Non-Packet-Loss-based Rate Adaptive Video over the Internet

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A congestion-level measure based on packet dispersion rather than packet loss, using a fuzzy rule set rather than an equation-based approach is proposed. Tests show that non-packet-loss-based control of transcoded video is well behaved across a tight link in the face of characteristic Internet cross-traffic and results in smooth variation of the received video quality.

Introduction: Knowledge of the network state allows transcoder adaptation of a pre-encoded video bit rate by varying the re-quantization parameter. In TCP-Friendly Rate Control (TFRC) [1], which is now an RFC, an equation captures the network state, determining congestion primarily from packet loss events. However, packet loss of intra-coded pictures leads to progressive deterioration of a video sequence group of pictures (GOP). Ideally, a more sensitive measure of congestion is required, which is not reactive to rather limited information conveyed by packet loss. The system should also be a good neighbour to co-existent TCP traffic on the same link, as TCP uses cooperative congestion control. This letter proposes a non-packet-loss-based measure of congestion that forms, along with its rate of change, an input to a fuzzy logic controller. A transcoder changes the encoded video bit rate to the rate determined by the fuzzy controller. It is the combination of transcoder and fuzzy logic controller that makes the system as a whole robust to the non-linearities present in congestion control feedback loops. These results show that the fuzzy control scheme adapts the video rate to the available bandwidth in the face of a typical mix (as determined by measurement studies) of Internet traffic, with behaviour that is comparable to TFRC. TFRC [1] itself is not adapted to variable bit rate (VBR) video, using fixed sized packets, whereas the received video quality from the fuzzy controlled transcoder system gracefully degrades in response to increasing background traffic, as a result improving the subjective viewing experience.

Methodology: Experiments were made with a VBR European-formatted SIF-sized MPEG-2 video-clip with moderate motion, details in Table 1. Each picture contained eighteen slices and each slice was encapsulated in an IP packet, with UDP transport, as is normal for video to avoid delay. The streaming system for unicast flows, Figure 1, measures both the time-smoothed sending rate dispersion (`Ds`) and receiving rate dispersion (`Dr`), at frame intervals, and a congestion level determination unit at the sender, calculates a congestion level (`Con`) based on the normalized difference between `Ds` and `Dr` and its frame-by-frame change (`dCon`), which are the two inputs to the fuzzy controller. The controller employs a simple Mamdani inference model and centroid-of-area defuzzification. Table 2 shows the fuzzy rule set. The sender then modulates the sending rate by applying a control signal (`Ctrl`) to a transcoder, which accordingly changes the quantization level. The scheme varies the video quality by varying the number of bits generated for each picture slice but does not change the inter-packet gap (IPG). The result is a stream of variable-length packets (`Sipg`) with a fixed IPG. The receiver calculates averaged dispersion of the IPGs for every frame. The dispersion results from the sharing of intervening router buffers by other traffic flows and is recorded whether packet loss occurs or not. (If packet loss does occur then the dispersion average is taken over the number of packets received before the next frame.)

Simulations modelled a network with dumbbell topology, the main feature of which was a variable bandwidth bottleneck representing a tight link at a core network edge. One fuzzy-controlled video source and ten TCP sources were passed across the link. Internet measurement studies [2] have demonstrated a typical link traffic mix to consist of longer term flows, “Tortoise”, representing file transfers, and transient HTTP connections, “Dragonflies”. The first five TCP sources were “Dragonflies” with a random duration of between one and five seconds generated from a uniform distribution and with an off duration of between one and five seconds, also randomly generated from a uniform distribution. The remaining five TCP sources were configured as “Tortoise” with an on duration of between five and twenty seconds and an off duration between one and five seconds, all also randomly generated from a uniform distribution. Ten experiments were conducted for each bottleneck bandwidth. In the first experiment, only one TCP source was present as background traffic, in the second two TCP sources were used as background traffic and so on, and all ten TCP sources were on as background traffic for the tenth experiment. The buffer size of the bottleneck link was configured to be twice the bandwidth delay product, with 100 Mbit/s access links from sender and to receiver to ensure congestion only occurred at the bottleneck link. In an independent set of tests with the same cross-traffic configuration, a TFRC controller dispatched fixed-size packets (700 B payload) across the same network tight link, varying the IPG according to the available bandwidth, as estimated by the TFRC feedback mechanism. To ensure fairness the publicly available TFRC ns-2 simulator model (in the form of `object tcl` scripts to drive the simulator) were availed from `http://www.icir.org/tfrc/`, with the fuzzy models available from this letter's first author.

Results: In Figure 2, each data point represents the bit rate of the congestion controller under test on the vertical axis against the average background rate of the flows for each of the Dragonfly and Tortoise experiments along the horizontal axis. The rate for each experiment is averaged over time as well as over the background flows. The fuzzy-controlled video bit rate was able to adapt to the available network bandwidth without disadvantaging the background TCP traffic. When TFRC was run independently, its behaviour was comparable. In Figure 2 a) for a 2 Mbit/s constriction, compare a T1 link at 1.544 Mbit/s or E1 at 2 Mbit/s, the maximum video sending rate was 800 kbit/s. Once the background traffic increased to 1.2 Mbit/s, the bit rate gradually falls. This trend is also shown in Figures 2 b) for a 0.5 Mbit/s constriction with the encoded video bit rate in general reflecting the available network bandwidth. As an example, Figure 3 a) shows the behaviour over time of Fuzzy–controlled video and TFRC-controlled flow, when there are ten background flows, while Figure 3 b) shows the flow-averaged TCP response of the background traffic. In Figure 3 a) it is apparent that the Fuzzy-controlled response is smoother, whereas the TFRC shows a residual saw-tooth bandwidth probing effect. In Figure 3, TFRC is more aggressive towards the background flows than the fuzzy controller. The quality of the received video was calculated in terms of the luminance (Y) peak signal-to-noise ratio (PSNR) and presented in Figure 4, for the controlled video in Figure 2. The results show that the received video quality also generally smoothly declines with available bandwidth. The fuzzy controller is closely comparable to a TFRC controller, representing good practice on a best effort IP network, as tests at other bandwidth constrictions also demonstrated.

Conclusions: This letter has demonstrated a fuzzy rule based controller in combination with a transcoder. This system offers the ability to smoothly vary the encoded video bit rate by means of the transcoder and results now show it coexisting with typical Internet cross-traffic. The tests show that the system is at least comparable with TFRC but is additionally suitable for VBR video streams, when low or no packet loss is sought.

References

1 M. Handley, S. Floyd, J. Pahdye, J. Widmer, `TCP Friendly Rate Control (TFRC): Protocol Specification', RFC 3448, Proposed Standard, January 2003.

2 N. Brownlee, K. C. Claffy, `Understanding Internet Traffic Streams: Dragonflies and Tortoise', IEEE Communications Magazine, 40(10):110—117, October 2002.

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Table captions:

Table 1: MPEG-2 video clip characteristics.

Table 2: Fuzzy rule inference table, showing input linguistic variables and resulting output variables.

dCL = change in congestion level, P = positive, N = negative, VH =very high, H =high, M = medium, L = low, Z = zero, E = extra.

Figure captions:

Fig. 1: Fuzzy controlled video transcoder system.

Fig. 2: Fuzzy video and TFRC control schemes, a) 2 Mbit/s and b) 500 kbit/s bottleneck bandwidth.

——ı—— TFRC
……x……Fuzzy

Fig. 3: Fuzzy video and TFRC control schemes with a 2 Mbit/s bottleneck bandwidth a) the controlled flows response b) sending rate response for ten TCP flows.

a) ——ı—— Fuzzy
……x…… TFRC

b) ——ı—— TCP/Fuzzy
……x…… TCP/TFRC

Fig. 4: Received Y-PSNR of a Fuzzy video stream control with a) 2 Mbit/s b) 500 kbit/s bottleneck bandwidth and an increasing background traffic load.

—— Y-PSNR

Table 1

Feature	Value	Feature	Value
Size	352×288 pel	Duration	40 s
Colour depth	24-bit	Input datarate	0.8 Mb/s
No. of frames	1000	GOP structure	N=12, M=3
Frame rate	25 f/s		

Table 2:

	Congestion Level (CL)				
dCL	L	M	H	VH	EH
NVH	PH	PM	PL	Z	NL
NH	PM	PL	Z	NL	NM
NM	PL	Z	Z	NM	NM
NL	PL	Z	NL	NM	NH
L	Z	NL	NM	NH	NH
PL	NL	NL	NM	NH	NH
PM	NL	NM	NH	NH	NVH
PH	NM	NH	NH	NVH	NVH
PVH	NM	NH	NVH	NVH	NVH

Figure 1:

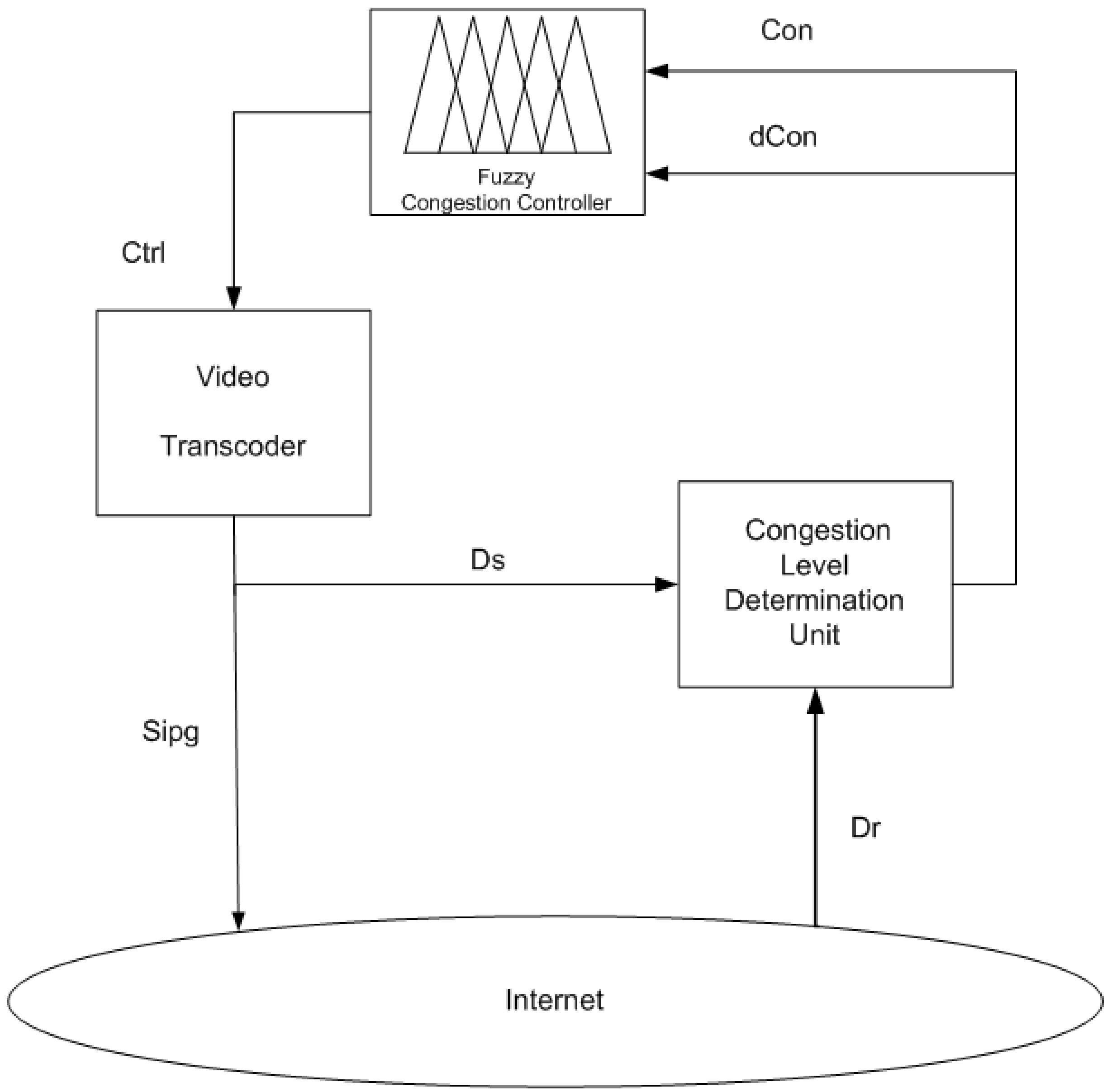
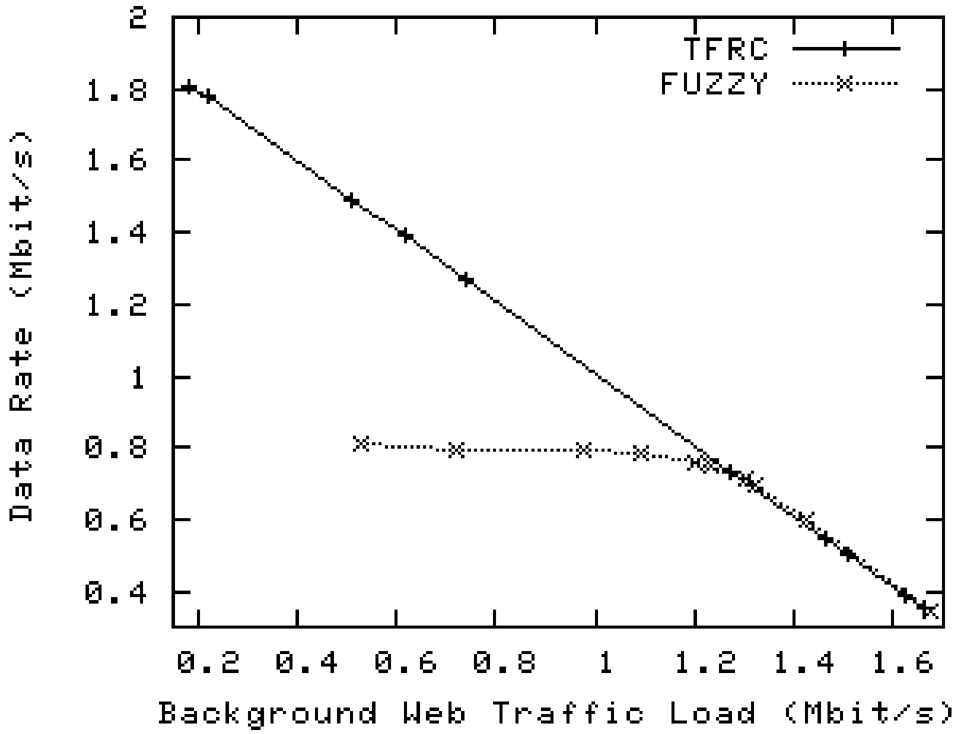
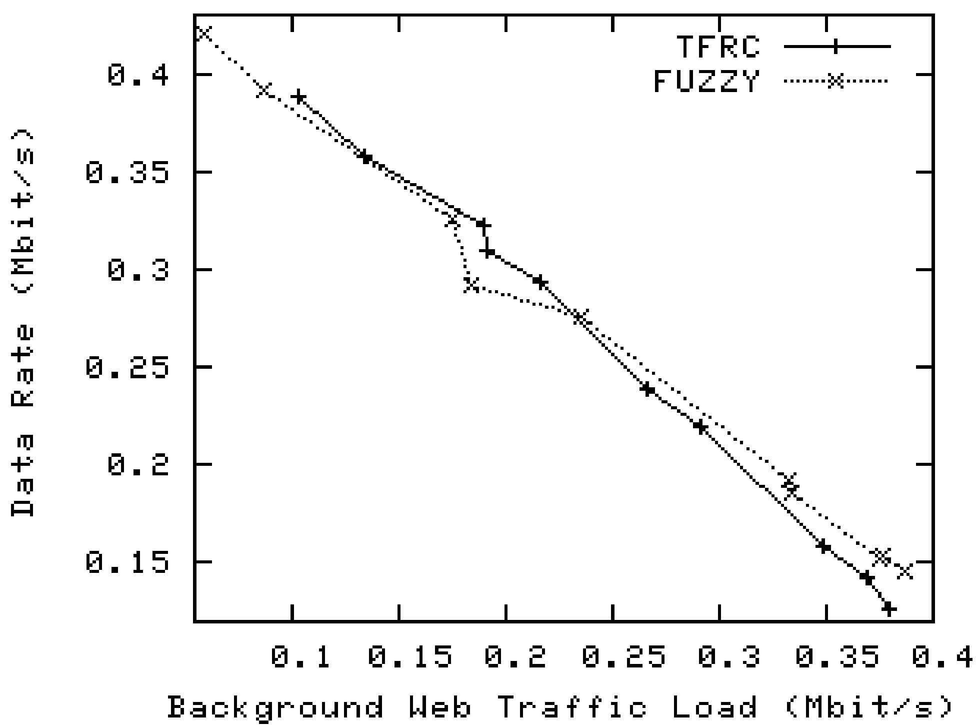

Con
dCon
Fuzzy
Congestion Controller
Ctrl
Video
Transcoder
Congestion
Level
Determination
Unit
Ds
Sipg
Dr
Internet

Figure 2:



TFRC
FUZZY
Data Rate (Mbit/s)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2 0.4 0.6 0.8 1 1.2 1.4 1.6
Background Web Traffic Load (Mbit/s)

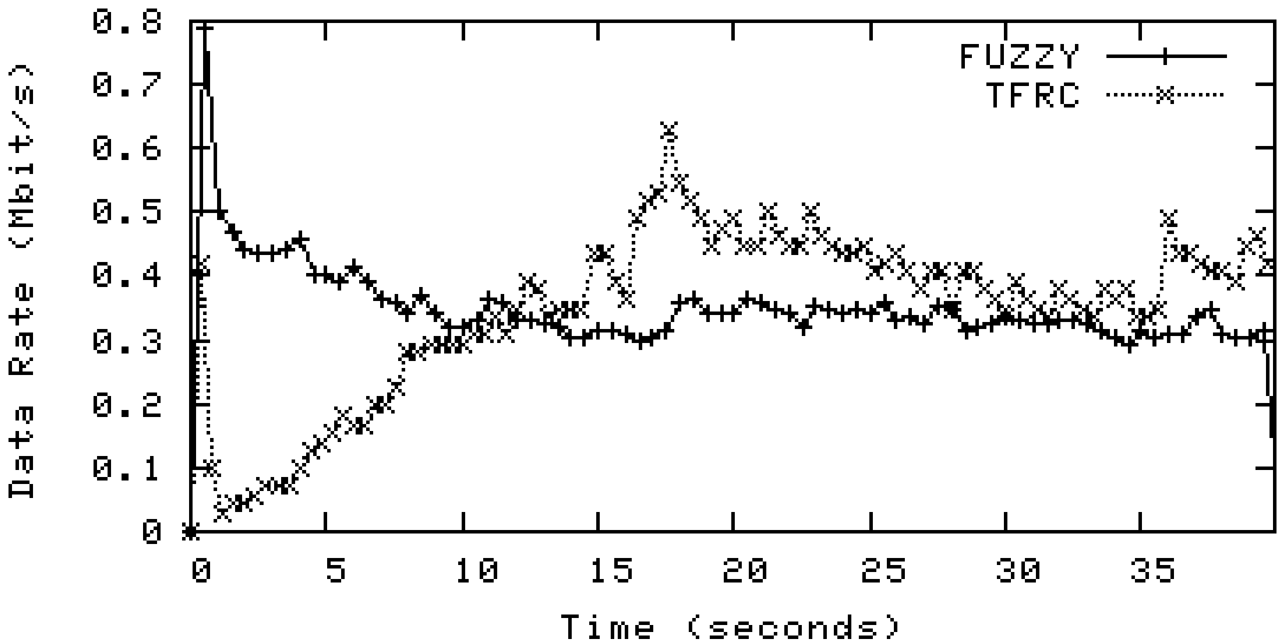
(a)



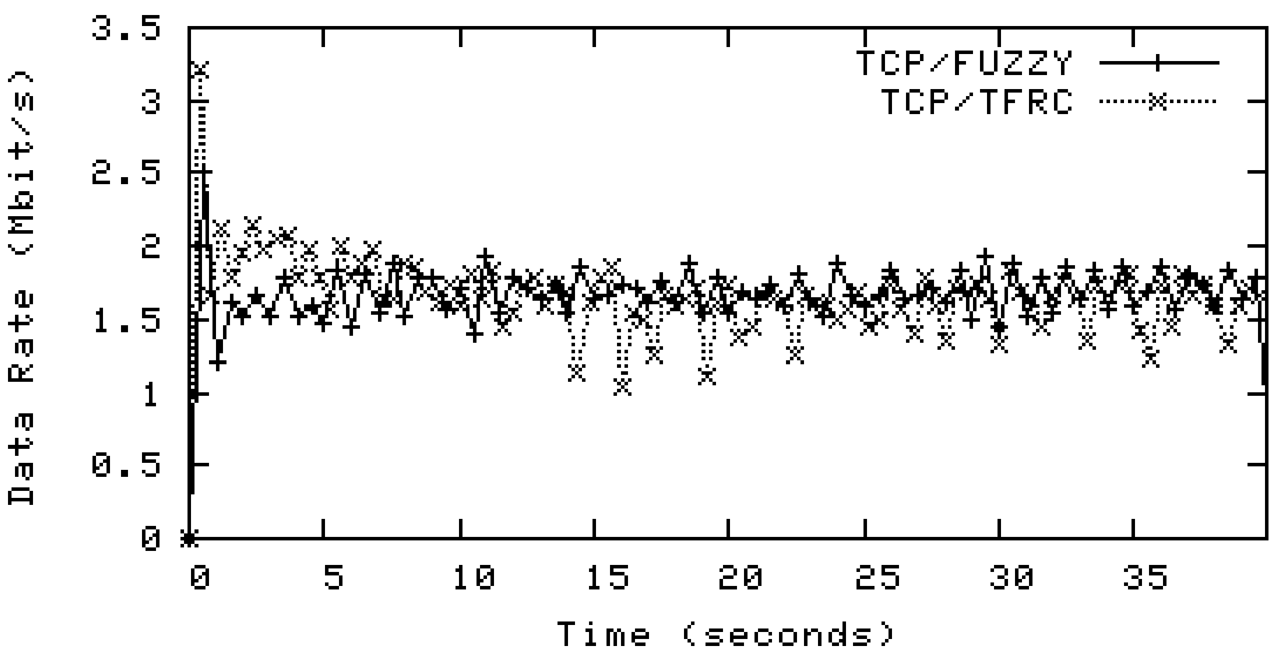
TFRC
FUZZY
Data Rate (Mbit/s)
0.4
0.35
0.3
0.25
0.2
0.15
0.1 0.15 0.2 0.25 0.3 0.35 0.4
Background Web Traffic Load (Mbit/s)

(b)

Figure 3:

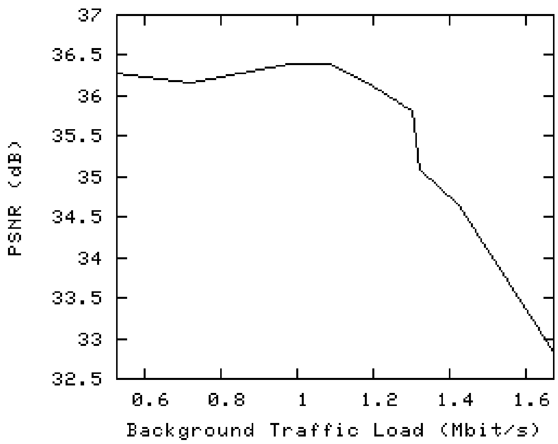

FUZZY
TFRC
Data Rate (Mbit/s)
Time (seconds)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
5
10
15
20
25
30
35

(a)

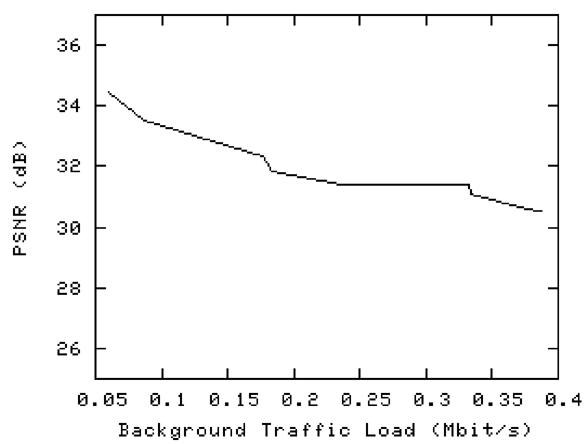

TCP/FUZZY
TCP/TFRC
Data Rate (Mbit/s)
Time (seconds)
0
0.5
1
1.5
2
2.5
3
3.5
0
5
10
15
20
25
30
35

(b)

Figure 4:


37
36.5
36
35.5
35
34.5
34
33.5
33
32.5
PSNR (dB)
0.6
0.8
1
1.2
1.4
1.6
Background Traffic Load (Mbit/s)

(a)


36
34
32
30
28
26
PSNR (dB)
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Background Traffic Load (Mbit/s)

(b)