Designing a traffic management system to utilize a digital cable network

Kevin G. Aguigui, PE, PTOE, Kevin J. Fehon, PE, and Rafat Raie, PE

Abstract-- The City of Walnut Creek is in the process of replacing its existing traffic management system with a new advanced traffic management system. The new system will consist of a new central control system, new Model 2070 controllers, closed circuit television (CCTV) cameras, and a new communications network system. The icons™ central system was selected by the City to replace the existing VMS-330 system. The overall replacement will take place over three separate phases focusing on the major arterials for the initial phases and incorporating the downtown area in the final phase. A key element of the City's new system is the use of a digital cable network for communications between the central system and the field elements.

The City's central system will utilize the network of a local digital cable company for the communications between the central system and the field traffic controllers, as well as the CCTV cameras (video signals and control). The digital cable network utilizes standard 10Base-T frames and Internet Protocol (IP) packets for the video and data transmission.

At each traffic controller location, an interim solution which "packetizes" the controller's serial data will be implemented which will be replaced when the controllers are able to properly encapsulate data into IP packets for transmission. The video signal at each CCTV location will need to be compressed using readily available equipment. The cable modems proposed for the system can accept up to four devices and multiplex them into a single 10Base-T output.

The new system will have to contend with the potential for increased latencies with the cable network, and the upstream (field to headend) limitation of the cable network. The network infrastructure consists of a hybrid fiber/coax system with coax cable to the field elements and fiber between the Cable Modem Termination System (CMTS) and the cable network headend. From the headend, there will be a fiber connection to the City's traffic signal shop which houses the central computer system.

This paper will discuss the basic network configuration, the design challenges of the system, and the future enhancements to the system.

K. G. Aguigui is with DKS Associates, 1956 Webster Street, Suite 300, Oakland, CA 94612 (telephone: 510-763-2061, e-mail: kga@dksassociates.com)
K. J. Fehon is with DKS Associates, 1956 Webster Street, Suite 300, Oakland, CA 94612 (telephone: 510-763-2061, e-mail: kjf@dksassociates.com)
R. Raie is with the City of Walnut Creek, 1666 North Main Street, Walnut Creek, CA 94596, (telephone: 925-256-3529, e-mail: raie@ci.walnut-creek.ca.us)

I. Introduction

The City of Walnut Creek is currently implementing a new Advanced Traffic Management System. The system will use the icons™ central computer software at the Traffic Operations Center (TOC) and Model 2070 traffic controllers. As part of the new system implementation, the City will be utilizing a digital cable network for communications between the central system and all of the field elements including traffic controllers, CCTV cameras and, in the future, changeable message signs.

During the life of the existing system, the volume of traffic using the arterial roads in the city has increased dramatically with the number of signalized intersections also increasing. In addition, the dramatically increased volume of traffic on the adjacent freeways has meant that the City's streets suffer more often and more severely when there are incidents on those freeways.

All this has led to a need to replace the City's signal system and improve the staff's ability to monitor and manage traffic in real time, and respond to incidents in a timely and more comprehensive manner. At the same time, increasing awareness among the City's neighbors of the same issues, and improved equipment that they have recently installed and continue to plan, presents opportunities for better cooperation and integration of activities, when appropriate.

The City already has a comprehensive network of copper signal interconnect cables used for the existing signal system (Figure 1). Almost all the signals in the city are connected to the central master via this City-owned signal interconnect cable. While this cable has given excellent service, its capacity has been reduced through damage and failures of some of the wires within the cables. Fortunately, sufficient spares were included in the initial design that those failures have not reduced the cables' serviceability. However, since the existing communications system is a half-duplex, one-pair system, it may not be able to accommodate the new system which operates at full duplex over two pairs. Additionally, the transmission distances for the video feeds will dictate a series of amplifiers if the copper interconnect is used. Thus, a copper-based solution was not economically feasible.

Figure 1 – Existing Signal System

An option of installing a fiber optic network for the CCTV cameras only was considered. However, this option was determined to be costly requiring extensive modifications to the existing conduit infrastructure, including new conduits along several roadway segments.

II. BACKGROUND

The following field equipment changes are currently planned for implementation over the next three years:

- Replace all the existing controllers with Model 2070 and Model 2070N controllers running NextPhase™ software;
- Install CCTV cameras at up to 32 incident detection locations; and
- Install 11 fixed CCTV cameras to provide traffic information over the internet.

The first 16 of the proposed incident detection locations are illustrated in Figure 2. All the proposed incident detection cameras will have full pan-tilt-zoom (PTZ) capabilities. The existing TOC is near the City's Corporation Yard as illustrated also in Figure 2. It is currently proposed to maintain the TOC at that location, and provide a supplementary TOC at City Hall, with full operational capability. However, the space available at the TOC will be temporarily reduced in the near future, to accommodate the transportation and traffic engineering staff who will be relocated during the reconstruction of City Hall.

All of the existing communications cables are terminated at the Corporation Yard. Following the upgrade of the system, it is proposed that the new signal master be located here, along with video monitors for the incident detection cameras, suitable for use by the technicians on a day-to-day basis for routine analysis and maintenance.

A local digital cable service provider approached the City about installing a network within the City, which the City realized as an opportunity for its Traffic Management System. An agreement between the City and the digital cable provider, Seren Innovations, stipulates that the cable provider will provide service to all traffic signals and

CCTV cameras identified by the City for a fee charged per location.

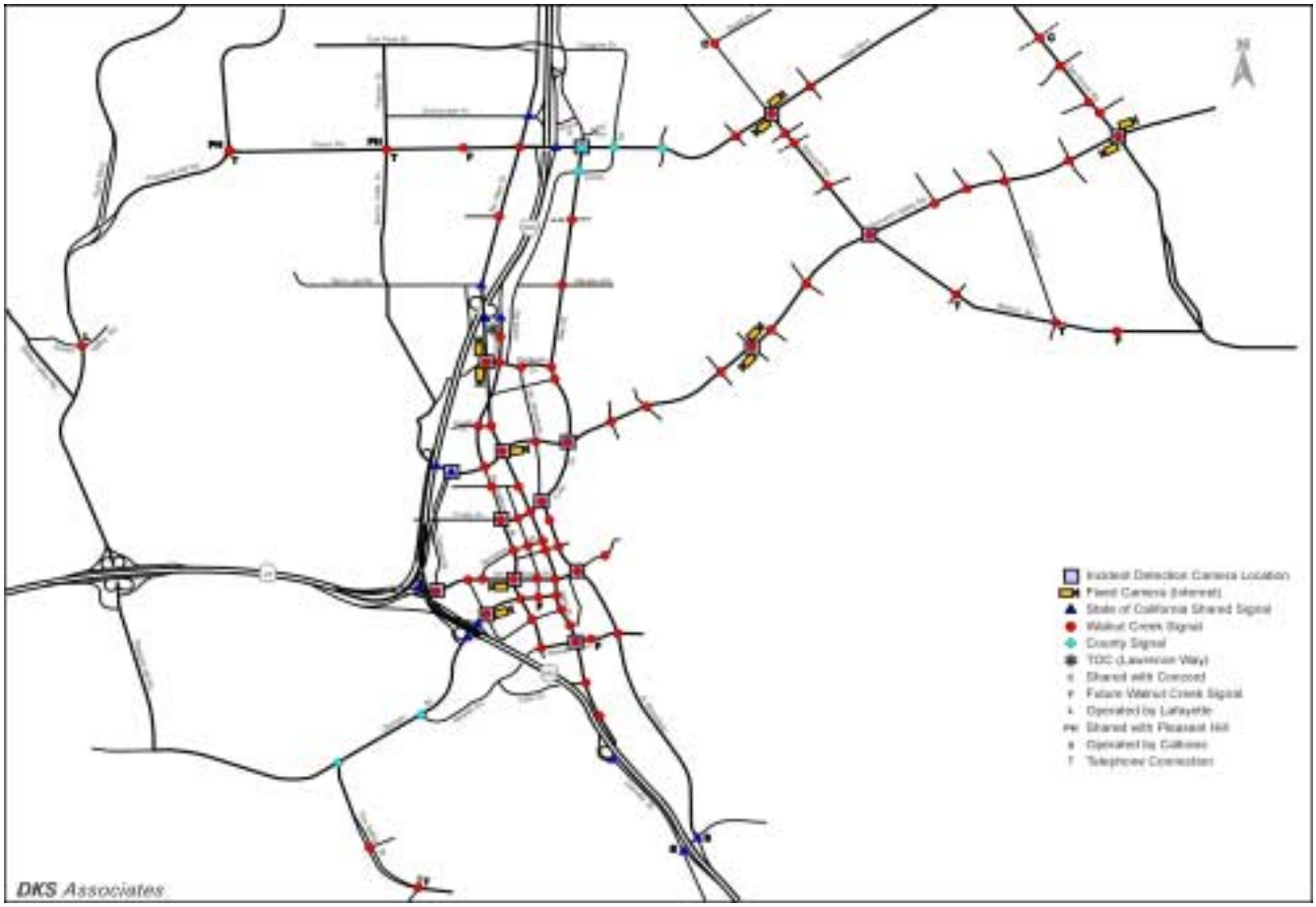

Figure 2 – Initial System Elements

III. PLANNED INFRASTRUCTURE

Seren Innovations has approval from the City to install a hybrid fiber/coaxial cable network to provide cable TV, telephone and internet services throughout Walnut Creek. This network is currently being installed. Its backbone will be provided by fiber optic cables connecting CMTS nodes to the "head end" located in the City of Concord. Each node will serve approximately 400 end users via coaxial cable and a "cable modem".

All communications between field devices and the two TOCs will be via the digital cable network. Communications between the Corporation Yard TOC, the City Hall supplementary TOC, and between remote workstations and the central system master will be via the City's local area network, INET. Figure 3 illustrates the basic network architecture of the new Traffic Management System.

The two TOCs are proposed with equal functionality, although the majority of the switching and control equipment will be located at the main TOC at the Corporation Yard. This configuration is illustrated in Figure 4. The central equipment, communications hubs and video switches will be located in the main TOC.

At the City Hall TOC, it is proposed to have the same functionality as the main TOC. However, this facility would mainly be used by the City's traffic engineering staff for routine observation and fine-tuning of the signal system, and to trouble-shoot traffic problems. It would also be used by emergency personnel during incidents and emergencies, and provide an opportunity for the public to observe the City's operations.

This facility will have two console positions with fully-functional central system workstations, a large video screen and several small monitors capable of displaying any camera and views from the workstation screens, and will have control of all cameras. The video switching will be set up so that the staff at the City Hall TOC will have over-riding control of cameras.

IV. COMMUNICATIONS

The cable network provider will be providing network access at every signalized intersection, where up to four devices are able to be connected. At each access point, the provider will provide a coaxial cable connection with a 4-port cable modem. It is anticipated that up to two cameras, one traffic controller and a dynamic message sign is the most number and type of devices that would be connected to a single cable modem.

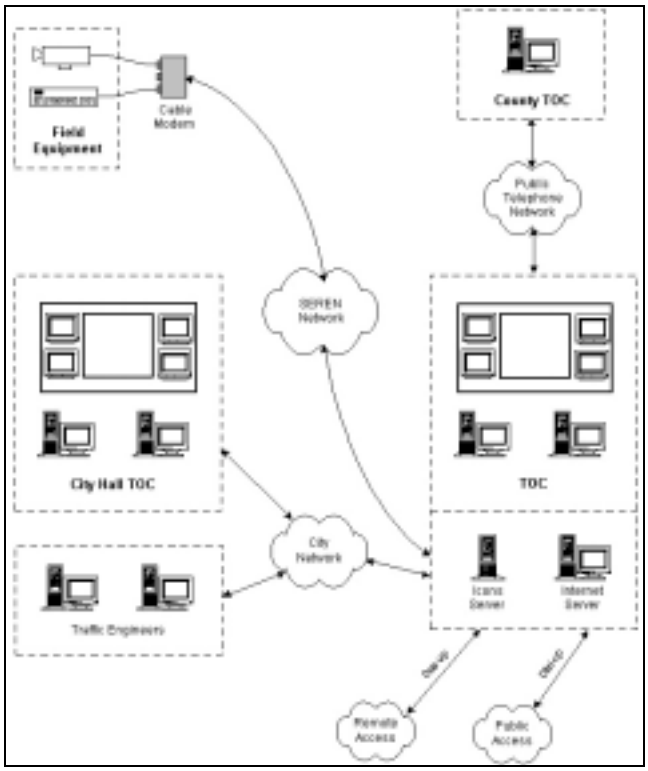

Figure 3 – Basic Network Architecture

A. Data Transmission

In the downstream (central to field) direction, a data stream from the central server destined for a traffic controller is easily encapsulated into an Internet Protocol (IP) packet for transmission. The issue is in the upstream (field to central) direction where an outgoing data stream is typically sent directly to the EIA 232 port. The controller addressing is done through data channel and drop configurations in the network. The application software driving the Model 2070 controllers is currently not able to encapsulate the data streams into an IP packet.

A typical layout for a traditional traffic management system would link up to eight (8) traffic controllers together in a "drop and repeat" configuration over a single communications channel. The central server takes care of the communications through polling-based protocols utilizing time division multiplexing (TDM), controller channel and drop configurations. This configuration is normally referred to as a "point-to-mulitpoint" configuration.

While the Model 2070 controller has an RJ-45 port with an Ethernet hardware driver, the application software currently does not have the necessary software drivers to utilize this Layer 2 (data link layer) protocol. Thus, the true benefits of a 10Base-T network are not able to be realized for the initial phases of this project. Since the Ethernet message can only be directed to one IP address, the master end will require the provision of a separate RS232 channel for each signal that is on-line, rather than assigning multiple field devices per channel (point-to-point versus point-to-multipoint). Therefore, since a conversion is needed for the data streams, each field device must be assigned a single IP address and a dedicated channel.

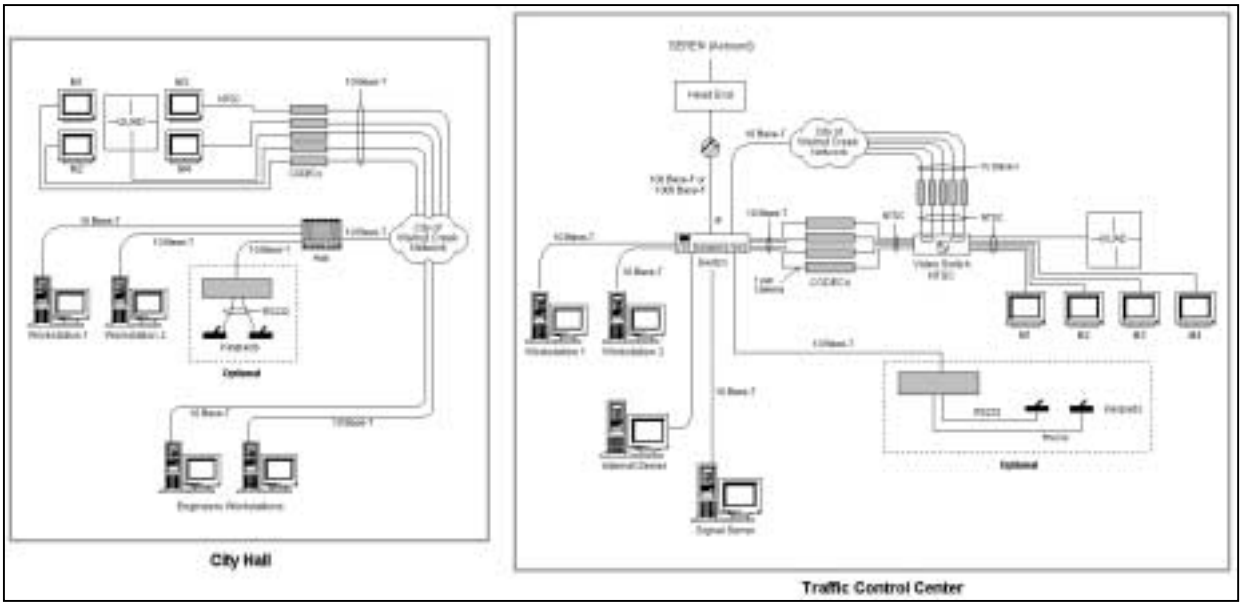

Figure 4 – Ultimate Network Configuration

Since the software driving the Model 2070 controllers is not able to properly encapsulate data streams into Transmission Control Protocol (TCP) or User Datagram Protocol (UDP) datagrams, and IP packets for transmission over a TCP/IP or UDP/IP network, an "interface", or "converter" is needed, as described below, to connect the traffic controllers to the cable network. This converter, also referred to as a serial/ethernet interface is needed at both ends (field and TOC).

Since the data streams between the cable modems in the field and the TOC must be in standard 10Base-T frames, and since the traffic controllers are connected to the network via an EIA/TIA 232 port, a 232 to 10Base-T "converter" is needed for packetizing the data streams for connection to the cable modem. From there the cable provider assigns the cable modem (and therefore each field device) an IP address. At the TOC end, the 232 to 10Base-T converter is connected to a port replicator, or a digiboard for proper channelizing of the data streams into and out of the central computer master. Figures 5 and 6 illustrate the configurations.

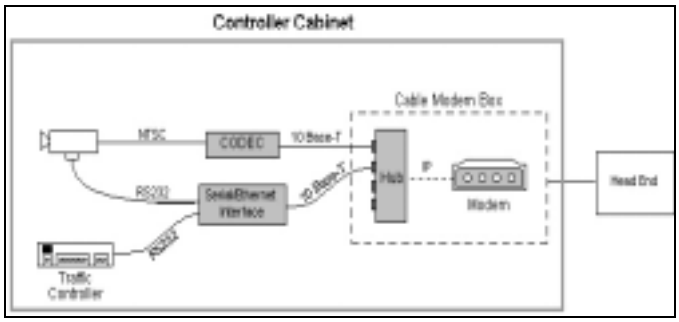

Figure 5 – Network Elements in Controller Cabinets

The bandwidth required for the traffic controllers is very small in relation to the video bandwidth, and so is not considered to be an issue. The key parameter in the controller communications is the low latency tolerance within the network. While the new central system can be tuned to accommodate a range of network latencies, the practical maximum latency that can be tolerated without any noticeable degradation of performance is approximately 10 ms (milliseconds). The expected latency in the digital cable network is less than 7 ms, and is therefore not expected to be an issue for the controller communications.

B. Video Communications

Since multiple devices are to be connected to a single cable modem, the video signal from each CCTV camera has to be in 10Base-T format as well. This constraint presented several challenges in the design of the video system. In addition, the bandwidth limitation presented by the cable network presented challenges in terms of video compression technology.

While each cable modem can accommodate up to 10 Mb/sec of throughput in the upstream direction, the cable network, being a shared network, has limitations on the upstream bandwidth for a given cable frequency spectrum. For this reason, several different solutions were sought to fit within the network's constraints while achieving the goals and objectives of the City's Traffic Management System. While suitable cameras with MPEG outputs and PTZ inputs in Ethernet format are expected to be available within one to two years, and will therefore be suitable for use in later phases of this project, they are not suitable for this type of installation at present.

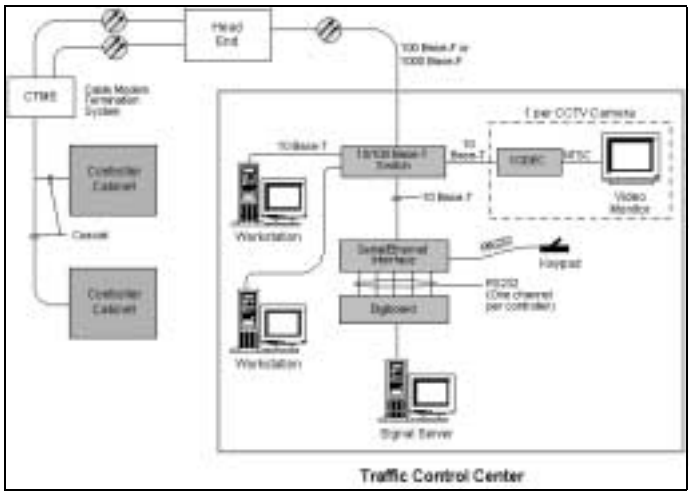

Figure 6 – Network Elements in the TOC

All the cameras currently marketed for ITS applications, and with specifications suitable for year-round, outdoor applications, have analog outputs. They will therefore require a codec to digitize the signal and convert it into Ethernet format. Several models of codec are available that have been successfully used in similar applications. In future years, when suitable digital cameras with built in compression units become available, a standalone codec will not be required at the field end.

One of the first challenges of designing the video network was determining the most effective way to properly digitize and compress the analog video signal (NTSC) from the cameras. Several solutions were investigated including cameras with built in coders/decoders (codecs), and separate external codec units. The single constraining factor on selecting the most appropriate codec(s) was the environmental readiness of the device to withstand harsh field environments with ratings satisfying the National Electrical Manufacturer's Association (NEMA). This factor clearly eliminated most of the available products on the market today. Consideration was given to the use of digital cameras with a 10Base-T output. These are currently available for web-cam and video conferencing applications. While there is a wide range in the quality of the output of these cameras, in terms of resolution and frame refresh rate, few have pan-tilt-zoom (PTZ) control and none have suitable environmental enclosures. Based on the research, a standalone codec with a standard 10Base-T connection was determined to be the best solution.

Whether or not the data from the pan-tilt-zoom unit was integrated into the 10Base-T stream was not a determining factor since the serial to Ethernet converter could be utilized if the data was not integrated. This is discussed further below. Several video systems are currently available where some have the PTZ data encapsulated within a 10Base-T frame, while others utilize a separate serial interface.

The communications system will have an upload (field to headend) data capacity of 10 Mb/sec in a bandwidth of 3.3 MHz, and a download (headend to field) data capacity of 38 Mb/s at each field location. Based on the current technology for video compression, it is anticipated that each camera will need an upload capacity (bandwidth) of up to 2 Mb/s for good quality full motion video. Depending on how the newer compression technologies are implemented within the available products, it may prove that slower bandwidths will be acceptable for full motion video.

Some of the video compression formats and standards include Motion JPEG (MJPEG), ITU H.261 and H.263, and MPEG II, MPEG IV and the upcoming MPEG VII. Based on the discussions with the cable network provider, utilizing the MPEG II standard at 1.5 Mb/sec, or the MPEG IV standard at 384 Kb/sec may prove to be the most worthwhile to satisfy the needs of the City while remaining within the constraints of the network. Currently, the MPEG II video compression standard is more widely deployed in vendor products.

The current proposition is for the cable provider to assign cameras to channels that are exclusively for the City's use, to ensure that picture quality and/or speed are not compromised. A maximum of five cameras can be assigned to each 3.3 MHz channel with a preferred maximum of four. Transmission of video from the headend to the TOC is classified as a download from the perspective of the communications network so there is ample bandwidth for this portion of the transmission of video images. At the TOCs, the digital video signal could be displayed directly on suitable screens or decoded to analog and displayed on NTSC TV monitors. Figure 7 illustrates the network with an analog video switch, while Figure 8 illustrates the network with a digital video switch.

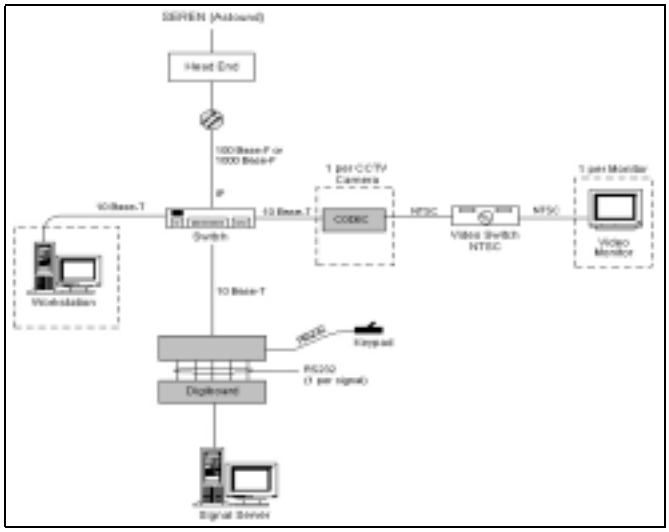

Figure 7 – Analog Video Switching

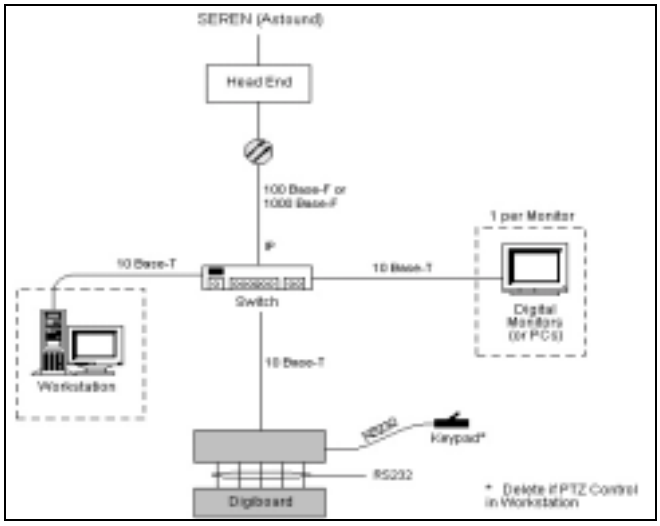

Figure 8 – Digital Video Switching

V. CONCLUSIONS

When designing a Traffic Management System to utilize a digital cable network, some of the key factors in the design include:

- Ensure the central system is tolerant of network latencies in data transmission. This may warrant newer communication protocols that are event-driven versus the traditional polling-based protocols.

- Determine if additional equipment is necessary to interface a drop and repeat, TDM-based network with an IP-based cable network.

- Perform bench testing of video transmission and compression equipment prior to any field installations to determine the minimum tolerable bandwidth requirements for proper video quality and resolution.