Rate adaptive video transmission over ad-hoc networks

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A packet control mechanism via a cross-layer feedback to reduce bursts of packet drops for transmission of video over mobile multihop ad-hoc networks is presented. With this approach, the application layer would be capable of controlling the packet transmission flow in accordance with the multihop characteristics of the routing layer.

Introduction: Under best effort ad-hoc network environments where the routing and channel characteristics are expected to vary dynamically (e.g. mobility conditions), providing reliable multimedia services is becoming a challenge. A crucial factor affecting ad-hoc channel performance is the deterioration of the network throughput performance as the number of transmission hops increases [1]. This behaviour is mainly the result of contention to access the same channel (i.e. using carrier sense multiple access protocol), which tends to increase as the signal hops through more intermediate nodes. At the same time, nodes located far away from each other can simultaneously transmit packets (i.e. by being outside the contention range).

Nevertheless, for peer-to-peer video communications in order to utilise the maximum possible bandwidth, it would be beneficial to develop a rate matching technique that can dynamically control the source bit rate in accordance with the multihop characteristics of the ad-hoc channel. Therefore, in this Letter we present a cross-layer feedback control technique to improve the ad-hoc network performance for real-time video communications. This is also based on developing a rate-matching algorithm that can dynamically control the packet generation rate with respect to the number of hops the signal traverses before reaching its destination.

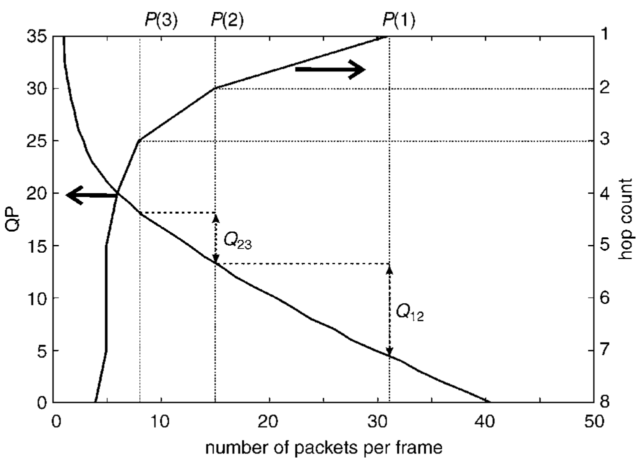

Fig. 1 *Selecting quantisation range (Q_{range}) with respect to transitional hop-count*

$Q_{12} = Q_{range}$ for change of hop-count from 1 to 2 (or vice versa)
$Q_{23} = Q_{range}$ for change of hop-count from 2 to 3 (or vice versa)

Rate control: In ad-hoc routing protocols such as ad-hoc on-demand distance vector (AODV) [2] and dynamic source routing (DSR) [3], each node maintains a routing table for an entry (destination) with the hop-count (number of hops from source to destination) and sequence number. This information can be used at the application to control the transmission rate in accordance with the hop-count. In the case of AODV, the hop-count can be extracted from the routing table information. If a route change is the consequence of a link breakage, any intermediate node (between the source and destination) detecting the link breakage (to the next hop), will send the route error (RERR) message back to the source node. The source node therefore may use the reception of RERR as an indication of a link breakage. As soon as a new route is established the application layer, upon receiving the hop-count information from the routing layer, would be able to adjust its bitrate in accordance with the permissible transmission rate. In the case of video communications, the bitrate can be adjusted by changing the value of the quantisation parameter (QP). This parameter has been specifically defined in the syntax structure by all video coding standards as a means to control the video transmission rate. Its value, which can have direct bearing on the video quality, is selected as a two-way compromise between the average transmission rate and the video quality. Here, we have considered the new video-coding standard known as H.264/AVC [4].

In our cross-layer implementation, the application layer checks its routing information at the beginning of each frame. Thus, the value of the QP remains unchanged during each coding frame. Fig. 1 shows an example of the average number of packets per P-frame (prediction frame) against the QP value for a near-fixed packet size (i.e. 600 byte).

Two pre-recorded head-and-shoulder video sequences with differing degrees of motion activities were used to plot the QP variations against the average number of packets per frame. Fig. 1 also includes the permissible average number of packets per frame against hop-count, which was measured using the Ricean fading model with Ricean factor, $K = 10$. IEEE 802.11 WLAN technology [5] and the AODV ad-hoc routing protocol [2] have been used in these experiments. The link failure detection was based on a fixed number of unsuccessfully retransmitted packets [2]. Accordingly, we have set the maximum number of IEEE 802.11 MAC retransmissions to 2 (i.e. retry limit = 3). Therefore, if the transmitting node does not receive any acknowledgment after two retransmission attempts, the link will be declared broken and the new route discovery process will be initiated. In the cross-layer design, the transmitting node upon receiving the new hop-count should then update the QP value in order to meet the targeted number of packets before encoding the incoming frame. The main objective is to adjust the video packet rate with respect to the change of hop-count, which has a nonlinear relationship with the throughput rate. To estimate the quantisation parameter, its value is recursively updated as,

$$QP_n = QP_{n-1} + \delta QP_n(h) \quad (1)$$

where $\delta QP_n(h)$ is the QP update at the given hop-count $= h$. QP_{n-1} and QP_n are the quantisation values for frame $n-1$ (previous coded frame) and n (the current frame), respectively. Now let us define,

$P(h)$ = permissible number of packets/frames at the hop-count $= h$ (i.e. for frame n: $P_n(h) = P(h)$)

P_{n-1}: measured number packets on the previously coded frame

$Q_{i,j}$ = range of QP values that can change the number of packets/frames with respect to the change of hop-count from $h = i$ to $h = j$

$\Phi_{i,j}$ = a multiplication factor whose value is determined by the change of hop-counts from i to j, where

$$\Phi_{i=j} = 1 \quad (2)$$

and

$$\Phi_{i\neq j} = \left|\frac{Q_{i,j}}{P(h=i) - P(h=j)}\right| \quad (3)$$

Based on the above definitions, at the beginning of each coding frame (i.e. frame n), the δQP is estimated as,

$$\delta QP_n(h) = \text{integer part of } \{\Phi_{ij} \cdot \{P_{n-1} - P(h)\}\} \quad (4)$$

Note that the $Q_{i,j}$ is obtained according to the transitional hop-counts from i to j with respect to the permissible number of packets/frame at each hop-count. For better clarity, Fig. 1 shows an example of how $Q_{i,j}$ is selected (e.g. $Q_{1,2}$ or $Q_{2,3}$ in this Figure).

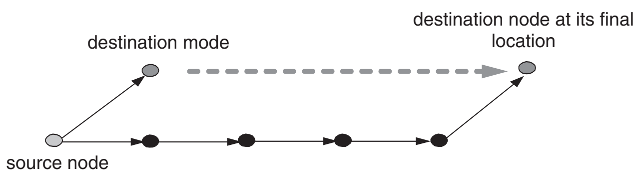

Fig. 2 *Change of hop-count scenario where destination node moves left to right undergoing one to five hops*

Results: We assessed the performance of the above rate-matching scheme via our real-time simulation testbed. For this we imported our H.264/RTP/UDP/IP video streaming package into the Qualnet simulation tool [6]. A pre-recorded video sequence was encapsulated into 612-byte RTP packets (including the RTP header), before being transmitted in real time over a multihop ad-hoc channel according to the scenario depicted in Fig. 2.

In this scenario, the destination node moves from left to right by undergoing 1-to-5 hops. The Ricean fading model with $K = 100$ was used to assess the cross-layer feedback performance. At the beginning of each video frame the packet rate is updated according to (4). If the hop-count remains the same, the QP would be still updated according to (2) and (4), in order to adjust to the changes in motion activity. If a new hop-count is detected, the encoder calculates the new packet transmission rate based on (3) and (4).

Fig. 3 shows the number of packets at each frame with and without rate control. In addition, we included the packet loss rate (averaged over a period when the hop-count remains unchanged). With the cross-layer control, we can observe that the targeted number of packets have been effectively met as soon as the new hop-count is detected. Because of the cross-layer rate control, the average packet-loss rate remains almost unaffected by the change of hop-count.

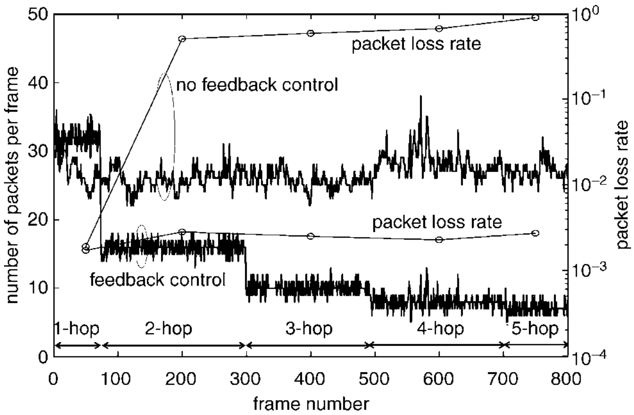

Fig. 3 *Number of packets per frame against packet loss rate*

Conclusions: A cross-layer feedback mechanism with a rate control approach is proposed. This overhead-free feedback approach is based on acquiring critical information from the underlying routing layer. To adapt to the changes in the network topology, we developed a recursive rate control algorithm capable of handling packet flow at the application layer in order to reduce the packet drop rate. It has been shown that this method can effectively control the packet-loss rate by avoiding excessive packet drops, which could affect the resynchronisation process at the decoder.

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