Emergency Video Multi-Path Transfer over Ad Hoc Wireless Networks

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***Abstract*—Ad Hoc networks utilize multi-hop radio relay without the need for a base station, supporting mobility and allowing them to be quickly deployed in an emergency. Real-time video communication across an ad hoc network allows helpers to better understand the nature of the problem within a disaster area but the lack of centralized routing and network resource management is challenging, particularly if the wireless nodes have limited processing power. Multi-path solutions have been proposed for video transfer. This paper investigates two practical schemes, Video Redundancy Coding and a proposal of the paper, H.264 codec redundant frames. The paper reports that redundant frames when used in combination with multi-path do result in as much as 10 dB improvement in delivered video quality, making the difference between acceptable and unacceptable visual communication in a disaster scenario.**

***Index Terms*—ad hoc wireless, multi-path, video streaming, Video Redundancy Coding, redundant frames**

I. Introduction

In a man-made or natural crisis, it is vital that emergency workers in a team can readily communicate between each other [1] as they move across the scene of a disaster. However, the disaster itself may well have removed the communication networks within the vicinity. Various technologies present themselves as replacements such as satellite, IEEE 802.16 (WiMAX), and wireless mesh networks, all of which can employ IP routing. However, if the workers are mobile a wireless network without infrastructure is more suitable, as the nodes (essentially the workers equipped with wireless transceivers) can organize themselves, routing data from any node to another. Ad hoc wireless networks [2] become part of the solution, allowing small teams (10-20 people in [3]) to move through the area on foot or possibly on some form of vehicle. Multi-hop routing must then cope with nodes going out of range or adverse channel conditions.

Real-time video communication will significantly aid the ability to describe the scenario to other members of the group. Because of the display resolution and processing power of hand-held or wearable devices Quarter Common Intermediate Format (QCIF) 176×144 pixel resolution at a maximum of 30 frame/s (fps) and possibly as low as 10 fps is likely [3]. This is convenient as supportable data rates across multi-hop paths could be low. Because loss of packets from a reference frame within the 12 or 15 frames of a Group of Pictures[1] (GOP) has an effect that endures to the end of the GOP, the packet loss ratio is important. Encoded video streams are fragile as temporal redundancy is removed through the processes of motion estimation and compensation [4]. However, they are also sensitive to display and decode deadlines [5], depending on the size of the receiver playout buffer, which acts to smooth out jitter. Jitter (variation of delay) is also important in that a packet arriving after its deadline at the decoder is simply dropped by the decoder. If video communication is two-way or interactive, as in a videophone link between two members of the emergency team, then mean delay is also relevant.

Raw video transmission results in such high data rates that compression is inevitable. The state-of-the-art H.264/Advanced Video Coding (AVC) standard [6] currently provides high coding efficiency along with many flexible features, including redundant frames [7], which can be employed for the protection of Multiple Description Coding (MDC) video streams. In MDC [8], two or more versions or descriptions of the same video stream are sent over different, preferably disjoint, routes across a network. Either description can serve to reconstruct the video but an enhanced quality version is produced by combining both descriptions. Therefore, if packet loss occurs on one of the paths then this can be compensated by the encoded bitstream from other paths. MDC also may reduce the bandwidth requirement [9] for any one route through an ad hoc network, at a cost in increased coding redundancy. In this work, we make the common assumption for simplicity that there are just two streams that exploit path diversity. In fact, simplified versions of MDC are simulated, as in practical schemes the complexity of an MDC decoder, which needs to reconcile several streams as well as avoid encoder-decoder drift, could overwhelm the processing capability of a mobile node.

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[1] The distinction between picture and frame is only relevant for interlaced video and the terms are inter-changeable when progressive video is considered.

Since hurricane Katrina, the U.S. Department of Defense has been requested to provide real-time video from the scene of major disasters back to the various command operations centers of USNORTHCOM, FEMA, and DHS in order to provide better awareness of the situation and to assist in establishing a more complete operational picture. Therefore, real-time video communication back to a base node (for relay to a satellite or Unmanned Aerial Vehicle) is also an application of the schemes developed in this paper.

In an emergency scenario, if the workers are in a vehicle then clearly power to drive their radio transceivers is available from the vehicle. If civil emergency workers are on foot then the size of their packs and consequently battery capacity, weight and volume are a concern. All the same, in a civil emergency, teams can openly collect or be dropped fresh batteries. However, there is also a need for inter-group communication and relay to a base node in military emergencies [10]. In those circumstances, an army patrol might covertly operate away from its base for a long time and battery renewal would become a problem. In both civil and military emergencies equipment must also be ruggedized [10]. To consider all of these issues is well beyond the scope of this paper and, in fact, others have addressed these in the open literature, as augmented reality involving video projection (but not video communication) has long been investigated for such applications [11]. Specifically, the appendix of [12] reports low-power hardware video codecs and the body of [12] reports the prospects for battery capacity improvement, especially via hybrid fuel-cell, super-capacitor batteries for wearable computers. It is also possible [12] to vary the operation of a video codec to be battery friendly.

Thus, the main contribution of this paper is indeed to compare practical schemes for emergency video streaming over multi-paths in a way that is cognizant of the numerous parameters that can affect the behavior of an ad hoc network. An objective measure of the delivered video quality, Peak Signal to Noise Ratio (PSNR)[2], is provided as well as network statistics. Network statistics can be misleading, for example, if the packets that are lost contain redundant frames or non-reference frames as these may not significantly affect the delivered quality. The paper proposes that H.264's redundant frames when combined with multi-path video transfer will result in higher quality delivered video, which is counter-intuitive as multi-path transmission and redundant frames can both increase the data traffic. As far as the authors are aware, redundant frames have not been previously employed for this purpose within an ad hoc network.

Mobility patterns and wireless propagation within an urban environment is not a contribution of this paper, not least because this topic comes within the scope of vehicular ad hoc networks (VANET), for example see [13]. Recent earthquakes in Pakistan and the tsunami across the Indian ocean have both highlighted the importance of rural and semi-rural settings.

The rest of this paper is organized as follows. Section II examines related video streaming schemes for ad hoc networks. Section III further discusses MDC-like schemes including the simplified ones used in this paper. Section IV details the network parameters for the simulations, while Section V presents our results. Finally, Section VI draws some conclusions.

II. RELATED WORK

The research in [14] examines point-to-point Constant Bit Rate (CBR) video streaming in a 15-node network in a $1000 \times 1000\text{m}^2$ area. The reference 'Foreman' QCIF video clip at 30 fps was simulated at rates ranging from around 50 kbps up to 350 kbps. GOP sizes were varied with playout buffer settings equivalent to 350 ms and 500 ms of video. The paper reported that as the number of multi-path routes increased to six, the delivered video quality increased. Unfortunately, [14] did not report on node mobility or radio range. However, the paper did show that optimal regimes exist but that simple formulas require perfect network traffic knowledge by each node, which is impractical.

A denser node distribution (60 nodes in a 1200 m × 800 m area) was chosen in [15] with the well-known random waypoint [16] mobility model and with maximum speeds varying from 2.5 m/s to 15 m/s. The playout buffer size was 100 ms of video storage with video streamed at a rate of 192 kbps for 12 fps. Radio range was 250 m for an IEEE 802.11 wireless LAN in ad hoc mode but the node pause period was not given in the paper. Because of the node density, the effects of mobility were not strongly felt, because it is not possible for nodes to quickly loose radio contact with surrounding nodes (resulting in broken wireless links). Though Reed-Solomon (RS) Forward Error Correction (FEC) was employed in simulations, it should be borne in mind that this RS FEC has quadratic computational complexity which may overwhelm battery powered devices. The paper showed the advantage of the authors' multiple tree algorithm for video multicast. A paper by the same authors [17] amongst other results showed that, provided the paths were disjoint, IEEE 802.11's Carrier Sense and Medium Access with Collision Avoidance (CSMA/CA) is unlikely to lead to traffic interference. This line of research was continued in the authors' most recent contribution at the time of writing [18], in which the robustness of the paths is estimated in advance. For example, the received signal strength could be reported along with the level of contending cross-traffic. This work's strength is that physical tests have now confirmed the findings.

A number of alternative ways of taking advantage of path diversity have been investigated. In [19], transfer of a base layer and one or more enhancement layers over multi-paths was combined with Automatic Repeat Request (ARQ). Unlike MDC, if the base layer is not received correctly, in layered video, the decoder cannot reconstruct the original video. By assuming that the

[2] PSNR = 10 log (MAX^2/MSE), where MAX is the maximum intensity value possible for a pixel, and ME is the pixel-wise mean square error between a reference frame and the frame under test.

display deadline was twice the round-trip time (300 ms), it is possible to send one ARQ to protect the base layer. A realistic channel model with 'bursty' errors and path breakdowns was assumed. The ARQ scheme was shown to improve PSNR by up to 10 dB, upon sending the layered video over multi-paths without ARQ.

In a general context, the research in [20] concluded that layered video is competitive with MDC if the rate is modified according to the distortion. However, rate-distortion analysis is compute intensive and unlikely to be used for live video on mobile devices. In [21], two further multi-path schemes were compared with layering combined with ARQ, namely: 1) feedback requesting reference frames; and 2) a variant of MDC with motion compensation. In the first of these approaches, the problem of decoder-encoder synchronization was tackled by a negative ARQ indicating the most recent successfully received reference frame upon which motion compensation can be based. Therefore, this scheme also assumes sufficient playout time and bandwidth to allow ACKs. Sending ACKs will also cause more control packet overhead, which can be high. In the variant of MDC tested, no ARQs occur but a correction method at the decoder counters drift between decoder and encoder. The CSMA/CA MAC was assumed with a multipath variant of the reactive Dynamic Source Routing (DSR). The authors concluded that acceptable video quality is possible but which scheme is selected is dependent on the ad hoc scenario.

In [22], the term ad hoc is used in the sense that there is direct wireless communication between nodes, rather than via a network access point. The authors consider the Scalable Video Coding (SVC) extension of H.264 and reduce the number of small packets generated by means of packet aggregation. In [23], the network capacity, flow and rate allocation are jointly optimized across the wireless protocol stack in such as way that the network traffic as a whole benefits. A distinct average improvement in video quality was demonstrated compared to a non-cross-layer approach. Another route to improvement [24] is to improve MDC error concealment at the decoder by combining the predictions from both streams in spatial (intra-) decoding. However, any improvement in video quality reported in [25] could not be applied to the emergency scenario unless there is a way to copy the same video to multiple sources. An interesting suggestion is contained in [26], that hierarchical routing may improve the performance of ad hoc network video streaming. Finally, in this examination of very recent work, in [27] a restriction on the number of hops and an increase in the data-rate to 5.5 Mbps was advocated for comfortable transfer of H.264 video over an ad hoc network.

III. VIDEO STREAMING AND MULTI-PATH

In general, MDC is difficult and computationally complex [8] because it requires synchronization between encoder and decoder to reduce motion estimation error drift. Unequal channel error protection is possible [28] and the coding rate can be adjusted according to the path characteristics and the likely distortion in the received video [29]. Various forms of splitting can occur including in the spatial [30] and frequency domain [31], but we consider temporal splitting in which a number of practical solutions have been proposed. In mobile devices with a limitation in battery power and/or processor computation power, simplicity is advisable.

Such a scheme is Video Redundancy Coding (VRC) [32] in which two independent streams are formed from encoding odd and even frame sequences and sending them over different paths. By insertion of intra-coded I-frames (spatially coded with no removal of temporal redundancy through motion compensation) either sequence can be resynchronized at the decoder, at a cost in increased data redundancy compared to sending a single stream with I-frames. VRC was selected by us as one practical and simplified alternative to full MDC.

To improve error resilience in both paths, redundant pictures intended for error resilience in H.264, can serve to better reconstruct frames received in error. Redundant frames (or strictly redundant slices [4] making up a frame) are coarsely quantized frames that can avoid sudden drops in quality marked by freeze frame effects if a complete frame (or slice) is lost. The main weakness of the redundant frame solution is that these frames are discarded if not required but the redundancy is still likely to be less than including extra I-frame synchronization, as redundant frames are predictively coded. A subsidiary weakness of this scheme is the delay in encoding and transmitting redundant frames, making it more suitable for one-way communication. We have investigated redundant frames as this is a new feature of the H.264/AVC codec which has had comparatively little investigation.

An alternative way to avoid the need for I-frame synchronization [33] lost frames in one description are reconstructed from temporally adjacent frames in the other description. In this solution, all frames apart from the first I-frame in each description are predictively coded (P-frames) from previous frames, though reconstruction may occur with the aid of past and future P-frames. However, reconstruction with P-frames from a different description reintroduces the risk of picture drift from lack of synchronization between encoder and decoder. To overcome this problem, redundant pictures intended for error resilience in H.264, can serve to better reconstruct [34] P-frames received in error. This is a new scheme which involves modification of the way that the reference codec works. Therefore, in this paper we use redundant frames in a more direct manner.

Fig. 1 illustrates the schemes tested in this paper. The frame numbers indicate the raw video frame from which a coded frame is constructed. Frames are decoded with motion compensation from reference frames in the same stream. The problem of MDC decoder complexity is avoided by separately decoding frames from each stream. In Fig. 1a, a single stream or description is sent as an I-frame followed by a series of P-frames in the Baseline Profile of H.264/AVC. In this Profile, Context Adaptive Variable Length Codes (CAVLC) (dynamic Huffman entropic coding) is employed for simplicity, with some reduction in latency for interactive applications. The GOP size was set to 15 frames before a new I-frame. In Fig. 1b, for VRC the skip frame(s) facility of the H.264/AVC Main Profile has been taken advantage of. This profile allows bi-predictive B-frames with greater coding efficiency than if only P-frames were to be employed. The GOP size was again 15 frames with the usual repeating pattern of two B- and one P-frame until the next I-frame. B-frames may be dropped with no impact on later frames. In the Main Profile, Context-Adaptive Binary Arithmetic Coding (CABAC) results in a 9-14% bit saving at a small cost in computational complexity [35]. In Fig. 1c, redundant frames are sent in each stream, at a cost in latency but a potential gain in delivered video quality. There is only one initial I-frame as upon loss of the first I-frame or a subsequent P-frame, its matching redundant frame (if not lost) is available as a substitute.

The QCIF video clip Foreman was as a point of comparison with previous studies (refer to Section II). Foreman, intended for communication between mobile devices, exhibits the typical features of a hand-held camera and, because of scene motion and scene cuts, exhibits a higher coding complexity. By way of comparison another significantly less-complex reference QCIF sequence, Bridge (closed), was also considered. Table I records the H.264/AVC CBR-encoded data rates employed in the simulations.

The frame rate of the video stream was set to be 15 fps. As buffer memory significantly contributes to energy consumption, actively during access, and passively due to the need DRAM refresh, the size was set to three frames (with buffer sharing for two stream schemes). This implies that the delay deadline is 198 ms, which is actually larger than that in [15].

IV. AD HOC NETWORK SIMULATION

The Global Mobile System Simulator (GloMoSim) [36] simulation library was employed to generate our results. Total simulation time was 400 s. GloMoSim was developed based on a layered approach similar to the OSI seven-layer network architecture. IP framing was employed with UDP transport, as TCP transport can introduce unbounded delay, which is not suitable for deal-intolerant video streaming. The Ad-hoc On demand Distance Vector (AODV) routing protocol [37] was selected as it does not transmit periodic routing messages, which, for proactive, table-driven protocols, can result in greater control overhead unless network traffic is high.

In reactive protocols such as AODV routes are discovered only when they are actually needed. AODV discovers routes in a hop-by-hop fashion rather than through source routing. Sequence numbers avoid routing loops. A disadvantage of a reactive protocol is the latency introduced by the route discovery process, which is judged in these simulations for its impact on video. At the data-link layer, CSMA/CA MAC was set up, as previous studies (refer to Section II) also mostly assume IEEE 802.11 wireless systems.

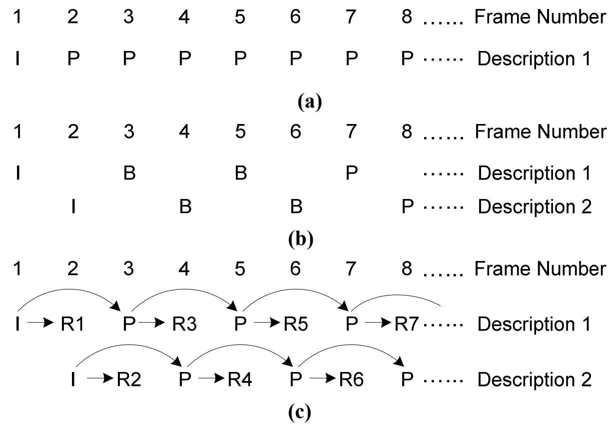

Figure 1. Different path diversity schemes: a) Single stream b) VRC with odd and even descriptions, c) Two streams with redundant frames.

TABLE I. DATA RATES FOR MULTI-PATH SCHEMES

Stream	CBR datarate (kbps)
Single	52.42
Odd	51.93
Even	51.95
Redundant 0	51.26
Redundant 1	51.24

TABLE II. PARAMETERS FOR MULTI-PATH EXPERIMENTS

Parameter	Value
Wireless technology	IEEE 802.11
Channel model	Two-ray
Max. range	250 m
Roaming area	1000×1000 m^2
Pause time	5 s
No. of nodes	20
Min. speed	0 m/s
Max. speed	1 – 35 m/s
Mobility model	Random waypoint
Routing protocol	AODV

The parameters for the simulations are summarized in Table II. GloMoSim provides a two-ray channel model with antenna height hardwired at 1.5 m, and with a Friss free-space model with parameters (exponent, sigma) = (2.0, 0.0) for near line-of-sight and plane earth path loss (4.0, 0.0) for far line-of-sight. The radio range was 250 m with 1 Mbps shared maximum data-rate. Setting the bandwidth capacity to the latter value in the simulation allows modeling of a limited available bandwidth.

The random waypoint mobility model was employed with 20 nodes in a roaming area of 1000×1000 m^2. In this model, nodes are usually placed randomly in the simulated area. After pausing, the node moves to another random destination at a speed between a minimum and maximum speed. The pause time (time spent once a node reaches its destination) was set to 5 s. The minimum speed was 0 m/s, while the maximum node speed ranged from 1 to 35 m/s, i.e. from a slow walk to fast motorbike speeds. However, manual intervention occurred by us in the initial placement of the nodes in such a way that ensured disjoint paths were found by the simulator. After, the initial node placement no further intervention took place. The issue of how to achieve disjoint paths from within AODV is outside the scope of this paper. As an example, in [38] split multipath routing was added to the Dynamic Source Routing (DSR) protocol.

Two cross-traffic sources were set up sending 100 packets each at intermittent intervals over the simulation period. It is certainly true that cross-traffic will be present, yet such sources can generate large control packet overheads which interfere with the traffic of interest.

For the video source described in Section III, each frame was placed in a single packet, unless an I-frame, in which case two packets were employed. An I-frame may occupy as much as 1 kB, whereas a B-frame will commonly be encoded in less than 100 B. This implies that though encoder CBR mode is selected, an encoder output is never completely CBR. In line with the practice in [15], if one of the I-frame packets arrives before the playout deadline but the other does not this is counted as "acceptable", as partial decoding can still take place while the other packet arrives.

Notice in our arrangement all three videos are played out at 15 fps. The single stream is coded at 15 fps, whereas both streams are coded at 15 fps in the two description schemes and played out at 15 fps. This allows for substitution of frames within the final merged two stream sequences should a frame(s) be lost. Of course, substitution of frames can only take place if the appropriate reference frame or redundant frame (if needed) is available. As is normal [5], previous or 'freeze frame' error concealment was turned on at the decoder, rather than more complex concealment.

V. RESULTS

Fig. 2 records the ratio of bad frames in single path transfer of the Foreman video stream. A bad frame occurs either because a packet bearing a video frame is lost in radio transmission or the frame is delivered too late for its display deadline. Loss rates above 10% are likely to make video quality doubtful. From the Figure, it will be seen that the bad frames rate hovers about this value, depending on node speed. Variations in performance with speed resulting in less frame loss at certain speeds are also seen in other studies reported in Section II. If nodes are on average in proximity to each other for sufficient time for packet transfer then less packet loss occurs. Clearly travelling at some speed gives an advantage but at walking pace frame loss is higher, which implies a dual path solution may lead to better quality video as it gives more opportunity for packets to be transferred.

Turning to average end-to-end delay, Fig. 3, it is clear that there is about 2 s start-up delay before the packets are delivered. End-to-end delay is defined as the time from when a packet is dispatched to the time it is received. However, jitter is broadly consistent and low, Fig. 4, across the node speeds. This implies that interactive video applications are unsuitable for single-path transfer but a fixed-sized playout buffer that is dimensioned to absorb about 0.15 s of the video stream will reduce the chance of

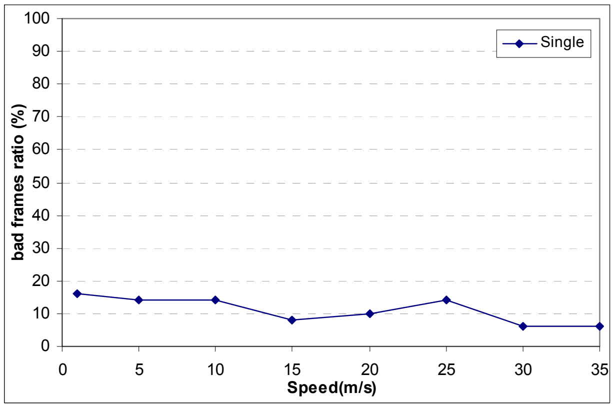

Figure 2. Bad frame ratio with variation in node speed for single stream transfer

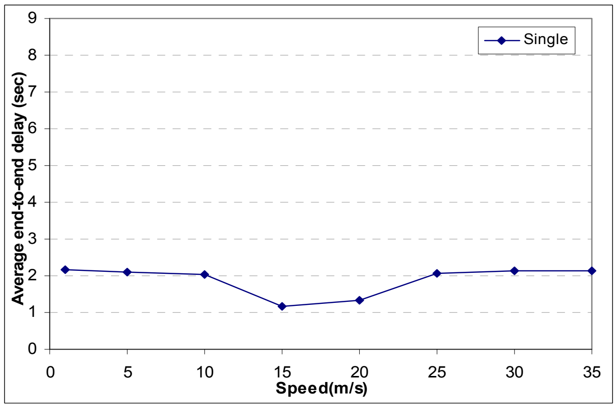

Figure 3. Delay with variation in node speed for single stream transfer.

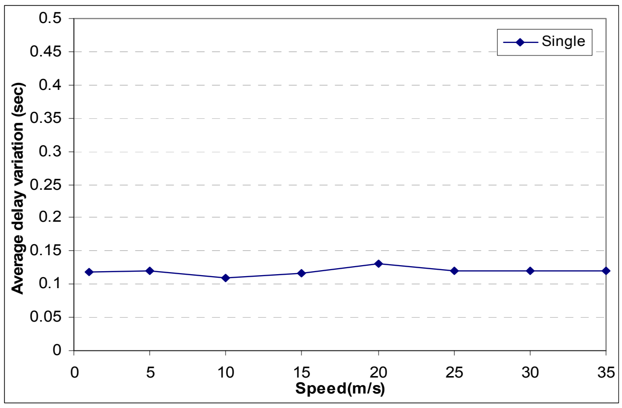

Figure 4. Jitter with variation in node speed for single stream transfer.

frame loss through buffer underflow. This is a small extra duration beyond the 2 s or so of end-to-end delay. The results from VRC streaming over dual paths are represented in Figs. 5–7. From Fig. 5 it is apparent that when one stream suffers excessive bad frames another can compensate. Moreover, the lower level of frame loss is below 10%. From detailed inspection, the major cause of bad frames is packet loss rather than missed arrival deadlines. This is the reverse of the single stream situation, when in most cases bad frames occur through late arrivals. The result is consistent with low levels of

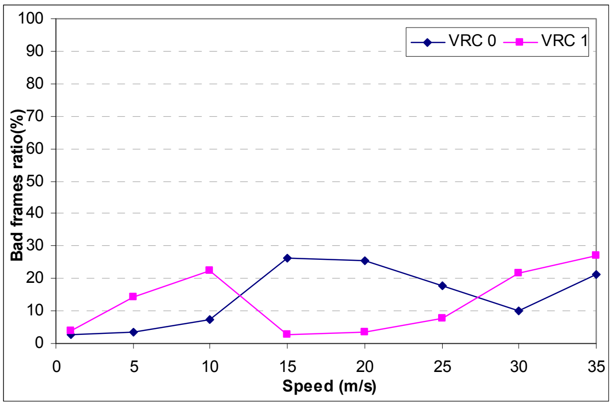

Figure 5. Bad frame ratio with variation in node speed for VRC dual stream transfer.

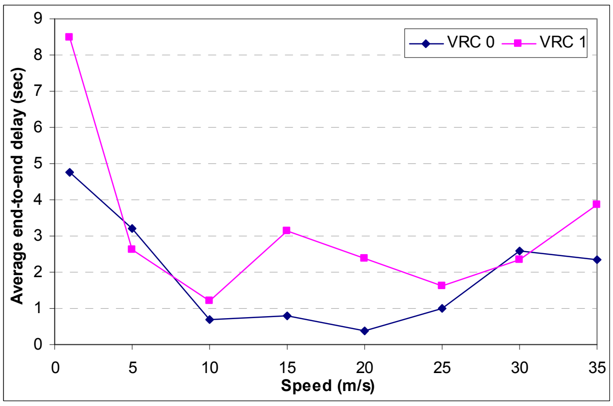

Figure 6. Delay with variation in node speed for VRC dual stream transfer.

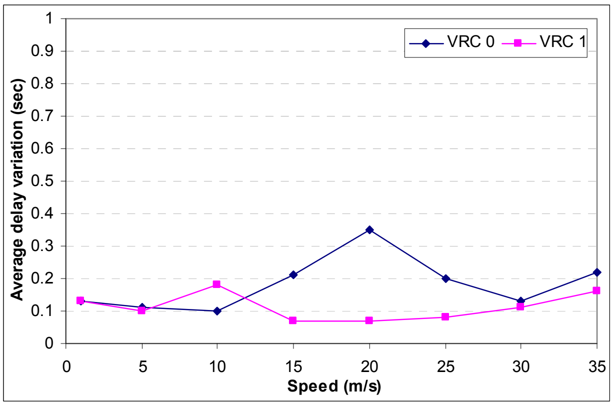

Figure 7. Jitter with variation in node speed for VRC dual stream transfer.

jitter in the VRC case. However, from Fig. 6, delay is high, again making interactive video unfeasible. Delay also now varies considerably depending on node speed. Jitter levels, Fig. 7, may be increased.

From Fig. 8 reporting dual path streaming with redundant frames, it will be apparent there is again a compensatory pattern of bad frames occurring, so that the weakness of one path can be balanced by the strength of

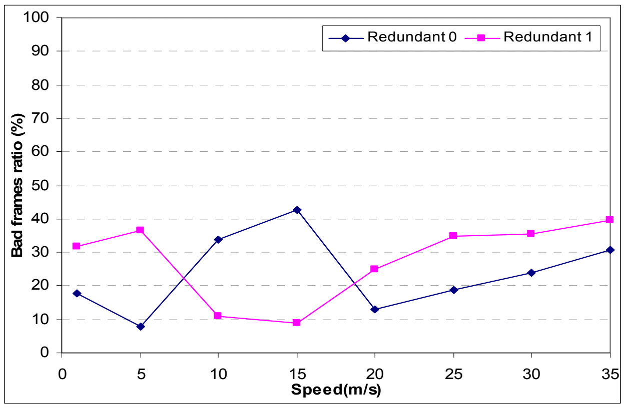

Figure 8. Bad frame ratio with variation in node speed for dual stream with redundant frames transfer.

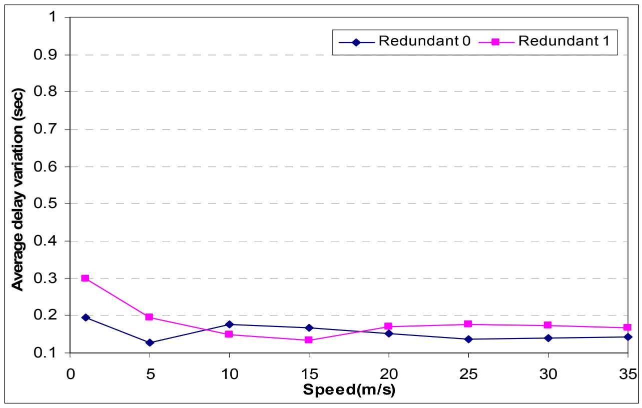

Figure 9. Jitter with variation in node speed for dual stream with redundant frames transfer.

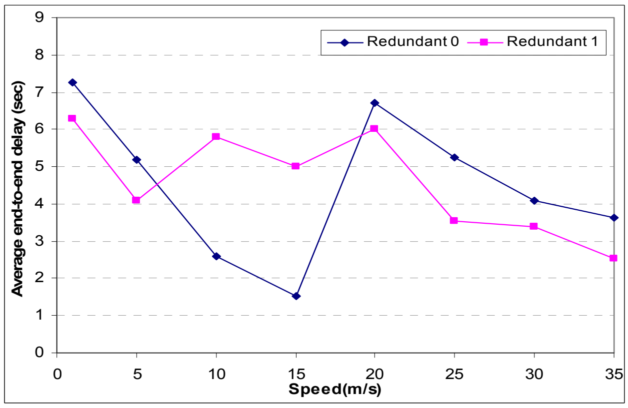

Figure 10. Delay with variation in node speed for dual stream with redundant frames transfer.

the other. The number of frames dropped through late arrival is generally higher than in VRC streaming, but this should not be surprising as additional redundant frames are now being sent. However in general, sending redundant frames results in greater packet loss and consequently more bad frames than in VRC streaming. This is not necessarily a problem for the resulting video quality if a majority of redundant frames are lost, as from Section IV these frames do not contribute to the decoded video sequence except when they are used to replace lost P-frames. Jitter levels, Fig. 9, for redundant frame streaming are consistent across the speeds, implying that the playout buffer size can be conveniently set. End-to-end delay, Fig. 10, is high and erratic according to node speed. Therefore, a viewer will be subject to a start-up delay before a video stream arrives. However, start-up delay is obviously less of a problem in an emergency setting, as unlike conventional streaming in which a video is selected and then there is a wait before it arrives in this situation, the receiver does not know when the stream was originally started. Thus, there would be no effect noticed by the video viewer. Once again end-to-end delay is high and it is unlikely that changes could be made to reduce the delay to allow an interactive application.

Control packets consist of route requests, replies, and error messages. Fig. 11 shows the overhead from all control packets including cross-traffic control packets during the video streaming sessions. The overhead is the number of control packets over the number of data packets received. There are normally considerably more short control packets than data packets. It can be seen that at a speed of 15 m/s the set-up of the simulation results in more control packets from the cross-traffic sources during the single stream session. This was traced to the need for the cross-traffic to take long multi-hop routes at that speed. Interference between cross traffic and video stream can consequently lead to lost packets within the video stream.

This is a general rule, as no firm conclusions can be made about which speed to avoid in order to reduce the impact of overhead. However, there is a rising trend in overhead from control packets with speed. It is known [39] that distributed routing is less energy efficient than source routing but for a short-lived emergency situation, it is assumed in this paper that energy consumption is of secondary importance (refer to the discussion in Section I on battery provision).

In Fig. 12, the resulting delivered video quality is compared for the Foreman clip. Recall that the PSNR vertical axis is logarithmic, which implies that the delivered video quality is quite considerably better with the insertion of redundant frames in multi-path. Between 30 and 35 dB quality is generally considered good, while below 20 dB a video may well be unwatchable at times. The quality for the less complex Bridge sequence is shown in Figs. 13-14, when it is apparent that the differences will be less noticeable. Still there is a 2 dB gain from redundant frames with multi-path, which is normally adjudged a significant coding gain. However, at higher bad frame percentages, there is a disadvantage from using VRC multi-path, whereas VRC is always better for Foreman.

We also considered the effect of reducing the number of nodes from 20 to 10 in Table II. Recall from Section I and [3] that this is the lower limit for the expected number of nodes in this type of scenario. Fig. 16 shows the result of a simulation with two sizes of roaming area, 1000×1000 m^2 , and an area a quarter the size, i.e. 500×500 m^2. The redundant frame solution was applied.

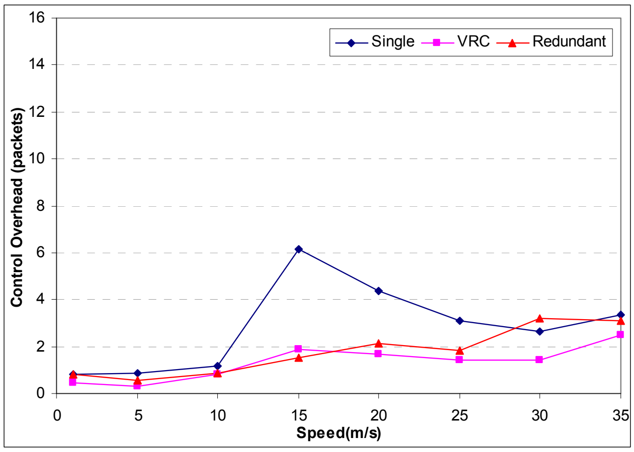

Figure 11. Overhead from all control packets for the three schemes.

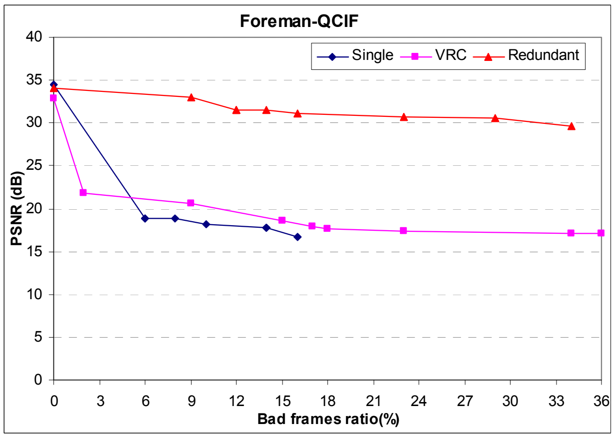

Figure 12. Delivered video comparison for Foreman between the three tested schemes.

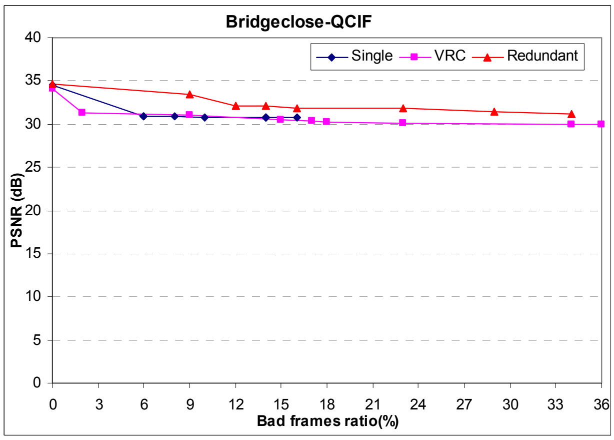

Figure 13. Delivered video comparison for Bridge (closed) between the three tested schemes.

From Fig. 16, it is apparent that for the settings of Table II, while the nodes may be sufficiently clustered for one of the paths to allow satisfactory transmission, the other path suffers far too heavy bad frame rates. If the roaming area is reduced sufficiently then the situation is

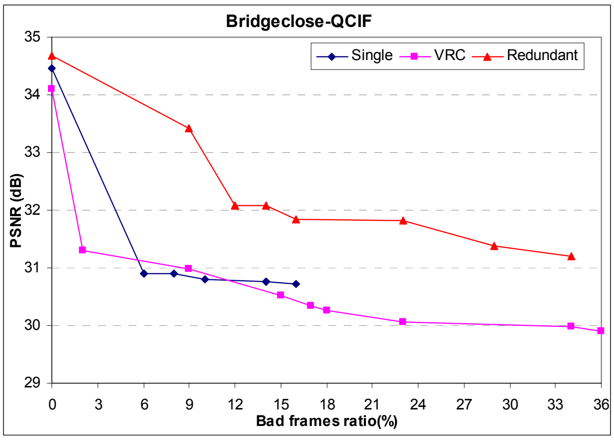

Figure 14. Delivered video comparison for Bridge (closed) between the three tested schemes with expanded vertical axis.

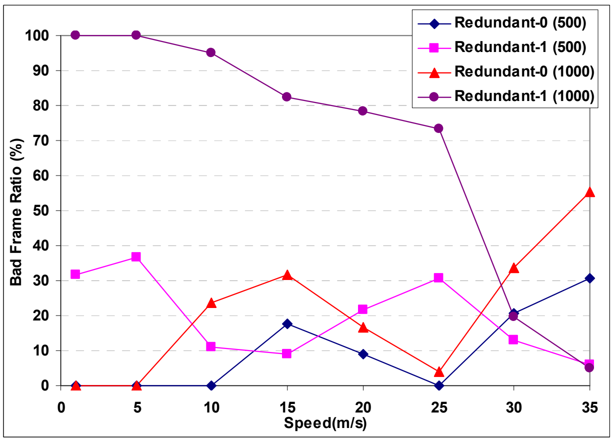

Figure 15. Bad frame ratio for 10 nodes in 500 × 500 m^2 and 1000 × 1000 m^2 roaming areas for the redundant frames scheme.

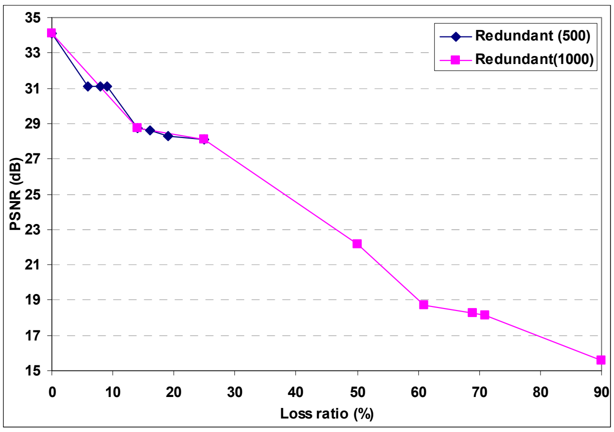

Figure 16. Video quality (PSNR) for 10 nodes in 500 × 500 m^2 and 1000 × 1000 m^2 roaming areas by packet loss ratio.

restored. In Fig. 17, the expected video quality is analyzed according to the received frame loss ratio. In some cases, the limited losses in one path within the 1000 × 1000 m^2 roaming area compensate for the high loss rates of the other path. The combined loss rates over both

(a)

(b)

(c)

(d)

Figure 17. Sample frame with 15% error for a) no error, b) single stream c) VRC dual streams, and d) multi-path with redundant frames.

paths within the 500 × 500 m^2 roaming area were confinedwithin a narrower range, leading to good quality video throughout provided the redundant frame scheme is used. Therefore, video transfer is still possible if the nodes are sufficiently dense within the roaming area. Where resources, i.e. people with wireless transceivers in the emergency teams, are limited it is important than the geographical operation area is restricted.

By way of a casual visual check, Fig. 17 shows a sample frame with no errors in Fig. 17a. It is very apparent that the quality is unacceptable at below 20 dB for single path delivery in Fig. 17b, whereas a small gain in dB makes Fig. 17c for VRC acceptable for this frame. However, around the hat, for example, degradation is apparent whereas the hat is crisper in outline in Fig. 15d, though there are still some errors with redundant frames.

VI. CONCLUSION

It is lack of communications in an emergency or disaster that most impedes recovery. This paper has shown that an ad hoc wireless network does permit one-way, video transfer, provided multi-path is used. The result is the ability to provide real-time visual information at a disaster scene. Perhaps surprisingly, given the number of bad frames is higher, in simulations inserting redundant frames allows lost or dropped predictive frames to be reconstructed, resulting in a considerable improvement in delivered video quality over single path transfer. Jitter levels were also low, leading to a smaller energy conserving playout buffer requirement. One negative finding is that all schemes suffer from high start-up delay and could not be used for interactive video. Node speed may have a considerable impact on the number of bad frames, as can the presence of cross traffic. It is probably the case that video communication will be erratic and dependent on the ad hoc scenario. The redundant frame multi-path scheme proposed by this paper shows that video transfer is possible and is practical, whereas previous work had resulted in rather complex schemes to implement, which, however attractive to researchers, would stretch the wireless node capability.

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