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Priority-Controlled Networks for Road Management[†]

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This paper describes an Intelligent Transport System, created using an intelligent distributed network of cameras and sensors. The video bandwidth required between the video concentrator and the remote traffic control center was reduced by priority control of video feed: cameras are automatically selected based on audiovisual cues derived by processing outputs from associated, or collocated, microphones and cameras. As a result, it was possible to use a low-cost Gigabit Ethernet but still obtain sufficient image quality and latency for real-time image streaming, and create a viable alternative to conventional centralized traffic control systems that require more expensive Asynchronous Transfer Mode internetworking.

Key Words: Quality of Service, congestion control, priority control, traffic control, road management

1. Introduction

Future public infrastructure such as Intelligent Transport Systems (ITS) - with many networked CCTV camera terminals connected to a network - used for traffic control and road management systems are expected to be more cost effective and efficient to operate. Here we propose a networked sensor system for priority control that uses the latest network technology to reduce deployment and running costs .[1)]

Up to now, to provide the bandwidth and latency required for streaming real-time MPEG-2 images, expensive controlled media access methods such as ATM (Asynchronous Transfer Mode) have been used. And camera prioritization for real-time image streaming has been discussed from the viewpoint of network technology.[2)∼4)] Gigabit Ethernet potentially offers lower costs, but its CSMA/CD protocol limits its traffic-handling capacity when multiple nodes are involved.

We decided to use a distributed-intelligence architecture, with each node 's cameras and sensors in close proximity linked by a Gigabit Ethernet. We found that, in practice, such a system based on a Gigabit Ethernet costs about 1/7 that of an equivalent ATM-based system.

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2. Conventional Road Management Systems

A typical road management camera network is shown in **Fig. 1**. The example in the figure shows a tunnel with many CCTV cameras around the tunnel mouth. Each camera is connected by an optical fiber to a remote-operated video switch that can select any one of the CCTV cameras and link it to the road management center. In this example, the cost of the optical fiber link from each camera to the video switch is quite high, and images from only one camera can be transmitted to the road management center at a time.

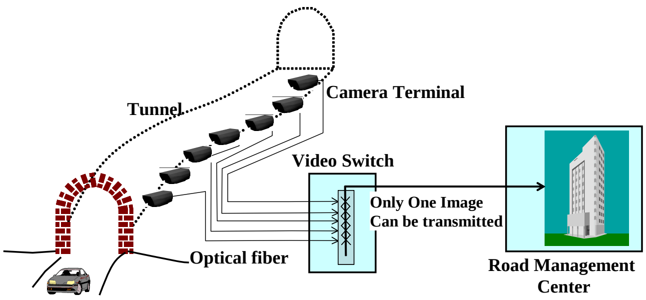


Fig. 1 A Typical Road Management Camera Network

Moreover, as shown in **Fig. 2**, to connect two or more cameras simultaneously by an ATM network to the road management center is even more expensive.

3. Priority-Controlled Networks

Features of our network Solution for Road Management

When considering future system architectures, the following requirements should be noted:

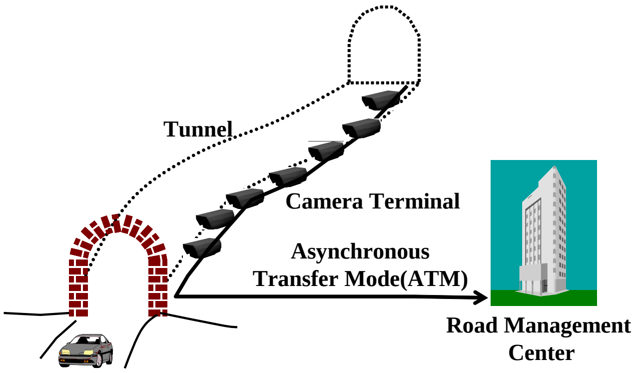


Fig. 2 A Road Management System using ATM

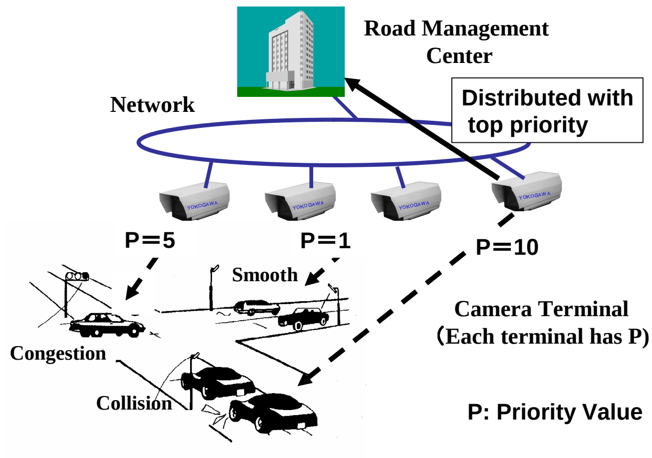


Fig. 3 A Priority-Controlled Road Management System

(1) **Only Images of Abnormal Situations are of value**

In traffic control / road management systems, only images that capture accidents - or notify the management of vehicles that have broken down - have value. That is, under normal circumstances it is not necessary to distribute images on the network.

(2) **Network Topology**

Conventional systems use special ring topologies rather than Internet-like multi-path switch or VPN-based architectures. Many cameras are installed, but only a few can be monitored simultaneously from the road management center. Typically, the distance from the cameras to the road management center is several km or tens of km.

(3) **Required QoS**

Real-time streaming of images requires that variation in image delay time be kept within about 100 ms. Required bandwidth is at least 6 Mbps because of its image quality.

(4) **Scalability**

It must be easy to install additional camera terminals in a road management system.

4. Priority Controlled Image Distribution

An example of a priority-controlled traffic control / road management system is shown in **Fig. 3**.

Several dozen sensor terminals with associated CCTV cameras are connected in a network, and the priority value of each terminal is computed based on processed camera images, or the results of measurements by sensors. For traffic control / road management systems, microphone is useful sensor that can detect collision sounds.

When sensor/camera terminals detect phenomena such as traffic accidents and vehicle breakdowns in real time, the affected sensor/camera priority values are increased.

Now, suppose we have a system with 100 camera terminals connected to Gigabit Ethernet. In a present system, over 80 cameras are installed in a tunnel in a metropolitan area to avoid blind corners. Bandwidth required to transmit 100 video images is 6Mbps $\times$ 100 = 600 Mbps, but throughput and latency of Gigabit-Ethernet is not sufficient to support this. Not only video stream but also the control data are transmitted in the network. And UDP is used as video protocol and TCP as the control data respectively. In this case, video stream should be minimized because the transmitted rate of TCP would be decreased by its window flow control when UDP packets exist in the same networks.[5] In addition to the restriction on UDP packets, the number of display monitors at the management center must be limited because the watcher who sits in front of the display monitors can only recognize a limited number of displayed items, which is usually less than 6. So the number of transmitted video data should be minimized to be the same as the number of display monitors.

If, however, we transmit signals from only the 6 cameras with higher priority, then Gigabit Ethernet can provide sufficient QoS. Since only the most useful images are transmitted, the data are not crowded on the networks, so a limited number of video data can be transmitted in high video quality and latency. We consider this to be at least equivalent to the conventional real-time video stream system such as the ATM-based system from the viewpoint of the watchers in the management center.

Several schemes for network QoS management with best-effort real-time video streaming on an Ethernet or the like are illustrated in **Fig. 4**.

The two methods that have been proposed earlier are

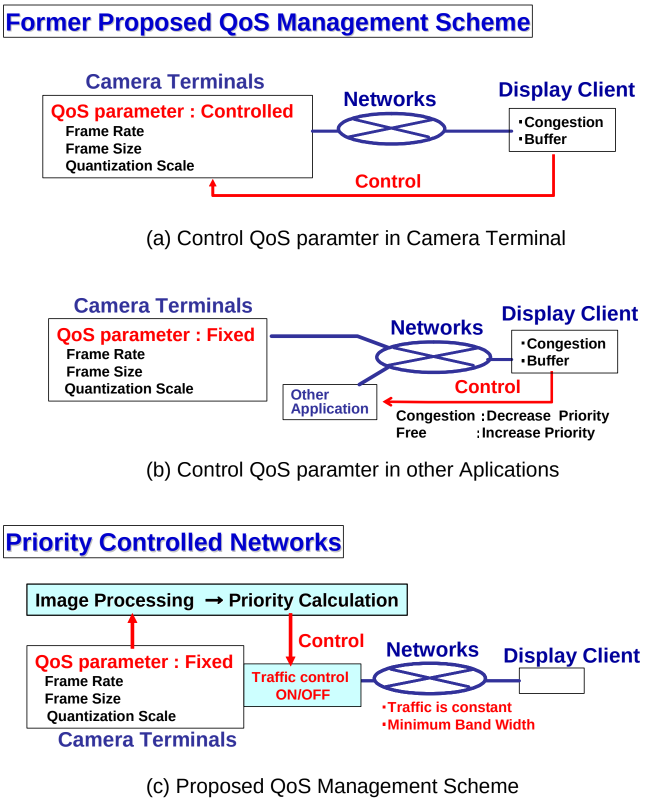


Fig. 4 QoS Management Scheme for Real Time Video Stream on Best Effort Network such as Ethernet

as follows: Fig. 4**(a)** shows one QoS Management Scheme whereby the Display Client controls the parameters of the video stream, such as frame rate, frame size and quantization level of Camera Terminals according to network congestion and historical display buffer status. When congestion occurs, the parameters of Camera Terminals are changed to lighten the network load. [3),4)] Fig. 4**(b)** shows another QoS Management Scheme whereby the Camera Terminal parameters are fixed, but the priority of other applications that feed traffic into the network are varied - depending on network congestion and historical display buffer status - to assure adequate QoS for the video stream. [2)]

Fig. 4**(c)** shows our proposed priority-controlled network, in which the traffic prioritization control is performed based on the processing of images captured by camera terminals. Priority is calculated from a processed image, and a fixed number of cameras - those with highest priority - feed their video data stream onto the network. So the traffic on the network is constant, and an adequate network QoS can be maintained.

5. Basic Architecture

We considered two possible system architectures: (1) autonomous distributed sensor terminals, each of which evaluates its own priority, and disables video output if the priority is below a threshold, and (2) concentrator type with a central controller that compares the priority of terminal results, selects those whose images are of high priority, and distributes their images. (See **Fig. 5**)

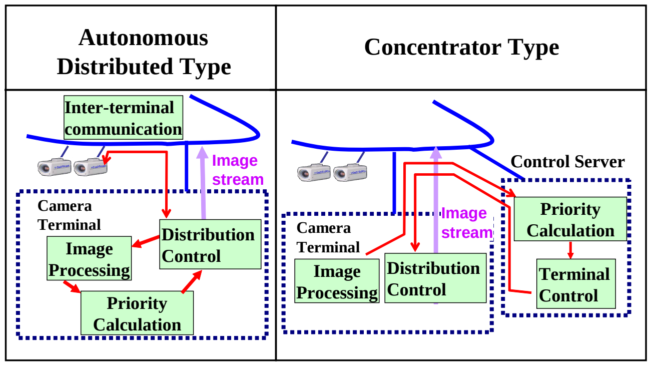


Fig. 5 Two Possible System Architectures

5.1 Autonomous distributed type

The basic composition of the sensor terminal component of the priority-controlled network is shown in **Fig. 6**.

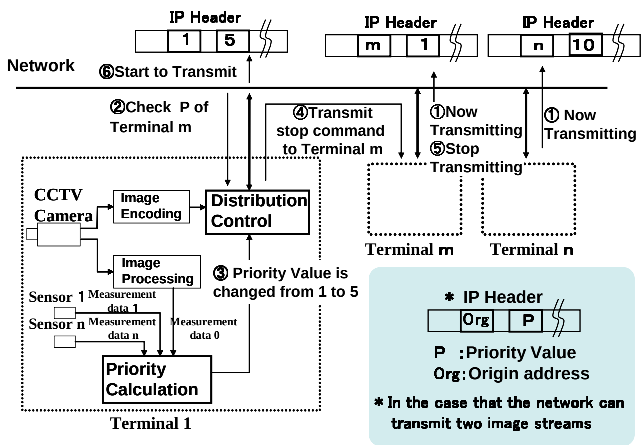


Fig. 6 Basic Composition of Terminal of Autonomous Distributed Type

The two required functions are as follows:

Priority Calculation Function

The priority value for every sensor terminal is computed from the result of image-processing the camera output, and from the results of measurements by a sensor.

Here, a numerical value of 1 (minimum) - 10 (highest) is assigned to each terminal as priority value. For example, consider the case where the sensor is a microphone combined with a camera. The speed of vehicles is measured by image processing.

Although priority value =1 when vehicle flow is smooth, when vehicle speed becomes 0 km/h, this is judged as traffic congestion, and the priority value is changed to 5.

If collision-like sounds are detected by the microphone at this time, this will be judged to be a collision, [higher] priority value =10 will be set, and the image from the camera at the accident spot is assigned top priority for distribution to the control center.

Distribution Control Function

Each sensor terminal monitors, in real time, packets distributed on the network by other sensor terminals. The transmitting terminal and its priority value are determined from the IP header of each packet.

When a sensor terminal receives a packet with priority value lower than its own, it " votes " by transmitting a distribution stop command to the lower priority terminal and starts to distribute its own images.

5.2 Concentrator control type

Here, priority calculation is not performed in each sensor terminal - for example, each sensor terminal measures the speed of vehicles, detects collision-like sounds, and transmits this captured data to a control server.

The control server computes the priority value of each sensor terminal based on this captured data, two or more sensor terminals to distribute images are selected as a result, and the required images are distributed; here adequate network bandwidth is secured by transmitting control signals to each sensor terminal (disabling lower priority image output).

The basic configuration of the sensor terminals and control server of the priority-controlled network is shown in **Fig. 7**.

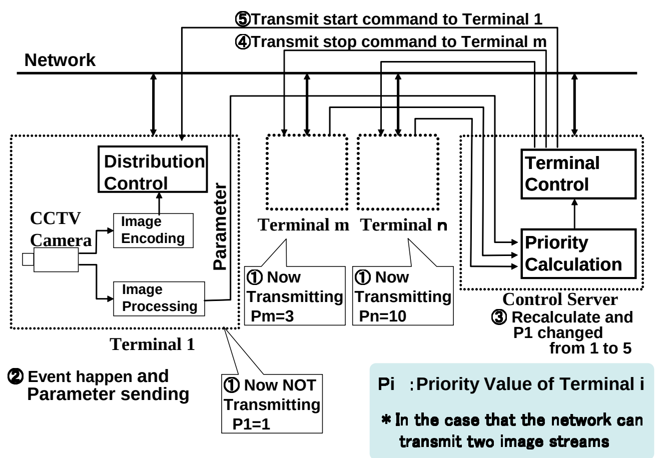
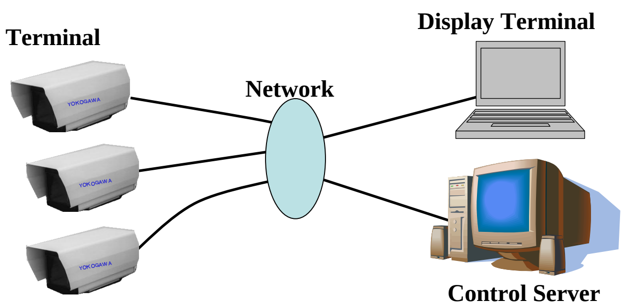


Fig. 7 Basic Composition of Terminal and Control Server of Concentrator control Type

Every sensor terminal transmits the results of image-processing of the camera output to the control server, which computes the priority value for every sensor terminal from these signals. Here, a numerical priority value between 1 (minimum) and 10 (highest) is assigned to each terminal, the same as for an autonomous distributed scheme.

6. Application to ITS (prototype system)

The outline of an actual prototype system built to evaluate feasibility is shown in **Fig. 8**.



Protocol	IP/UDP/RTP/MPEG2-PS(TS)

Video Format	MPEG-2, ITU-T H.262
Profile Level	MP@ML,SP@ML
Bitrate	6Mbps
Multiplex-Format	MPEG2-PS(TS)

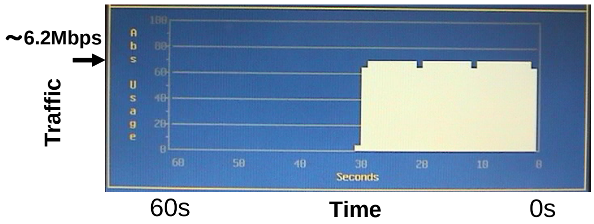
Fig. 8 Prototype System

In most present traffic control / road management systems, analog video switches are used to alternate images captured by different sensor terminals. In the case of an ATM-based system, analog video switches are also used after converting from MPEG-2 into analog video data, which enables the images to change smoothly. The key factor of the proposed system is smooth video switching containing constant traffic load.

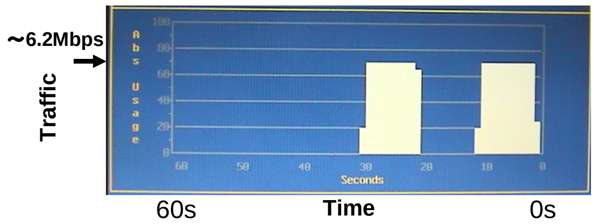
A prototype system consists of 2 sets of camera terminals connected by Ethernet to a control server PC, and the usefulness of images displayed on a connected display terminal in the switching period was evaluated. And we also confirmed the traffic load on the network contain 6Mbps without increasing to 12Mbps. In the prototype system, we adopted design-friendly Concentrator control type.

Fig. 9(a) and Fig. 9**(b)** show the measured network traffic of 2 cameras and that of one of the cameras respectively.

In this case, two camera terminals are active, one of them has a higher priority than the others, and the priority changes every 10 seconds. Each camera needs 6.2Mbps bandwidth to transmit its video stream. Measurement



(a) **Measured Network Traffic of all the cameras**



(b) **Measured Network Traffic of one of the cameras**

Fig. 9 Measured Network Traffic

shows that the traffic on the network remains constant.

7. Conclusions

We described a priority-controlled network that realizes a low-cost traffic control / road management system. The video bandwidth required between the video concentrator and the remote traffic control center was reduced by priority control of video feed: cameras are automatically selected based on audio-visual cues derived by processing outputs from associated, or collocated, microphones and cameras. As a result, we were able to use low-cost Gigabit Ethernet but still obtain adequate bandwidth and latency for real-time image streaming, and create a viable alternative to conventional centralized traffic control systems that require more expensive Asynchronous Transfer Mode internetworking. A larger-scale version of the prototype is being tested with a view to commercial application.

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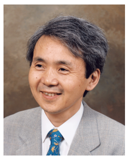
Ichiro Masaki



He received BS and MS from Waseda University, Japan in 1971 and 1973 respectively. From 1981 through 1993, he was working on vision-based vehicle guidance, machine vision systems, and other ITS-related projects at General Motors Research Laboratories near Detroit. During that time period, he founded IEEE Intelligent Vehicles Symposia. He received Ph.D. from Osaka University in 1991. He moved to MIT (Massachusetts Institute of Technology) in 1993 and he is currently the Director of the Intelligent Transportation Research Center at MIT's Microsystems Technology Labs. He is also Founding chair of IEEE Intelligent Vehicles Symposia, an Administration committee member of IEEE ITS Society, and a member of IEEE.

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