Wireless Handover with Application to Quadcopter Video Streaming over an IP Network

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***Abstract*— Monitoring oil pipelines can be accomplished by Quadcopters equipped with video cameras flying alongside a pipeline. Backhaul of a video stream from the Quadcopter's camera can be via a series of WiMAX base-stations placed alongside the pipeline. This paper considers a significant problem that can arise, video service interruption as a handover occurs between WiMAX base-stations. The paper presents a scheme for hard handover recovery during video streaming to a remote monitoring station. The selective NACK scheme trades a reduced but acceptable video quality during handover for improved end-to-end latencies compared to unselective NACKs. Both forms of NACK (selective and unselective) promise better video quality (by several dB) than with UDP transport or traditional congestion-controlled streaming, which results in long delays during handovers.**

Keywords—NACKs; Quadcopter; video streaming; WiMAX; wireless handover

I. INTRODUCTION

The Quadcopter [1] is a micro aerial vehicle (MAV), which, due to its easy availability, has been the subject of research into control algorithms, sometimes aimed at larger unmanned aerial vehicles [2]. A Quadcopter has four rotors, Fig.1, that can be independently controlled to guide its flight path. However, the interest in this paper is not so much in control algorithms to stabilise the flight of the MAV but in streaming video from a camera that is mounted between two of the rotor-bearing arms of Quadcopters. We hope to take advantage of such a camera to stream video to a remote monitoring station, sending video over an Internet Protocol (IP) network. In particular, Quadcopters are a way of checking the integrity of oil pipelines, which often pass through regions difficult to access on a regular basis.

In this application, a number of IEEE 802.16e (mobile WiMAX) [3] base stations (BSs) are spaced at regular intervals along a pipeline in order to backhaul the video stream to a remote monitoring station. Mobile WiMAX is shown to have an operating range of about 2 km at 2.3 GHz in [4] (though in an urban microcell). If a Quadcopter flies along the route of a pipeline, it will pass out of range of one BS and into range of another, whereupon a horizontal handover takes place. It is this issue that is the principal research focus of this paper, as it is the need for handovers that presents the principal technical challenge to streaming video from a Quadcopter. We assume that the Quadcopter is equipped with H.264/AVC codec [5] for video compression and a WiMAX transceiver for communication to BSs. There is already a considerable literature on wireless video streaming methods [6], including over mobile WiMAX [7] but this research generally does not consider the issue of handovers.

During handover, service interruption occurs, necessitating recovery from packet loss to restore the video stream, which action, however, causes an increase in end-to-end packet latency. It is possible to anticipate a handover via pre-buffering, e.g. [8], but to do this requires some form of soft handover operated at higher layers of the standard protocol stack. However, though mobile WiMAX support three handover mechanisms, only the mandatory Hard Handover (HHO) at layer 2 can be accomplished with a single channel at any one time, thus reducing equipment cost and improving BS capacity, which is why we selected HHO. The emerging IEEE 802.16m version of WiMAX discontinues the use of soft handovers, another reason to prefer hard handovers.

This paper proposes an HHO scheme with selective negative acknowledgements (NACKs) to recover lost video during the handover process, as this is preferable to WiMAX video transport directly through UDP transport [9] with no built in response to packet loss, or through an industry-standard congestion controller [10], or indeed with un-selective NACKs (which respond to the loss of all video packets). In the selective variety examined, only intra-coded I-frame packets when lost are retransmitted, which has the effect of speeding up video stream recovery after an HHO. I-frames act as anchor frames through all spatial or intra coding, allowing the compressed video frame to be reset, whereas other standard frame types reference other frames in order to be decoded.

Fig. 1. Quadcopter showing camera and adjacent oil pipeline

Notice that prior research often considers video streaming, including IPTV/video-on-demand services, over the downlink from the BS, whereas surveillance from a Quadcopter involves streaming over an uplink. As far as mobile WiMAX network frame is concerned [11], the ratio between the downlink and uplink sub-frames can be configured to give more bandwidth in the uplink direction. This differs from typical wired access over an ADSL in which the uplink share of the bandwidth is normally fixed and much lower than the downlink. There are issues when reversing the direction of streaming in terms of different types of packet scheduling at a BS compared to the Quadcopter acting as a mobile subscriber station (MS) but as traffic congestion over the wireless link is not present in this application, these issues are not considered in this study. Thus, in this study, we have reinterpreted previous results [12] for vertical handover between different wireless technologies (not horizontal handover, as herein, between the same wireless technology) in the light of the Quadcopter application. The direction of video streaming is reversed but given the prior discussion, we believe the results remain relevant.

II. METHODOLOGY

In IEEE 802.16e (mobile WiMAX), HHO employs a break-before-make procedure which reduces signalling. A mobile station (MS), in this case a Quadcopter, monitors signal strength from adjacent BSs before deciding upon a handover once an SNR threshold is passed, employing an hysteresis mechanism to avoid thrashing between BSs. The MS must then: obtain uplink and downlink parameters; negotiate capabilities; gain security authorisation and exchange keys; register with the BS; and establish connections. Though the industry WiMAX Forum specifies a maximum of 50 ms for HHO, this does not account for prior scanning to find a suitable BS, residual signaling after the connection has been made (network entry), the re-establishment of an IP network route to the remote server, and the loss of packets during signaling. This suggests a longer period of disruption in practice [13], though the actual period of changing connections may come within the specification, depending on speed and video frame size.

To judge the effect of HHO during video streaming from the Quadcopter, we employed the well-known ns-2 simulator was augmented with the NIST module[1] for IEEE 802.21 handovers, which is an emerging standard for wireless technology independent handovers [14]. IEEE 802.21 subsumes all the signaling activities mentioned in the previous paragraph, which previously took place in a technology-dependent manner.

In Fig. 2's simulation scenario, a remote monitoring station for the Quadcopter, RM, receives a video stream over an IP network. The Quadcopter (QC in Fig. 2) flies alongside a pipeline and between the mobile WiMAX BSs. The QC moves in parallel to the BSs, which are separated by 1.9 km. During this motion a handover occurs at the overlap between the signaling range of the BSs. (For simplicity, a single sector omni-directional antennas are assumed.) Various sources of congestion exist on the IP network that connects the BS to the remote monitoring station. These are included in the simulation to show the effect of other traffic, as the video stream passes over the IP network. Node A sources to node B constant bit-rate (CBR) data at 1.5 Mbps with packet size 1 kB and sinks a continuous TCP FTP flow sourced at node B. Node B also sources an FTP flow to the BS and CBR data at 1.5 Mbps with packet size 1 kB. Though the simulation accounted for re-establishment of the route between RM and the second BS, for simplicity of simulation, it is assumed that the same route across the IP network is selected. Not shown in Fig. 2 is the access service network that directly manages the IEEE 802.16e BSs.

In order to understand the selective NACK scheme, we briefly review video compression. Video compression is based on spatial and temporal redundancy reduction along with entropy coding. Spatial redundancy reduction results in Intra (I) frames, where each block of the picture is predicted from its neighboring coded block without reference to any other frame. The difference between the two blocks is transformed into frequency space, followed by quantization and entropy coding. Inter frames exploits the temporal redundancy between frames. In this process the movements of objects in the neighboring frames are modelled using motion vectors. The resulting frame is subtracted from the original frame to be encoded, and the residue is then coded as for Intra frames. Inter frames can be further divided in to Predictive (P) frames and Bi-predictive (B) frames. In P frames the prediction is made from earlier P or I frames, while in B frames the prediction can be made from an earlier and/or later I and/or P frame (or B-frame in H.264). I-frames act as coding anchors for later frames in a group of pictures (GoP). Therefore, they at least must be retransmitted to avoid significant loss of video quality. A GoP usually is 30 s in duration.

Fig. 3 illustrates the streaming scheme. Compressed I-, B-, and P-picture data are encapsulated as Network Abstraction Layer (NAL) units (part of the H.264/AVC codec network provision) before RTP (Real-time Transport Protocol)/UDP/IP network packetization and transmission. At the remote monitoring station, a record is kept of packet sequence numbers available through the RTP header and, if an out of sequence packet arrives from the QC, a NACK may be transmitted to the QC over the IP network to be placed in the next IEEE 802.16e sub-frame (assuming Time Division Duplex (TDD) operation for 802.16e) for forwarding to the video application on the QC.

Recall from Section I, that in the selective form of the scheme, only lost packets from I-frames are requested to be retransmitted rather than packets from P- and B-frames. The remote monitoring station only transmits a NACK if this is the first time that particular packet has been lost. Once a NACK arrives, the QC prevents transmission from its input buffer until a retransmission of the requested missing packet in the sequence has taken place. Not shown in Fig. 3, is a holding buffer that retains sent packets in the case of the need for a retransmission.

[1] National Institute of Standards and Technology (NIST) http://w3.antd.nist.gov/seamlessandsecure/[accessed Feb. 2014].

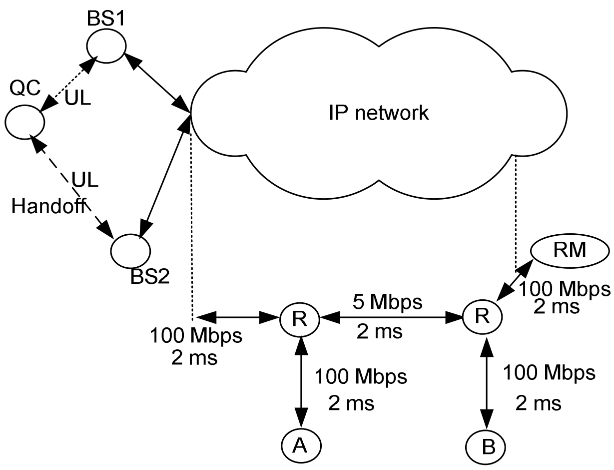

Fig. 2. Video streaming during handover scenario

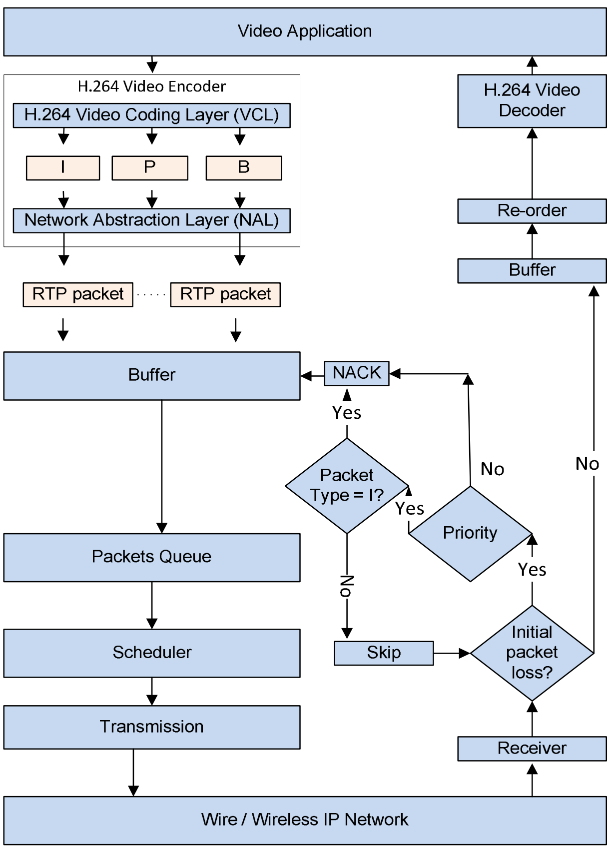

Fig. 3. Operation of selective NACK scheme

In simulations of the video stream, 35.5 s of the reference *Paris* video clip were H.264/AVC variable bitrate encoded with Common Intermediate Format @ 30 Hz. Group of Pictures structure was IBBP… with an intra-refresh rate of 15. H.264/AVC slicing was used to restrict the Maximum Transport Unit size to 1 kB.

A Gilbert-Elliott channel model [15] with 'bursty' packet losses modeled 'bursty' errors resulting from fast fading on the WiMAX wireless channel from the QC to a BS. The probability of remaining in the good state was set to 0.95 and of remaining in the bad state was 0.94, with both states modeled by a Uniform distribution. The packet loss probability in the good state was fixed at 0.01 and the bad state probability (PB) was made variable.

The WiMAX PHYsical settings (see Table I) were: a 5 ms Time Division Duplex (TDD) frame (5 ms is mandated by the WiMAX forum), 16-QAM (Quadrature Amplitude Modulation) ½ coding rate, guard time 1/16, resulting in a raw downlink data-rate 10.67 Mbps with a 3:1 uplink/downlink ratio, with an approximate range of 1.0 km. In Table I, the Quadcopter appears as a mobile subscriber station (MS), flying at a height of approximately 1.2 m. Buffer sizes were set to 50 packets.

TABLE I. IEEE 802.16E PARAMETER SETTINGS

Parameter	*Value*
PHY	OFDMA
Frequency band	5 GHz
Bandwidth capacity	10 MHz
Duplexing mode	TDD
Frame length	5 ms
Max. packet length	1024 B
Raw data rate (downlink)	10.67 Mbps
IFFT size	1024
Modulation	16-QAM 1/2
Guard band ratio	1/16
MS transmit power	245 mW
BS transmit power	20 W
Approx. range to MS	1 km
Antenna type	Omni-directional
Antenna gains	0 dBD
MS antenna height	1.2 m
BS antenna height	30 m
Receiving threshold	7.91e-15 W

III. EVALUATION

The effect on video quality and latency were assessed by simulation of the horizontal handover period, while streaming the *Paris* sequence as a test. Excessive packet jitter can result in display delays, while excessive packet end-to-end delay, becomes important if the video display is used to control the motion of the Quadcopter, which may be requested to re-examine a part of the pipeline that is of interest.

For naming convenience, the proposed NACK scheme is called broadband video streaming (BVS) in the graphs, and when used with selection of I-picture packets as proposed, BVS-I. TCP-Friendly Rate Control (TFRC) [10] was tested as an alternative end-to-end congestion controller. Fig. 4 represents a 10 s extract from the response to the same simulated channel conditions, illustrating the general drop in received throughput during the handover period. TFRC's throughput is reduced, because it increases the inter-packet gap when packet loss occurs, even though some packet loss may be due to channel error rather than congestion at the buffers. Immediately after the handover, BVS transport results in a large increase in throughput through re-transmissions. BVS-I has less re-transmissions, whereas UDP simply increases packet transmissions as much as possible as soon as bandwidth becomes available.

From Fig. 5 with the Quadcopter moving at 10 mps (22 mph), both BVS and BVS-I result in superior objective video quality (PSNR) compared to UDP-transport and TFRC. The data-points are the mean of twenty independent simulation runs while streaming the *Paris* video sequence in which the channels conditions differed according to the bad state probability of the Gilbert-Elliott channel model. From the summary in Table II, without retransmissions, packet loss approaches 10%. TFRC reduces its sending rate by increasing the inter-packet gap but only by effectively doubling the sending period of the *Paris* sequence. BVS without selective retransmission is better but its latencies are larger, especially the maximum packet delay that can result. However, by reduced retransmission in BVS-I, end-to-end latencies are reduced, thus identifying the selective NACK scheme as a suitable compromise between the greater packet losses of UDP and the delay resulting from unselective NACKs.

BVS-I's objective video quality at the remote monitoring station were compared for increasing QC speeds and different channel conditions, Fig. 6. At around 20 mps (45 mph) and above, BVS-I's quality becomes 'poor' as its quality drops below 25 dB. At low QC speeds, with shorter error bursts, BVS-I delivers 'good' quality video (above 31 dB). Simulation has also shown that at speeds above 45 mps (100 mph), HHO latency grows rapidly.

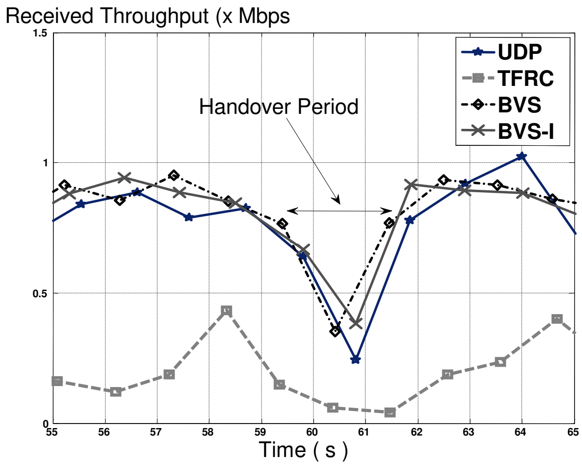

Fig. 4. Received data throughput during a handover

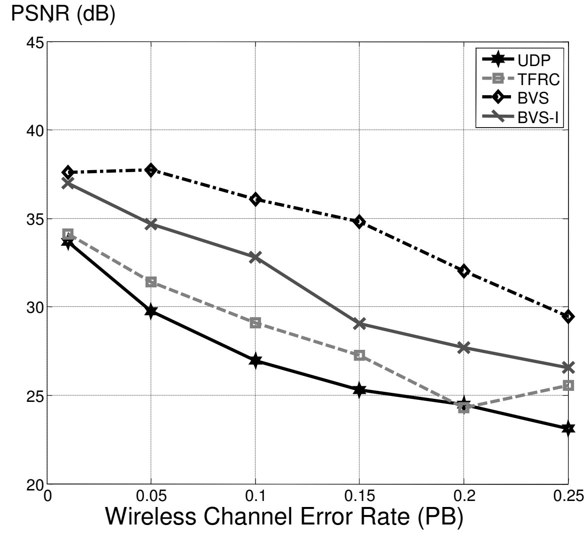

Fig. 5. Mean objective video quality (PSNR) during a handover, with varying channel conditions; PB is the probability of a bad period in the Gilbert-Elliott channel model.

TABLE II. STREAMING PERFORMNACE FOR PARIS VIDEO SEQUENCE DURING HANDOVER

	UDP	*TFRC*	*BVS*	*BVS-I*
Throughput (kbps)	762.9	371.1	819.2	766.4
Sending period (s)	35.43	72.97	35.70	37.49
Packet loss (%)	9.75	7.29	1.69	3.81
Packet jitter (s)	0.008	0.066	0.007	0.008
Mean packet end-to-end delay (s)	0.008	0.007	0.015	0.011
Max. packet end-to-end delay (s)	0.256	0.247	0.631	0.329
Mean PSNR (dB)	25.29	27.26	34.82	29.05
Standard Deviation of PSNR (dB)	3.28	3.31	3.42	4.91

IV. CONCLUSION

Video surveillance of pipelines by an MAV Quadcopter is a cost effective method of remote monitoring, though it does require the installation of WiMAX masts along the length of the pipeline. Monopole antennas [16] now represent a viable implementation technology for dedicated WiMAX communication.

This paper considered a NACK-based video streaming scheme aimed at tackling the critical issue of video stream interruption as the Quadcopter passes between WiMAX base stations. Results show that at moderate speeds video quality during a WiMAX handover could improve by as much as 9 dB using a NACK-based scheme compared with UDP but there is a cost in end-to-end delay, particularly maximum packet delay. This issue is resolved by selective NACKs according to picture type, while video quality remains acceptable. If real-time observation with limited interruption is required then the selective NACK scheme is preferable but otherwise a simple

NACK-based scheme is acceptable. Conventional application-layer congestion controllers perform badly whenever horizontal handovers occur. Future work will involve field tests of a Quadcopter surveillance system.

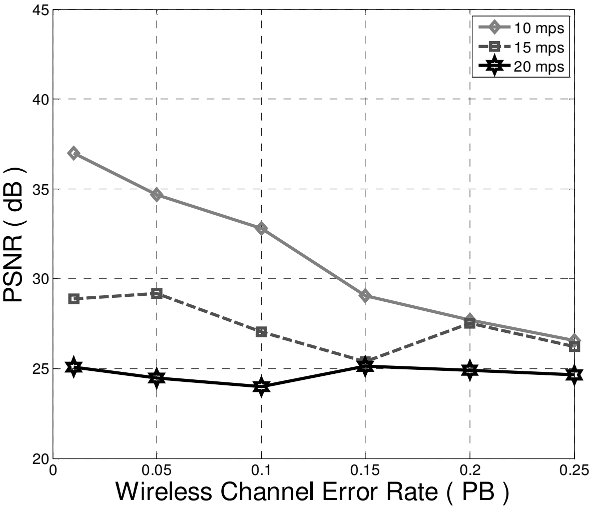

Fig. 6. Mean objective video quality (PSNR) during a handover when running BVS-I, with varying channel conditions and QC speeds during a handover; PB is the probability of a bad state in the Gilbert-Elliott channel model.

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