLOGY FOR TRAFFIC SIGNALS"

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The City of San Leandro is currently implementing a new Advanced Signal System. The system uses Econolite's *icons* central computer software and NEMA (ASC/2s) field controllers. A network of fiber optic cables will connect the *icons* communications server computer to those traffic signals located in close proximity to the existing or planned fiber optic infrastructure. The majority of the city's fifty-eight traffic signals, are located in remote locations that cannot be connected to city-owned fiber in a cost effective manner. The City chose to use an existing commercial communications service in the city as an alternative.

Abstract

The third phase of the City's Advanced Signal System is currently being implemented. This third phase will install several fiber spurs, closed circuit television cameras, and implement wireless communications to remote signals via an integration of Metricom's Wireless Ricochet Network with Econolite's ASC/2s controllers.

The City's icons central system will utilize this packet radio network operating under the Star Mode, a proprietary, connectionless service, via a virtual private network configuration. The modems operate in the 900 MHz range, and the network handles all routing, contention, and retransmissions.

The City's Advanced Signal System will utilize a new communications protocol being developed by Gardner Systems that is "event driven". This protocol dictates that a message is sent only when a change in status occurs, or when a request for information is received. This is very different from the typical polling based protocols used for nearly all of today's signal systems.

The City's system will use the State of California's AB3418E (extended) message sets for system communications. Since the network only needs addresses and timestamps for communications, any modem can be easily relocated to a new location with relatively little effort. Future enhancements to the protocol include support for NTCIP Class B messages, and transmission of controller event logs.

The City will implement modems at traffic signal locations that will ultimately be connected over fiber. As each of these signals is connected with fiber, the modems will be relocated to other more remote locations in the City.

This paper will discuss the basic technology and versatility of this packet radio network for communications with traffic signals, the new communications protocols being developed, and the future enhancements to this technology.

Problem Statement

The City of San Leandro currently has a number of traffic signals that are in either remote locations or on City arterials with no communications infrastructure in place. Although the City is implementing a fiber optic network to connect many of the existing signals, there are a few signals situated such that installing any type of wireline interconnect medium would require an extensive investment. In addition, the City has moved away from using field masters with the new traffic management system. Utilizing leased wireline technologies would require installation and recurring charges for each signal to be controlled, with each connection fixed for each signal. Leased telephone lines have long been used for traffic signal communications, but are unpopular and treated as an option of last resort by most cities due to the high on-going costs and reliability issues.

Given these parameters, the challenge was to find a technology that did not require a wireline medium, could be flexible in terms of relocating from one signal to another, and required minimal setup and installation time. Also, the medium is to be used as a temporary solution to monitoring and controlling an intersection until the controller is connected to the fiber network. This technology can also be used for emergency backup in case of a break in the fiber network interrupts communication to the controllers until the fiber service is restored.

SYSTEM OVERVIEW

This section discusses the overview of the City's Advanced Signal System including the existing conditions, system architecture, and integration of the various system components and the alternative communication solutions that were investigated.

Overall System Architecture

The City of San Leandro's Advanced Signal System consists of multiple implementation phases. It includes a comprehensive fiber optic network, a new central signal control system called "icons" (Econolite), new field controllers (Econolite ASC/2s) and cabinets, video detection systems, a closed circuit television system, and a high speed remote link to the City's Corporation Yard. The various phases of the project are prioritized in such a way that the backbone infrastructure was installed first taking adavantage of opportunities for other projects to assist with the installation of the infrastructure. The subsequent phases consist of adding signals on the heaviest traveled arterials in the City, including installing field equipment and new controllers.

The communications network consist of a fiber optic backbone that has assigned fibers for accommodating both the City's signal system as well as other City departments. The City of San Leandro did dedicate four fibers that will be used by the two school districts located within the city limits. The City's Main Library and several smaller libraries and Corporation Yard were the first departments to be connected over the fiber backbone. Other departments to be linked under separate phases include the City's Wastewater Treatment Plant, the City Attorney's office (located off site), and the fire stations operated by the County fire department.

As part of the expansion phases of the overall system, the City will has deployed a wireless packet radio system for real-time control and monitoring of traffic signals. The Metricom "Ricochet" network is the packet radio system that forms the base network for the wireless system. There are repeater antenna's located throughout the City installed on streetlight luminaire arms. Using the City's agreement with Metricom, industrial strength "field hardened" radio modems were purchased at discounted rates with the service set at about $30 per month for each modem placed into service.

The City of San Leandro entered into a franchise agreement with Metricom which provided several alternatives. They were as follows:

1. The City could receive a franchise fee of $30 per month for each Metricom unit installed within the City's right-of-way.
2. The City could receive free modems up to the number of Metricom units installed within the City's right-of-way and pay $30 per month for service.
3. The City could buy the modems ($800) and receive free service for up to the number of Metricom units installed within the City's right-of-way.

For the purposes of providing communications to the traffic signal controllers, alternative 3 was the most attractive.

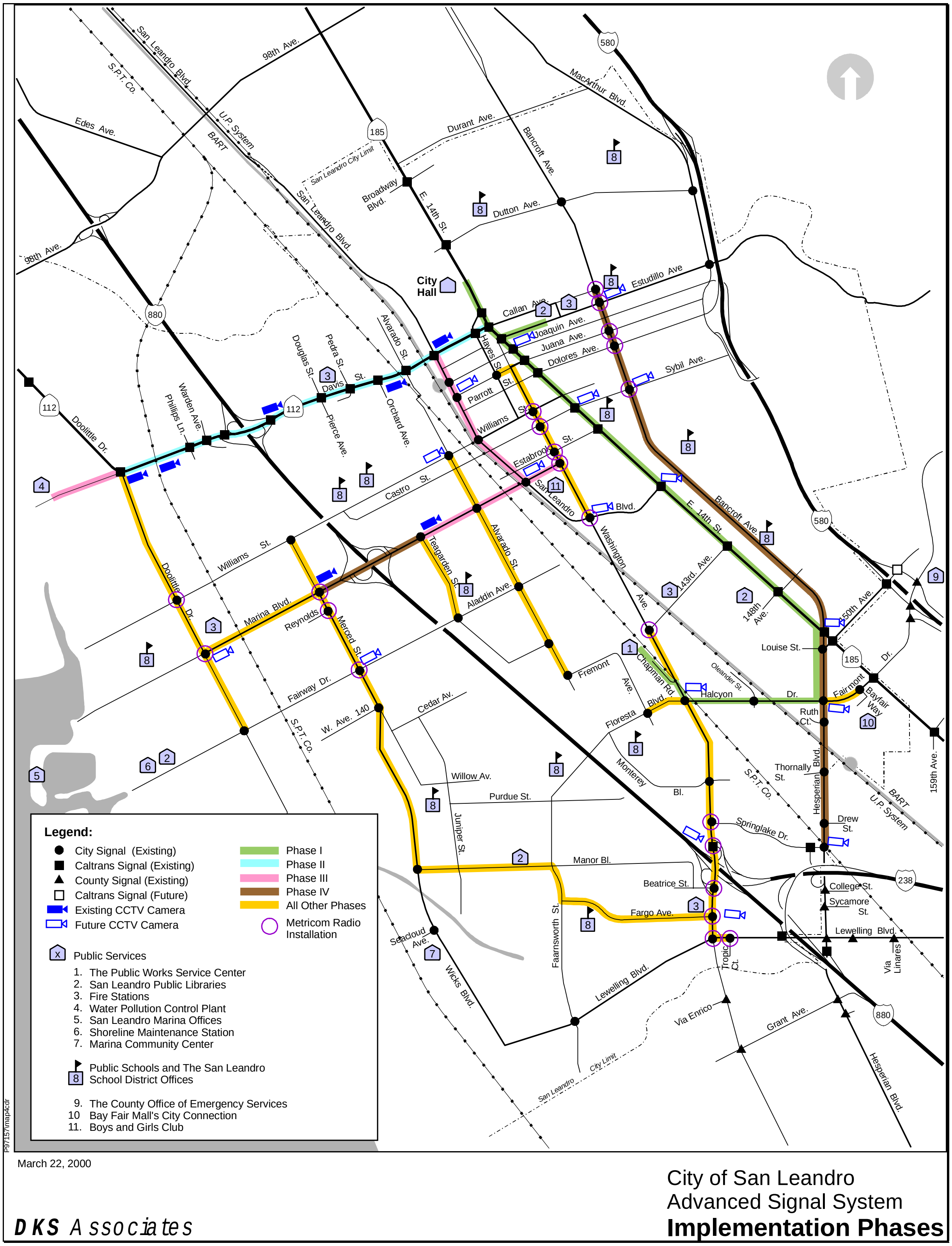
Figure 1 shows the overall planned Advanced Signal System including the various phases of implementation.

Existing Conditions

The City currently owns, operates and maintains 58 traffic signals. Prior to the installation of the new system, the interconnect infrastructure was sparse. The previous system consisted of field masters connected to a central computer over telephone lines, and connections between the field master and the local controllers over copper wire pairs. The interconnect was only deployed for a few signals on several arterials with little flexibility in configuring coordinated groups and communication channels.

Feasibility Study

The City's system consultant conducted a two-phase design and feasibility study of utilizing the Ricochet packet radio network for traffic signal controller communications. This study evaluated the required modifications to the central system software's protocol, the field equipment, and the overall cost to the City to implement the system.



The use of Ricochet was originally investigated by DKS Associates during the preliminary design of the new traffic signal system for the city. It was found that the concept was promising and worthy of further consideration. The second phase of the study was a more detailed investigation, conducted by Gardner Systems during Phase 2 of the overall advanced signal system implementation.

Background

The San Francisco Bay area is served by a commercial packet radio network called Ricochet, installed and operated by Metricom. This network uses a mesh net of spread spectrum radio transceivers, combined with gateways to the telephone system and Internet, to relay data packets to and from wireless modems. Consumers can purchase or lease wireless modems that can be attached to laptop computers, remote management devices, or any other device with a need for wireless wide-area communications within the Bay Area metropolitan region. The modems can be used for unlimited data transmission on the network as long as a monthly access fee (currently $30) is paid. Metrciom has also deployed a Ricochet network in some other metropolitan areas within the US.

System Integration

Traffic signal management systems, including *icons*, normally involve a central computer that polls every traffic signal about once per second to gather status data and to occasionally send a control command or new control parameters. This involves continuous transmission of data packets to and from multiple traffic signals on multiple communications circuits or channels. Traffic signals sharing a circuit, or channel (typically in the range of 4 to 8 signals in a system like *icons*) use time-division multiplexing, with each signal communicating with the central computer about once each second, or as fast as cyclical polling allows.

The communications protocol currently used in *icons* and other traffic signal systems relies on precise timing of transmissions and a low tolerance for delayed responses to achieve effective time-division multiplexing given the low baud rates (often only 1200 bits per second, or bps) supported by traffic signal controllers and typical multi-drop modems/transceivers over the long distances involved. Such a protocol cannot be used with Ricochet due to the variable latency (up to 2 seconds or so on rare occasions) that can be experienced on this shared packet data network. A polling protocol is also wasteful of shared bandwidth and does not take advantage of the routing and contention management capabilities of the Ricochet network.

Thus, in order to take advantage of the packet radio network, the icons central system software had to be modified to change the way the communications protocol worked. The traditional polling-based protocol needed to be revised to a demand-based protocol which is more tolerant of network latencies and delays, and utilizes the network's routing and contention controls. The integration of icons and its protocol with the Ricochet radio network is discussed in more detail in Chapter 3, Implementation.

Alternative Solutions

Two specific alternatives were evaluated for implementation: Spread spectrum radio and Microwave. Both systems would require an extensive network of repeater sites to get the connection back to City Hall. Other configurations included a single repeater site for all the signalized intersection sites to bounce their signal off of with the central repeater making the trunk connection to City Hall. This was not feasible since there are neither tall towers nor high elevation hills which would be able to provide the required line of sight to each signalized intersection site and City Hall.

Based on the extensive infrastructure and cost of the two alternative wireless systems, they were not determined to be practical for the City to consider for its signal interconnect needs.

IMPLEMENTATION

This section discusses the implementation of the Metricom network with icons as part of the City's Advanced Signal System including the system's specifications, requirements and field installation.

System Concept Design

The Ricochet modems have been installed in traffic signal controller cabinets throughout the City. The modems require a separate telemetry port on the controller for its communications with the controller. Each controller with a Ricochet modem is essentially a separate channel to the network all sending packets to the central modem located at City Hall. In return, the central modem sends data packets to the field with the controller's address located within the data packet. Because the network is a meshed network, i.e., multiple paths between each location, data packets are sent without regard to the network topology. The network takes care of examining the destination address of the packet and forwarding it on the next available path to its destination.

Ricochet network radios on poletops use spread-spectrum techniques to communicate with each other, with Ricochet radio modems, and with gateways to dial-up the public switched telephone network (PSTN) and the Internet. The network radios investigate the address of each packet and route it towards its destination. A particular data packet may be relayed through any number of network radios and perhaps through the telephone network on its way to its addressed destination. The network radios manage access and contention in the network, retransmit packets when needed, and temporarily store (buffer) data packets when needed.

In San Leandro, Metricom reports having deployed sufficient Ricochet network radios to provide radio coverage throughout the built-up portion of the city, including all signalized intersections. The system is designed to enable end-user modems to access the network from any outdoor location (any indoor locations accessible by 900 MHz radio signals) within the coverage area via a small antenna attached to the modem.

Figure 2 illustrates the overall data packet communications concept of the Metricom network used for traffic signals in San Leandro.

System Specifications

The Ricochet network supports two basic modes of packet radio communications in the end-user modem, ATDT Mode and Star Mode.

The ATDT Mode is a connection-oriented service (sets up and tears down circuit connections for every data exchange session) that emulates a dial-up modem and the ATDT command set. This mode enables the use of Ricochet for communications with the Internet and other networks and services reachable over the telephone network. ATDT Mode is commonly used by laptop computer users to access the Internet.

The Star Mode is a proprietary connectionless service (does not set up circuit connections) using a simple packet structure for peer-to-peer message exchanges between devices with Ricochet modems. Star Mode is intended for use in Virtual Private Networks (VPN), such as the traffic signal system. Within the industrial modem, there are variations on Star Mode that provide different addressing and data format options. The Ricochet modems have an RS232 physical interface. The industrial modems needed for traffic signal applications require a 12 VDC power source. They cannot be powered via the RS232 connector.

Using Ricochet's Star Mode, any device (or node) with a Ricochet modem can send a data packet to any other similarly equipped device on the network at any time. The Ricochet network takes care of routing and contention, to deliver the packet to its addressed destination modem. Delivery is not assured, and packets are occasionally lost without retransmission. The delivery time and order are also not assured or bounded.

The maximum packet size is 1083 bytes of user data. Larger byte streams are automatically broken into packets of this size and reassembled at the receiving modem. Packets are transmitted between radios at about 100 kilobits per second (kbps), but effective end-to-end throughput is similar to a 28.8 kbps telephone modem due to delays in the network. Packets are typically delivered within 300 milliseconds, but may occasionally take much longer (up to 2 seconds on rare occasions) when the network is congested. There is no significant difference in delivery time of different size packets in the range of 10 to 50 bytes as is typically sent in traffic signal applications.

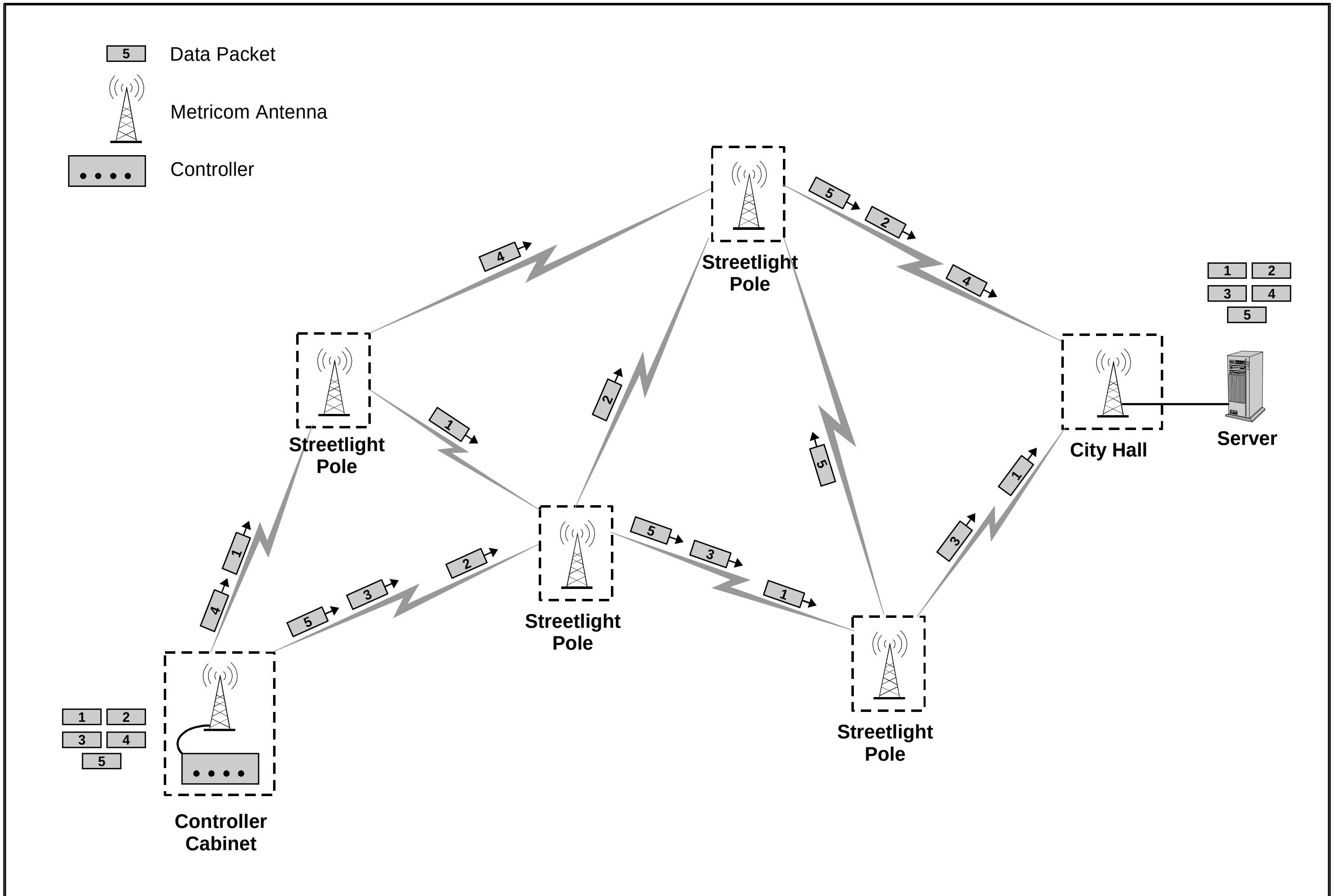


Figure 2
Ricochet Network for Traffic Signals

System Components

Communications over the Ricochet network requires several system components.

The system components for the field cabinets include:

- Ricochet modem
- Antenna (hockey-puck)
- Coaxial cable for antenna
- Power cable for the modem
- Serial cable for the modem
- Serial telemetry card for the controller

The system components for the central server include:

- Central modem
- Antenna (whip style)
- Coaxial cable for antenna
- Power cable for the modem
- Serial cable for the modem
- Serial communications port on the server

Figure 3 illustrates the system components of the Metricom system.

System Requirements

The system required several revisions to both the central system software and the field controller software in order to use the Ricochet network for communications with the traffic signals in San Leandro. Other items were required including the following:

- The system could only use the industrial Ricochet modems (model ICR-900) which were purchased from Metricom. The modems that were mounted in the controller cabinets have "vandal-proof" low profile (hockey-puck style) antennas suitable for mounting on traffic signal cabinets.

- There is one central modem located at City Hall. This modem is mounted in the equipment room connected to a whip antenna mounted on the rooftop at City Hall. This antenna location provides for the best signal reception between the central modem and the field modems.

- The City had to coordinate with Metricom to commence network service for the twenty-five modems deployed.

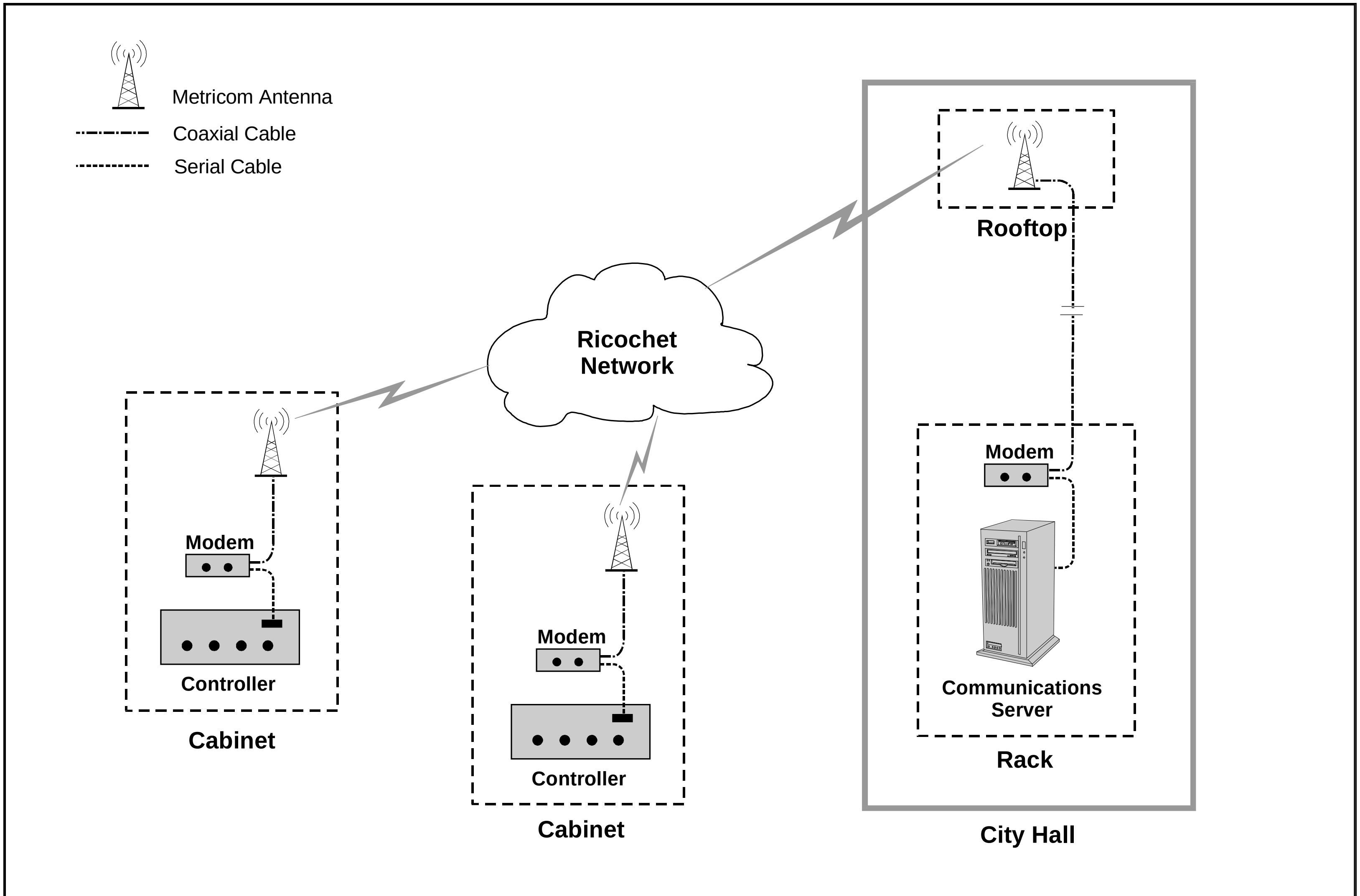


Figure 3
System Components (Metricom System)

- The Ricochet modem and antenna had to be installed into each cabinet slated to receive a modem. This included wiring for the power supply and external antenna, and the serial

- cable to the controller. The external antennae was self-adhering over a hole drilled in the cabinet for the coaxial cable to the modem.

- Each controller to be connected to a Ricochet modem required new software and telemetry cards with the modified version incorporating the new communications protocol.

- Though the Ricochet Modem claims to be compatible with from 12vdc to 24vdc power, it was found that the modems would "burn out" while operating under 24 vdc over a short period of time (typical 2 weeks). Thus, the City had to install voltage transformers at all TS-1 cabinets to step down the power from 24 vdc to 12 vdc. At the TS-2 cabinets, there were 12 vdc power sources, which eliminated the need for transformers.

Communications Protocol

The communications protocol for the Metricom system is drastically different from the traditional protocols used for traffic signals. In addition, the messages are based on standard message sets defined in California.

Listed below are some of the highlights of the protocol.

- The protocol is event driven and does not use polling.
- Controllers autonomously send a message to the central server at startup and when their status changes.
- Controllers also send a message when the central server asks for information or an acknowledgment.
- All messages will include the address of the source device as well as the address of the destination device.
- If a controller has not sent a message for a period of "x" seconds or minutes, it will send a message identifying the last message sent, to serve as a heartbeat message. If no message is received for "x" seconds or minutes, the central server will cease transmissions to a controller.
- The server will send a heartbeat to a controller if no other message is sent within "x" minutes. If controllers do not receive a message from the server within "x" minutes, they will cease sending messages to the server until a message is received. This avoids unnecessary network traffic if the server is not communicating.
- A message is transmitted to a controller only when it needs to acknowledge a message received from the controller, change parameters in the controller, issue a command to the controller, reset the controller's clock, upload information stored in the controller, or check the health of the controller if it has not sent any message for a long time.
- When a controller determines that a status message needs to be sent to the server because at least one status item has changed, it waits "x" milliseconds ("x">100) before sending the

message, and during that time, updates all status items in the message. This avoids repeated messages for closely spaced events.

- After receiving a status message, the central server will return an acknowledgement message to be defined, if the user so desires. The controller will retransmit the status message if a positive acknowledgement is not received within “x” seconds. Retransmissions will be attempted a maximum number of times, after which it will cease the retransmissions.
- The central server may request a snapshot status update (i.e., issue a GetStatus message) after startup.
- Both the server and controllers will send configuration commands to the attached modem at startup, and whenever communications fail.
- Controllers will not report detector presence status changes nor non-locked phase calls unless selectively instructed to do so by the server.
- All messages will include a timestamp indicating the time it was transmitted, in 0.1 second units since the start of the current hour. The combination of the source address and timestamp will serve as the unique identification (ID) for each message for use in acknowledgement messages. Retransmitted messages will include the original message timestamp and the time of the new transmission.
- The server will automatically send a clock reset message (SetTime) to each controller individually once per day at a user defined time, e.g., 4:00 AM to minimize the risk of large network latencies during clock updates.
- Status (response) messages normally will be sent autonomously when a status item changes, not in response to a Get request.
- Both *icons* and the controllers will use Ricochet’s Frame Recognition Mode, a variation of Star Mode.
- Messages are identical to those defined by AB3418 and AB3418E (extended) to the extent feasible.
- AB3418 and AB3418E messages supported are:

  – GetControllerID
  – SetTime
  – SetPattern
  – GetSystemDetectorData
  – GetShortStatus
  – GetStatus8
  – GetLongStatus8
  – GetStatus16

  Unless instructed otherwise, controllers will send Status8 or Status16 (if phases>8 enabled).

- Upload and download of timings will use the same format as currently used in *icons* for the ASC/2 controller under the AB3418 protocol.

This protocol is expected to provide a very good level of service for traffic signal management and not unduly load the Metricom network. The following are differences between signals using conventional communications protocols (once per second polling) and signals using the Ricochet network with the proposed protocol:

- Signals on the Ricochet network will normally have their status updated at the same or a faster rate, but the rate of update will be variable and will occasionally be slower than signals on the conventional channels.

- Unless the user turns on intensive monitoring, signals on the Ricochet network will not provide detector presence nor non-locked phase call information, but when turned on, the presence representation will be more realistic than for signals on conventional channels since the update rate will generally be faster.

- Time clocks in controllers will not be set as accurately using the Ricochet network, but should be adequate for signal coordination.

The protocol as described above is the maximum that was able to be achieved within the constraints of the project budget, and is considered adequate for the initial implementation.

However, several improvements are planned for the proposed protocol to provide more functionality and flexibility, and an overall improved level of service. Some of the improvements include:

- A more sophisticated clock reset algorithm to achieve more accurate clock times.
- Extending the protocol to support NTCIP Class B Messages
- Adding more information such as special function status, controller event logs, etc.

Field Installations

The field installations were performed by both City staff and vendor staff. Some of the items of work that were required included the installation of miscellaneous hardware items such as cables, wiring, fittings, and controller PROM chips. In addition, at the existing TS-1 cabinets, a separate transformer was needed to supply a 12 vdc source for the modems.

At City Hall, the central antenna was installed on the rooftop with the cabling installed in existing ceiling cavities and conduit without the need for new openings or borings in concrete or other substantial walls or floors.

CONCLUSIONS

This section discusses some of the issues associated with the wireless system deployed in the City. The discussion focuses on the benefits of the system and how the City intends on utilizing these benefits for expansion and maintenance of its Advanced Signal System.

Flexible Implementations

An advantage of Ricochet is that any signal at any location can be added at any time without having to establish a continuous cable path to City Hall, and modems can be relocated between signals when needed. It can therefore be used as an interim connection while waiting for future projects to install cable and as a temporary installation when cable breaks or construction interrupt traditional cable links.

Standard Interfaces

The system utilizes standard interfaces readily available within the industry. These Commercial Off-the-Shelf (COTS) interfaces include the following:

- Serial connections (RS-232)
- Connectors (DB-25, BNC)
- Communication protocol message sets (AB3418 and AB3418E)
- Cabling (Coaxial)

These standard interfaces enable the City to repair and replace equipment without being tied to a specific vendor or manufacturer. Future upgrades of the communications protocol may include compliance with national standard such as NTCIP and the Wireless Access Protocol (WAP).

Unlimited Capacity vs. Transmission Latency

The transmission baud rate (typically 28.8 kbps) is faster than the conventional traffic signal mediums currently deployed in the industry (1.2 kbps). This enables the implementation of the NTCIP standard without having to worry about communications bandwidth constraints. However, the issue of transmission latency may be viewed as a drawback with potential delays up to 2 seconds for data packets. It should be noted that this will only occur if the Ricochet network is congested which may only last a short period of time. Also, when not congested, the transmission latency will be much less than a second, in the millisecond range, which is superior to the traditional once per second polling methods.

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