Application-Layer Rate-Adaptive Multicast Video Streaming over 802.11 for Mobile Devices

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ABSTRACT

Multicast video streaming over IEEE 802.11 is unreliable due to the lack of feedback from receivers. High data rates and variable link conditions require feedback from the receivers for link estimation to improve reliability and rate adaptation accordingly. In this paper, we validate on a test platform an application-layer rate-adaptive video multicast streaming framework using an 802.11 ad-hoc network applicable for mobile senders and receivers. Experimental results serve as a proof of concept and show the performance in terms of goodput, delay, packet loss, and received video quality.

Keywords

Rate-adaptive multicast, wireless video streaming, 802.11

1. INTRODUCTION AND MOTIVATION

This paper addresses the problem of reliably multicasting a video stream over an IEEE 802.11 ad-hoc network with mobile nodes to satisfy the receivers' quality of experience (QoE). Our work has been motivated by the use of micro aerial vehicles (MAV) for civil applications, such as search and rescue, surveillance, and disaster management [3, 9, 19]. Such applications benefit from multicast wireless video streaming to transmit identical data to multiple users (see Fig. 1). However, achieving reliability, fairness among nodes, communication performance, and adhering to delay bounds is challenging [4, 5, 11, 15, 22, 23]. In particular, aerial mobility leads to dynamic network topologies with frequent link outages [2, 6, 10].

While existing license-based wireless communication technologies can in principle be used for MAVs, they bear infrastructure requirements that may not be available in disaster areas. In contrast, IEEE 802.11 does not require an infrastructure, is easy to setup, operates in the unlicensed spectrum [7], and is supported by many MAV platforms [10]. However, IEEE 802.11 was not designed for our scenario.

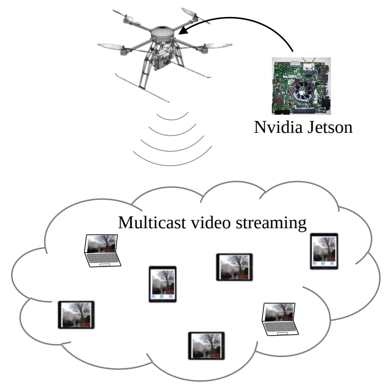

Figure 1: Multicast video streaming from a micro aerial vehicle (MAV).

Because the multicast frames in 802.11 are group addressed and are not acknowledged by the receivers, the ability to gain feedback from receivers about packet reception is a major issue [22]. In fact, without feedback, the source is not aware of packet losses and cannot retransmit lost packets or adapt the transmission rate. Approaches to provide feedback include promiscuous reception of unicast packet [8, 21], polling-based schemes [16, 18], and leader-based approaches [4, 12, 17]. However, these approaches require modifications in the medium access control (MAC) layer. Given the constraints of multicasting over 802.11 with mobility, the node providing feedback may at times lose connectivity with the source. This may make all other multicast recipients suffer from a possible smooth video reception. A feedback mechanism for retransmission and rate adaptation is required to achieve reliability and to satisfy receivers' QoE without any MAC layer modifications.

We discuss and validate an application-layer solution to gain feedback from the receiver nodes that works for any 802.11 wireless ad-hoc setup. The feedback received is not only used to retransmit lost packets but also to adapt the *video encoding* rate, the *link transmission* rate, and the *video frame* rate to obtain a smooth video reception. We refer to the combination and adaptation of these three parameters as

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Table 1: Comparison of schemes for multicasting over 802.11 (extended from [14])

Ref.	Scheme	Changes to MAC?	Reliability	Scalability	Rate adaptation	Evaluation
[16]	Polling based	Yes	None	Low	Joint reception correlation	Testbed
[18]	Polling based	Yes	None	Low	User experience in time	Simulation ns-2
[4]	Leader based	Yes	High	Low	Auto rate fallback	Simulation ns-2
[17]	Leader based	Yes	None	High	Beacon Signal	Simulation ns-2
[13, 20]	Directed multicast	Yes	High	Low	None	Testbed
[13, 20]	Unsolicited retries	Yes	Implementation dependent	High	None	Testbed
[13, 20]	Block ACK	Yes	Implementation dependent	Implementation dependent	None	Testbed
Ours	Dynamic leader	**No**	Medium	High	RTP packet feedback	Testbed

ELF rate adaptation. Our framework was initially presented and validated with simulations in [14] and it is extended and validated in this paper through testbed experiments that quantify performance in terms of achieved goodput, delay, and received video quality.

The paper is organized as follows. Section 2 covers existing approaches for multicasting and rate adaptation in wireless networks. Section 3 presents the proposed rate adaptation scheme for video multicasting. Section 4 discusses the experimental evaluation and Section 5 concludes the paper.

2. RELATED WORK

Approaches that can be used to multicast over 802.11 include the legacy 802.11 multicast, 802.11aa amendments, and schemes to gain feedback on packet reception from members of a multicast group.

The 802.11aa GATS specifies the directed multicast service (DMS), the groupcast with retries (GCR) unsolicited retries, and GCR Block ACK besides the legacy multicast service [20]. The legacy multicast mechanism is No-Ack/No-Retry service that uses the basic fixed transmission rate. The DMS converts multicast traffic to unicast frames intended for individual recipients. Reliability is ensured through retransmissions until frames are received correctly by all the recipients. While this scheme is the most reliable, it has a higher overhead and is not scalable.

The GCR unsolicited retries does not use an acknowledgment mechanism and retransmits the same frame several times. This method offers smaller overhead, higher scalability but lower reliability [13].

The GCR Block ACK scheme sends a burst of multicast frames and requests a block acknowledgment (ACK) of the transmitted frames from one or more recipients. The choice and number of recipients from which to gain a feedback is left to the specific implementation. Frames that are not received correctly by one or more recipients can be retransmitted until the retry limit is reached. This scheme offers a trade-off between reliability, overhead, and scalability [13].

In a multicast group, feedback on packet reception can be obtained via promiscuous reception of unicast transmission, polling schemes, and leader-based protocols [22]. With *promiscuous reception*, a member receives data from the source as unicast traffic, while other members listen in promiscuous mode [8, 21]. Each member needs to know the MAC and IP address of the node receiving the unicast traffic and, when this node leaves the group, the other members experience a total packet loss.

The *polling scheme* asks each receiver to acknowledge the reception of the packet that is re-multicast when an ACK is missing [16, 18]. This solution is not efficient for our problem as considerable network resources are needed.

Leader-based schemes select a member that is tasked to send the ACKs. The other members can send negative acknowledgments (NACKs) when packets are not received [4, 12, 17]. While these approaches address reliability by sending feedback through the ACK/NACK mechanism, they do not address the challenges of mobility and video streaming requirements of resilience to jitter and packet losses [14].

Table 1 compares existing schemes and our proposed approach, which is described in the next section.

3. ELF RATE ADAPTIVE MULTICAST

We use an application-layer ELF rate adaptation applicable to 802.11 ad-hoc networks. We advance our work in [14] by (*i*) adapting the video frame rate in addition to the encoding and transmission rates, (*ii*) performing an experimental evaluation on a real testbed, and (*iii*) identifying parameters that are applicable for outdoor real-time multicast video streaming. The notation we use in this section is listed in Table 2.

Members of the multicast group are assigned as *designated nodes* based on their signal quality from the source. Upon receiving a packet, the designated nodes provide feedback through an application-layer acknowledgment, `AL-ACK`, or else provide a negative acknowledgment, `AL-NACK`. The member with the highest signal quality becomes the *primary* designated node, P. Other members with good signal quality become part of the set of *secondary* designated nodes, S, which serve as backup of P. Non-designated nodes are part of the set of *best effort* nodes, B, which do not provide feedback and receive videos on a best effort basis [14].

Feedback received by the source is used for rate adaptation to reduce video distortion and for retransmission upon packet loss (see Fig. 2). Similarly to the leader-based schemes, the source assigns the roles to the receivers based on the signal quality [14]. However, we allow feedback from multiple receivers (designated nodes) and not from a single leader only. Unlike our work [14], which used the signal-to-interference-noise-ratio (SINR), we use here as indicator for signal quality to the connected devices the received signal strength (RSS).

To minimize feedback delays and channel contention time, the roles are assigned in a hierarchy. The source can adjust the ELF rate when the reception conditions of the receivers change, thus facilitating a smooth video playback.

The source assesses the signal quality of the member nodes to assign the feedback responsibility dynamically to a member node, accounting for the change in reception conditions due to mobility of both the source and receivers. The role assignment procedure is defined in Algorithm 1.

The first node joining the multicast group becomes P. Fewer than half of the nodes in the multicast group M can

Table 2: Notation

Symbol	Definition
M	Multicast group
V	A new mobile receiver node
R_X	RSS of node X
P	Primary designated node
$S = \{S_1, \cdots, S_{n_1}\}$	Secondary designated nodes S_i
$B = \{B_1, \cdots, B_{n_2}\}$	Best effort nodes B_i
card(.)	Cardinality of a set

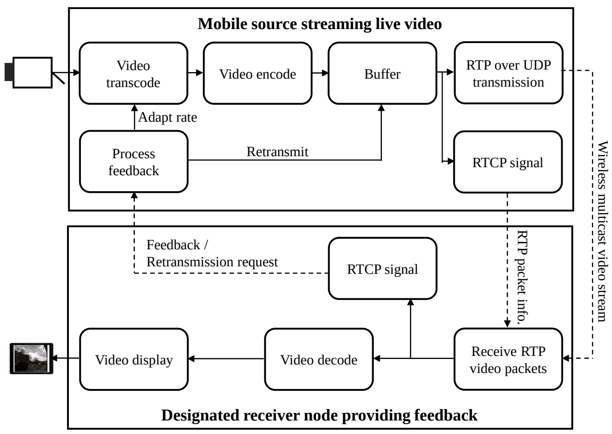


Figure 2: Source multicasts live video stream over the wireless medium as RTP packets. RTCP signaling provides RTP packet information to the receiver nodes. Designated nodes provide feedback about packet reception or packet loss. The source retransmits lost packets and adapts ELF rates.

be designated nodes. A node is assigned to S if [14]

$$\frac{\text{card}(S)+1}{\text{card}(M)+1} < 0.5. \tag{1}$$

A node joining can change between P and S_i, if $R_V > R_P$ or $R_V > R_{S_i}$, respectively. However, the role for P is assigned to another group member (the one with the highest signal quality) in case two consecutive AL-NACKs are received from P while an S_i responds with an AL-ACK. Otherwise, it is added as a member to M as B.

While P is responsible for sending AL-ACKs upon packet reception, either P or an S_i node can send an AL-NACK to request retransmission of lost packets.

To make the approach scalable, the number of designated nodes can be adjusted based on the network density.

The encoder has to choose the video encoding and frame rates for the next Group of Picture (GoP). We use the real-time transport protocol (RTP) for video streaming and its control protocol RTCP for signaling feedback about reception of RTP packets.

These following values are chosen experimentally: The *link transmission rate* is increased upon ten consecutive AL-ACKs from the designated nodes. It is decreased upon signal loss, i.e., when no feedback is received from any of the designated nodes. We use rates as $6, 9, 12, 18, 24, 36, 48$, and 54 Mbit/s. The *video encoding rate* is initially set to 512 kbit/s and it is increased by 5 % upon receiving an AL-ACK (up to a maximum of 8192 kbit/s). It is decreased by 5 %

Algorithm 1: Role assignment

Notation: See Table 2.
Input: V, R_V, R_P, R_{S_i}, R_{B_i}, card(S), card(M).
Output: Role is assigned to V joining muticast group M.

if card(M) > 0 **then**
  if card(S) > 0 **then**
    if $\frac{\text{card}(S)+1}{\text{card}(M)+1} > 0.5$ **then**
      if $R_V > R_P$ **then**
        $M \leftarrow V$, $B \leftarrow S_n$, $S \leftarrow P$, $P = V$
      else if $R_V > R_{S_i}$ **then**
        $M \leftarrow V$, $B \leftarrow S_n$, $S \leftarrow V$
      else
        $M \leftarrow V$, $B \leftarrow V$
      end
    else if $R_V > R_{S_i}$ **then**
      $M \leftarrow V$, $B \leftarrow S_n$, $S \leftarrow V$
    else
      $M \leftarrow V$, $B_i = V$
    end
  else if card(M) ≥ 2 **then**
    if $R_V > R_{B_1}$ **then**
      $M \leftarrow V$, $S_1 = V$
    else
      $M \leftarrow V$, $S_1 = B_1$, $B_1 = V$
    end
  else
    $M \leftarrow V$, $B_1 = V$
  end
else
  $M \leftarrow V$, $P = V$
end

upon receiving three consecutive AL-NACKs (down to a minimum of 128 kbit/s). The source retransmits the packet in the latter case. The *frame rate* is initially set to 25 frames/s and it is decreases by one frame/s (down to a minimum of 10 frames/s) upon three consecutive AL-NACKs if the video encoding rate is already at its minimum. It is increased again upon one AL-ACK.

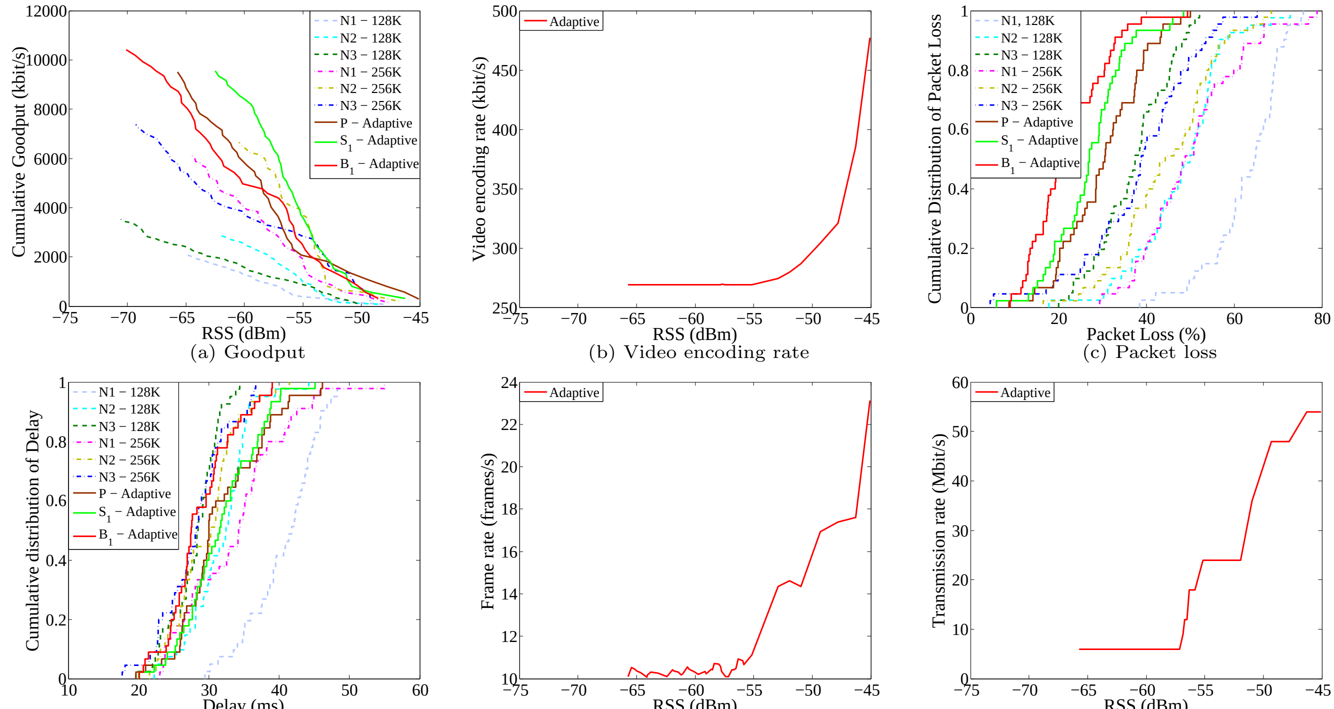
4. TESTBED EVALUATION

We built an 802.11a ad-hoc network using Atheros AR9462 wireless cards, which support 802.11abgn and independent basic service set (IBSS). To capture videos, Logitech C920 cameras that support full HD 1080p video quality at 30 frames/s with H.264 video compression are used. NVIDIA Jetson TK1 boards [1] are used for processing and video streaming; they have a quad-core 2.3 GHz ARM Cortex-A15 CPU and energy consumption of 1–5 W.

We evaluate our framework with a mobile source and three static receivers (N_1, N_2, and N_3). All nodes are on approximately one meter above the ground. We analyze the effect of the motion of the source on the received video stream quality at distances from 5 to 80 m. The three receivers are placed 5 m apart. We manually select the closest receiver node to the source as P, the second closest as S_1, and the farthest as B_1.

Our rate adaptive approach is compared with a fixed transmission rate of 6 Mbit/s and constant encoding rates of 128 kbit/s and 256 kbit/s. We evaluate performance in terms of received video quality, packet loss, and delay.

Figure 3 shows the mean values from five experimental runs. The cumulative goodput is calculated by adding the received bytes as the RSS decreases in order to observe the



(a) Goodput (b) Video encoding rate (c) Packet loss

(d) Delay (e) Frame rate (f) Transmission rate

Figure 3: Performance of multicast video streaming with the source moving away from the receivers.

Figure 4: Sample frames representing received video quality with CBR 6 Mbit/s encoded at 128 kbit/s (top row) and our rate adaptive scheme (bottom row) for a multicast video stream.

trend of the received packets with and without the feedback mechanism. The RSS is measured in decibel-milliwatts (dBm). The cumulative goodputs (Fig. 3(a)) of the receiver nodes P compared to N_1, S_1 compared to N_2, and B_1 compared to N_3 remain higher due to higher and adaptive encoding rate. As it moves away from the receivers, the source adapts the video encoding rate (Fig. 3(b)), frame rate (Fig. 3(e)), and transmission rate (Fig. 3(f)). The packet loss (Fig. 3(c)) of the receiver nodes remains lower with our approach compared to the fixed 6 Mbit/s transmission due to the feedback and retransmission mechanism. Due to a reduced packet loss, a smoother video is observed compared to the video of the legacy multicast. Balanced delays under bounds are observed in all cases (Fig. 3(d)).

To compare the received video quality of legacy multicast and our approach, sample frames captured at 5 s intervals are shown in Fig. 4. A high distortion is noticeable with the fixed rate transmission, while an acceptable video stream is received with the proposed rate adaptive approach.

5. CONCLUSIONS

We validated the feasibility of an application-layer rate-adaptive multicast video stream on an experimental testbed that does not require any modifications of the MAC layer and is suitable for mobile platforms equipped with cameras. Transmission, video encoding, and frame rates are adapted based on the received feedbacks from designated nodes. Reliability is achieved by retransmissions of lost packets, resulting in fewer packet losses. The proposed framework enables a smooth video reception and outperforms legacy multicast in terms of packet loss and video quality.

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