Optimum Delivery of Telemedicine Over Low Bandwidth Satellite Links

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Abstract - **Telemedicine is frequently used to support the delivery of medicine to remote regions, but it can often be the case that these areas are poorly served by communications. The AIDMAN project investigates the delivery of telemedicine in remote regions of Greece using satellite. However the high cost of such links can severely limit the bandwidth available to applications. In addition the satellite link is a clear channel and may be configured to emulate any protocol. This presents a problem of determining which protocol may best support the applications. We have modelled the three types of link protocol, circuit switched (ISDN), packet switched (TCP/IP) and cell switched (ATM) to determine how their characteristics affect the performance when bandwidth is severely restricted. We further investigate how performance may be optimised when the link is used to carry mixed traffic of real-time video conference and image transfer. Our simulation shows that TCP/IP can support telemedicine applications reasonably well, so long as the number of simultaneous image transfers are restricted. Furthermore, IPv6, which supports prioritisation of traffic, can overcome this restriction. Use of TCP/IP has further advantage, in that it permits integration of wider networks, is cheap, widely available and supports virtually all telemedicine applications. Real-time measurements using the virtual consultation workstations developed for the AIDMAN project on a low bandwidth link implemented on routers connected using ISDN to simulate a link with 128 kbps and on the GALENOS satellite network confirms the findings of the simulation.**

I. INTRODUCTION

The AIDMAN project [1] delivers routine clinical care to remote regions of Greece. However, many of these areas still only have poor communication infrastructure, relying on analogue telephone exchanges that are not capable of providing the bandwidth or reliability for telemedicine. Other methods must be employed in these areas. The AIDMAN project investigates the use of satellite to deliver such a high speed, high quality service to these areas. The system must also integrate centres connected through terrestrial links such as ISDN. The AIDMAN network is shown in Fig 1.

II. METHODOLOGY

The AIDMAN network has a mixed topology and variety of technology implementing its links. The choice of protocol for end to end connectivity within the network is not clear, and one of circuit switched, packet switched or cell switched may be employed. Each has technical advantage and ability to support a full range of telemedicine applications. For this reason we have chosen to simulate each of these to determine which is optimum for our application.

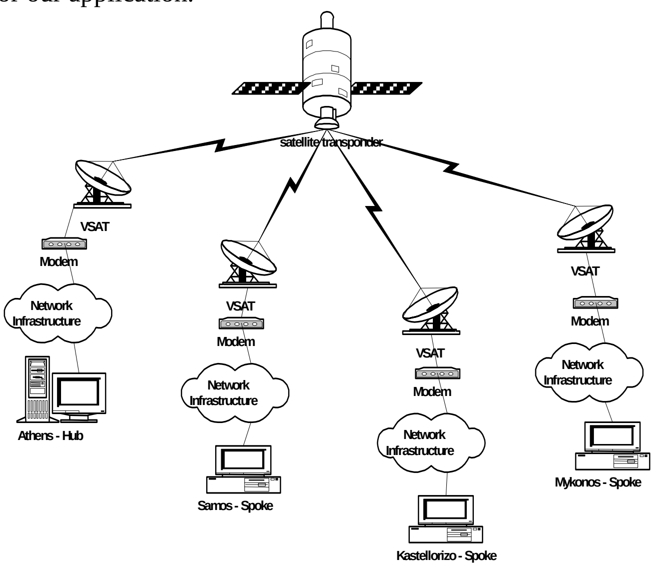

Fig. 1. AIDMAN Network

A. Circuit Switched

ISDN has been chosen for circuit switched and the network is shown in Fig 2. Video conferencing may be supported directly through the use of H320. In addition, T120, which is part of the H320 protocol, may be used to transfer images and allow applications to be shared between parties in a videoconference. H320 does not, however, support TCP/IP, and thus applications based on this protocol cannot be used at the same time as a videoconference. It would be possible to disconnect H320 and connect instead with an ISDN router to provide a separate TCP/IP connection. This would imply that any TCP/IP applications, such as DICOM, should be run before the videoconference session if images are to be exchanged for use within the session. ISDN has the advantage that, as each application has exclusive right to the full bandwidth, performance is guaranteed. It may therefore be used as a reference against which to compare the other two link topologies.

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Abstract

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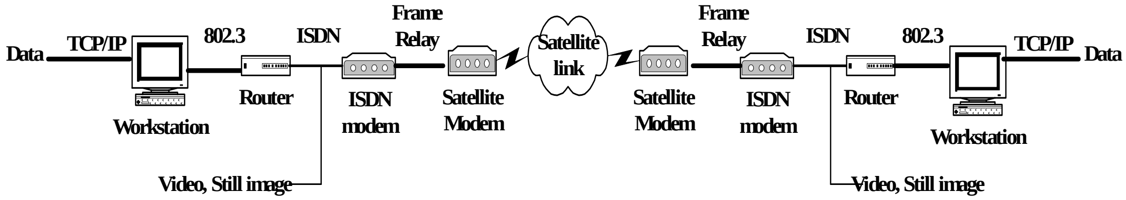

Fig. 2. ISDN Network

B. Packet Switched

TCP/IP has been chosen as the packet switched protocol, as it is universally available, cheap to implement and supports most applications. The network is shown in Fig 3. Video conferencing may be supported directly through the use of H323, which also supports T120. This has the advantage that H323 may control the total bandwidth in use by the video and T120 streams to the bandwidth available on the link. In addition other TCP/IP applications may transmit at the same time, but they will compete for bandwidth. These effects will be investigated. TCP/IP has a major advantage that it is a network layer protocol and therefore will integrate any number of link topologies and support end-to-end connection.

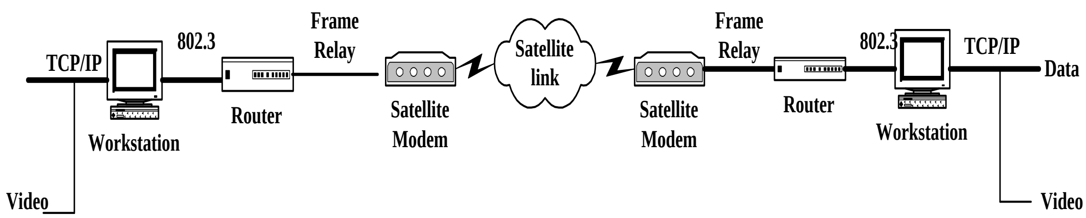

Fig. 3. TCP/IP Network

C. Cell Switched

ATM has been chosen as the cell switched protocol and the network is shown in Fig 4. This differs from packet switched in the size of the cells (53 bytes for ATM) and that it is usually used as a link technology rather than as a network protocol. ATM has the advantage that it implements quality of service, giving priority to specified streams of traffic and may interleaves streams at the cell level, but is known to be rather inefficient due to the large packet header overhead.

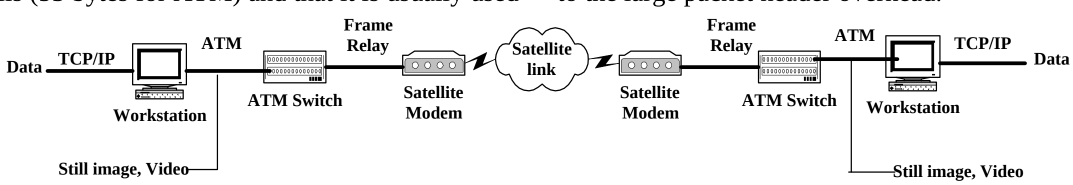

Fig. 4. ATM Network

D. Traffic Modelling

A typical telemedicine consultation session has been modelled with stages to cover all possible combinations of traffic. These are summarised in table 1 together with the results from the simulations. In addition, the same traffic has been analysed on a network to determine a model for the typical packet size. The relative frequency of packet size is shown in Fig 5, from which it is seen that this is approximately a normal distribution with average 790±20 bytes for video packets. We assume that each packet contains a single frame of video data, and so therefore for acceptable video quality, packet transmission rate must match video frame rate. Minimum video quality requires a rate of at least 10 frames per second, that is a maximum inter-frame arrival time of 100 ms. This will set the upper limit on acceptable frame jitter.

Image transfer frame size was determined as 1500 bytes (maximum frame). Note that the satellite link is assumed to have a mean propagation delay of 268 ms for all simulations. The measurements were also used to verify the simulation results of TCP/IP.

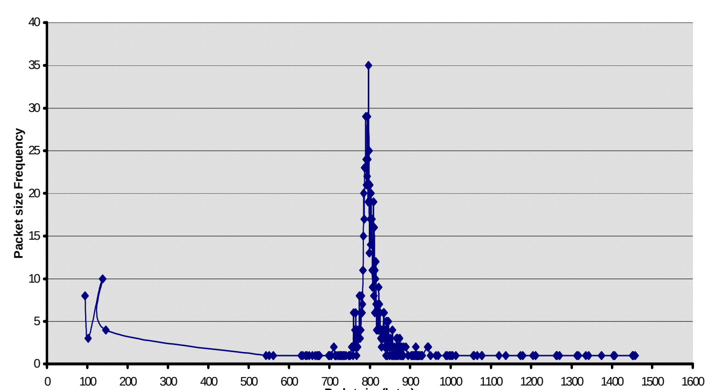

Fig. 5. Packet Size Relative Frequency

II. RESULTS

A.ISDN Simulation

ISDN, as a synchronous link, behaves almost perfectly, and simulation results match predicted values. Message delay consists entirely of propagation, transmission and packetisation delay. Quality of service is not an issue. Note that trial 5 cannot be performed, as the X-ray must be transmitted separately by setting up a TCP/IP connection over the ISDN link. This, in practice, can be inconvenient.

B. TCP/IP Simulation

Our TCP/IP simulations show that the 128 kbps satellite link is fully able to support X-ray and videoconferencing so long as each is performed separately, with little degradation in performance. However, the two do not work well together, with the transfer time for the X-ray becoming unacceptably large and more importantly, the videoconference suffering unacceptable delay and jitter (see trial 5 in table 1).

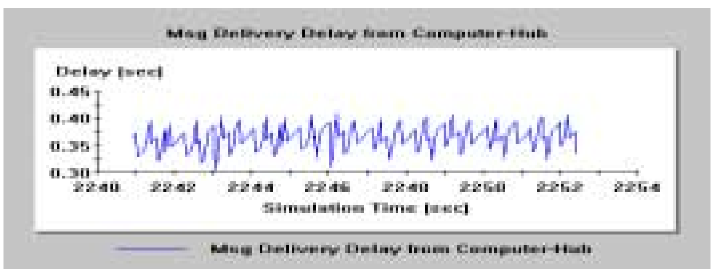

Fig 6. Packet Delay

The reason for the poor performance is demonstrated in Fig 6 (in this case for the 256 kbps link). Both the X-ray and the still image are transmitted using TCP connections, but T120 is not controlling the bandwidth used in the transfer of the X-ray, and it tries to transmit at full bandwidth. The flow control mechanisms of TCP/IP will throttle the ultimate transfer rate, as each TCP application will need to await an acknowledgement packet before transmitting further packets. However, the X-ray must be transmitted using what bandwidth is left over from the videoconferencing (approximately 13 kbps). However it tries to take more bandwidth, and so the video packets become enqueued and suffer delay. Moreover, each TCP application may place a packet in the queue before a video packet. Should these each be of maximal length then the video packet must wait 187 ms before being transmitted, with its own transmission delay of 57.5 ms, will cause and end delay of 244.5 ms, which exceeds the minimum of 100 ms for acceptable video quality. Note that if the network were able to prioritise transmission of packets in the queue, such as in IPv6, then the video packet would not suffer this jitter. Fig 6 demonstrates how video packets are alternately queued behind varying number of TCP packets, causing severe fluctuation in the delay.

The propagation delay of the satellite link causes problems other than the large end-to-end delay for speech and video. Communication protocols such as TCP/IP use flow control to limit the traffic entering the network in order to avoid congestion, a new packet cannot be transmitted until an acknowledgement is received. If this were purely a one-to-one exchange, then throughput would be severely limited whilst waiting for the acknowledgement to be received in a network with large propagation delays. In this case it is usual to use a window protocol. The effect is clearly demonstrated in Fig 7.

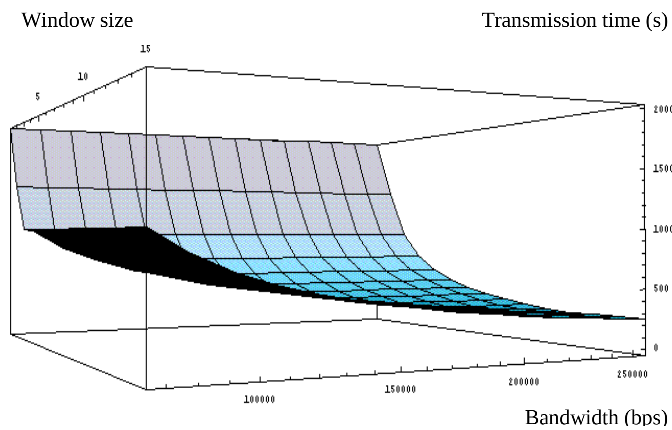

Fig 7. X-ray Transmission Time

Fig 7 shows how transmission time for a fixed size X-ray is affected by the bandwidth of the link and the window size for a satellite link with propagation delay of 286 ms. It is seen that the window size must be greater than a certain minimum to achieve lowest transmission time, but that ultimately, the bandwidth limits the time. Windowing could be used as a mechanism to limit the bandwidth available to a TCP application, however this is not deemed to be a reliable method and is not to be recommended in practice.

The performance at 128 kbps was so poor for the videoconference and X-ray transfer that a 256 kbps link was simulated. The results in table 3 show how the videoconference performance is satisfactory and the X-ray is transmitted in a reasonable time. Of course the X-ray alone benefits from the higher bandwidth.

These results demonstrate clearly the problem of lack of priority for the video traffic. For this reason we simulated a link having IPv6 which can prioritise the video traffic. As is seen in table 4, the performance for the video is maintained even under conditions where IPv4 failed completely.

C. ATM Simulation

ATM is based on small cells that can be interleaved more effectively than large packets. In addition, each stream (virtual circuit) can be guaranteed bandwidth and given priority. For these reasons we should expect excellent performance. Indeed the simulations show that performance can be met even for the 128 kbps link. However, ATM remains expensive, and applications specifically tailored for ATM are either not available or expensive. Note that the high overhead on cells impacts on throughput.

TABLE 1
TELEMEDICINE TRAFFIC AND TRANSMISSION TIMES AT 256 KBPS AND 128KBPS

Trial	Application	Size	Expected Transfer Time at 128 kbps(s)	256 kbps			128 kbps		
				Actual Transfer Time (s)	VC Delay (ms)	Jitter (ms)	Actual Transfer Time (s)	VC Delay (ms)	Jitter (ms)
1	X-ray	8 Mb	514	243			486		
2	Pure videoconference				322	15		385	35
3	Videoconference + Patient Data	2.5 kb	0.7 (assuming 32 kbps)	1.4	322	15	2.4	385	35
4	Videoconference + Still Image	45 kb	11.25 (assuming 32 kbps)	6.8	322	15	12.2	385	35
5	Videoconference + Still Image + X-ray	8 Mb + 45 kb		495	333	37	1352	2260	508

TABLE 2
IPV6 SIMULATION OF TELEMEDICINE TRANSMISSION TIMES

Bandwidth (kbps)	X-Ray (s)	Patient Data (s)	Still image (s)	VC Delay (ms)	VC Jitter (ms)
128	486	2.8	16.8	319	1.3
256	490	2.4	14.7	294	1.2

TABLE 3
ATM SIMULATION OF TELEMEDICINE TRANSMISSION TIMES

Bandwidth (kbps)	X-Ray (s)	Patient Data (s)	Still image (s)	VC Delay (ms)	VC Jitter (ms)
128	615	3.6	13.6	338	1.0
256	307	1.8	6.8	308	1.7

III CONCLUSION

Conclusions from our simulations and test measurements are clear. Low bandwidth satellite links can deliver a reliable service for telemedicine that would include videoconferencing and image transfer. In particular, TCP/IP may be used, so long as precautions are taken to limit the number of applications using the link simultaneously. This has the advantage of being cheap, widely deployed and able to integrate existing network infrastructure when using H323 end to end. With the introduction of IPv6 and hardware able to support QoS, then even low bandwidth links will be able to guarantee high quality video. The simulations also indicate that although 128 kbs is able to deliver a good service for transfer of large images, such as X-ray, and videoconferencing, these must be performed separately, otherwise the performance of both severely degrades. However, if 256 kbs can be provide, not only is the performance of the video maintained at all times, image transfer is improved. Of course high bandwidth would also allow improved video. It must be remembered that this replaces unreliable modems operating at 9.6 kbs, and any improvement is invaluable. Although ATM can be shown to give excellent performance, the poor availability of applications and its expense prevents it from being recommended at this stage.

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