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# A design for distortion-aware cooperative relaying over wireless video sensor networks

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**Abstract:** This paper describes a distortion-aware cooperative relaying (DACR) scheme for distortion minimized video transmission over wireless video sensor networks. We first introduce a simple performance metric considering the different spatial and temporal error propagation effects existing in a video packet. Then, we propose the DACR algorithm which achieves gradual video quality degradation due to packet loss under conditions of limited channel resources. Experimental results show that the proposed scheme outperforms other existing scheme, and can also support optimal video quality for variable channel status.

**Keywords:** optimal video quality, video distortion, H.264/AVC, error propagation, cooperative relaying

**Classification:** Science and engineering for electronics

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## 1 Introduction

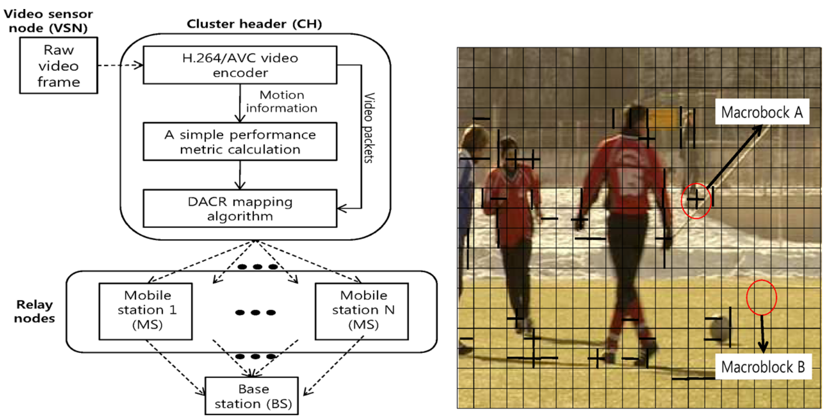
Wireless video sensor networks (WVSNs) are of interest for use in numerous applications such as video surveillance and environmental monitoring system [1]. Due to the channel resource limitation, the delivery of high quality video data is a challenge [2, 3].

The conventional approaches for solving this problem utilize multiple disjoint path, cooperative diversity, and cooperative spatial multiplexing for effectively transmitting a video stream [4, 5, 6].

In this paper, we propose a novel distortion-aware cooperative relaying (DACR) scheme for minimizing video quality degradation from delay violation and limited channel resources. We also propose an effective and simple performance metric that considers both temporal and spatial error propagation effects in hierarchical video coding structure, an effective performance metric with low complexity is proposed. Based on this performance metric, we develop a novel DACR mapping algorithm for minimizing video quality degradation from packet loss.

## 2 System architecture

Fig. 1 (a) shows the block diagram of the proposed DACR scheme. It is composed of low cost and powered video sensor nodes (VSNs), cluster header (CH), mobile stations (MSs), and base station (BS). VSNs collect the raw video data and transfer them into CH. CH produces video packets thorough




(a) (b)

**Fig. 1.** (a) Block diagram for proposed scheme (b) Mode information in 'FOOTBALL' test sequence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the H.264/AVC encoding module and calculates the performance metric from motion information. Based on video packets and performance metric, DACR mapping algorithm transfers video packets with high error propagation effect into BS by passing through MSs. Consequently, BS can achieve the distortion minimized video quality.

## 3 The proposed algorithm

### 3.1 Performance metric

The simple and effective performance metric is proposed for estimating the amount of video quality degradation from packet loss considering both temporal and spatial sides.

As shown in Fig. 2, if we represent the $i^{th}$ video packet in the $j^{th}$ frame as $p_{i,j}$ in a group of pictures (GOP), $\lambda_{i,j}$ and $\mu_{i,j}$ could be defined as the amount of temporal and spatial quality degradation in $p_{i,j}$. To quantify the temporal propagation effect of packet loss on the video quality with low complexity, we utilize the length of error propagation existing in each video packet. For example, a packet loss of the beginning frame makes a severer impact on the quality of the reconstructed sequence than that of the ending frame due to error propagation [7]. $\lambda_{i,j}$ is given by

$$\lambda_{i,j} = T + 1 - f_{i,j}. \tag{1}$$

where $T$ is the GOP size and $f_{i,j}$ represents the frame index of $p_{i,j}$.

The $\mu_{i,j}$ represents the amount of distortion from the error concealment (EC) algorithm from packet loss in H.264 decoder [9] which is calculated as follows.

$$\mu_{i,j} = \sum_{k \in S(p_{i,j})} D(p_{i,j}, k) \tag{2}$$

where $S(p_{i,j})$ is the set of pixels in $(i,j)^{th}$ packet and $D(p_{i,j}, k)$ represents the distortion from EC in $k^{th}$ pixel which is included in the packet $p_{i,j}$.

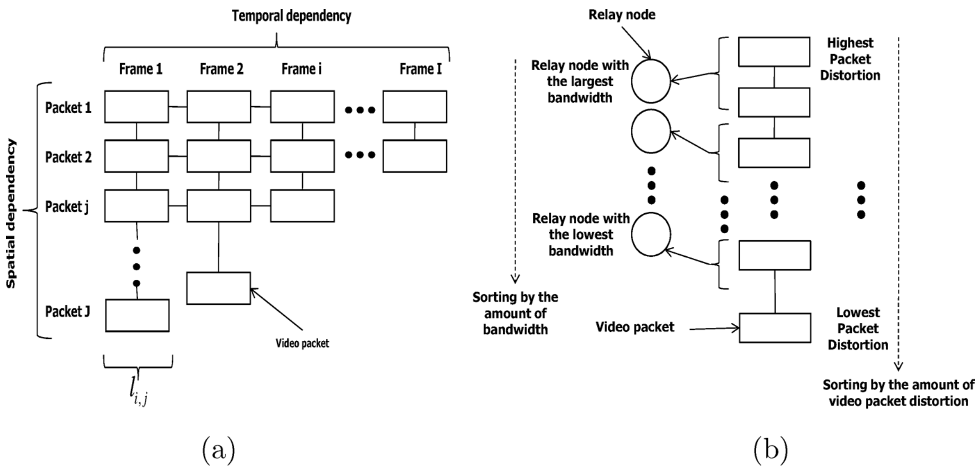


**Fig. 2.** (a) Spatial and Temporal dependency of video coding structure (b) DACR mapping algorithm


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To estimate the spatial distortion from packet loss at encoder side, we utilize a subset of pixels in a MB based on the following assumption: *Block mode in macroblock (MB) well represents a spatial correlation* [8]. From Fig. 1 (b), it can be observed that MBs with the small partition size are classified into the region with high frequency information, such as edge. On the other hand, MBs with the big partition size are classified into the homogeneous region, such as background. In the case of macroblock A in Fig. 1 (b), we calculate only 1 pixel in $8 \times 8$ sub MB for estimating EC in $16 \times 16$ MB. However, in the case of macroblock B with the block mode of $16 \times 16$, the EC of only 1 pixel is calculated. Thus we estimate a spatial distortion with low complexity by controlling a subset of pixels according to the block mode in a MB. As a results, the estimated value of (2) is represented as $\hat{\mu}_{i,j}$.

Based on $\lambda_{i,j}$ and $\hat{\mu}_{i,j}$, we define a performance metric, $\chi_{i,j}$, which is a combination of both effects from spatial and temporal video quality degradation:

$$\chi_{i,j} = \lambda_{i,j} \cdot \hat{\mu}_{i,j} \tag{3}$$

### 3.2 Distortion-aware cooperative relaying (DACR) scheme

Let $\mathbf{M}$ be the mapping matrix from video packet, $p_{i,j}$ to relay nodes, $r$ as follows.

$$\mathbf{M} = \begin{bmatrix} m_{0,0} & m_{0,1} & \cdots & m_{0,J-1} \\ m_{1,0} & m_{1,1} & \cdots & m_{1,J-1} \\ \cdots & \cdots & \cdots & \cdots \\ m_{I-1,0} & m_{I-1,1} & \cdots & m_{I-1,J-1} \end{bmatrix} \tag{4}$$

where $m_{i,j} \in \{r : 1, \cdots, R\}$ is the relay node ID. $m_{i,j} = r$ means that video packet, $p_{i,j}$ is transferred by relay node $r$. The objective of the proposed assignment scheme is to minimize the distortion by optimally mapping video packets into relay nodes. Let $D_0$ represent the total distortion if no video packets are received from all relay nodes, which can be expressed as follows,

$$D_0 = \sum_{i=0}^{I-1} \sum_{j=0}^{J-1} \chi_{i,j} \tag{5}$$

Also, when video packets is correctly received, the distortion reduction is defined by

$$\Delta D^{m_{i,j}} = \sum_{i=0}^{I-1} \sum_{j=0}^{J-1} \gamma^{m_{i,j}} \tag{6}$$

where $\gamma^{m_{i,j}}$ represents as follows.

$$\gamma^{m_{i,j}} = \begin{cases} \chi_{i,j} & \text{if } \; m_{i,j} \neq 0 \\ 0 & \text{Otherwise} \end{cases} \tag{7}$$

We define $D(\mathbf{M})$ as the amount of expected distortion by mapping video packets, $p_{i,j}$ into different relay nodes, $r$ through the assignment policy, $\mathbf{M}$. Based on (5) and (6), the objective function for optimal assignment of $\mathbf{M}$ is formulated as follows:

$$\min\left[D(\mathbf{M})\right] = \min\left[D_0 - \sum_{i=0}^{I-1} \sum_{j=0}^{J-1} \Delta D^{m_{i,j}}\right] \tag{8}$$


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subject to

$$\sum_{\hat{i},\hat{j} \in r} l_{\hat{i},\hat{j}} \leq B_r \tag{9}$$

where $l_{\hat{i},\hat{j}}$ the length of video packet $p_{i,j}$ as in Fig. 2 and $B_r$ is an available bandwidth of relay node, $r$. This means the bandwidth constraint of relay nodes. Then we propose the DACR mapping algorithm for solving the above problem in the following Steps 1 - 5.

Step 1) The video coding module collects the video frames from WSN by unit of GOP. Here, GOP size also represents the update period $T$ of DACR algorithm.

Step 2) Based on the spatial and temporal properties in video coding structure, we calculate the performance metric, $\chi_{i,j}$ from (3).

Step 3) Each video packet is sorted in the order of $\chi_{i,j}$ for mapping video packets into relay node. According to the amount of $B_r$ existing in the relay nodes, relay nodes is also sorted.

Step 4) A CH assigns the number of video packets to relay nodes. The current relay node transmits video data as many as the available bandwidth of relay node, $B_r$. If current relay node is filled with video packets, the next relay node which is based on the performance metric transmits the remaining video packets. This process is shown in Fig. 2 (b).

Step 5) If there is no video packet to transmit or there is no available relay node, this algorithm is terminated. In the case of latter condition, the remaining video packets cannot be delivered into BS due to the limitation of channel bandwidth.

## 4 Simulation results

To evaluate the performance of the proposed scheme with the new performance metric from (3) and the DACR algorithm, the 'Foreman' video sequence with QCIF resolution is encoded at 270 kbps using I and P frames from the H.264 reference software [9]. The GOP size and the frame rate are 15 frames and 15 fps, respectively. The packet size is set as 1280 bits and the length of each GOP, $T$ is 15.

For the performance comparison, the conventional scheme [5] without the new packet distortion level and the proposed cooperating relaying algorithm and No Error case are utilized, respectively.

It is assumed that total number of relay nodes (i.e. MSs) are 4. We utilize log-normal shadowing path loss model as a channel model between CH and MSs and it is given by

$$PL(d_i) = PL(d_0) + 10n \log_{10}\left(\frac{d}{d_0}\right) + X_\sigma \tag{10}$$


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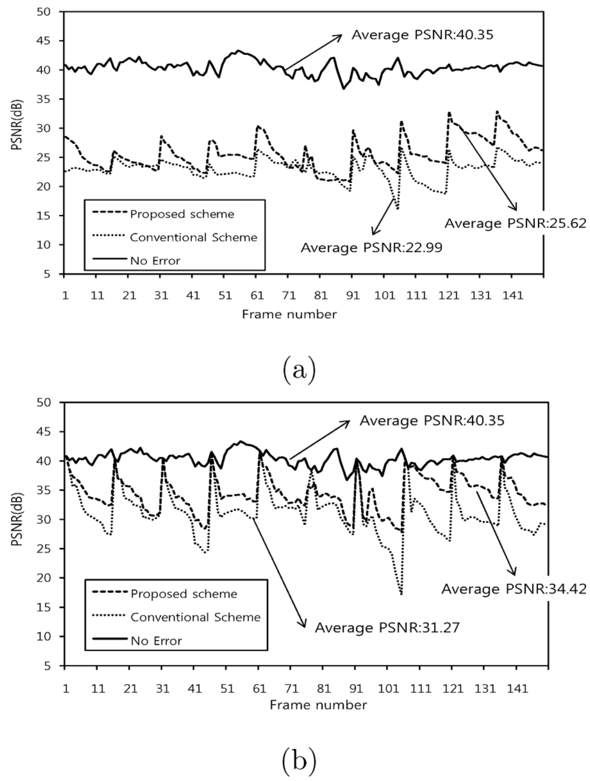


**Fig. 3.** PSNR performance comparison between the proposed scheme, conventional scheme, and No Error. (a) G1: total bandwidth of CH-MS = 214 kbps (b) G2: total bandwidth of CH-MS = 257 kbps

where $d_i$ is a distance from CH to $MS_i$, $d_0$ is a reference distance, $n$ the pathloss exponent, and $X_\sigma$ a zero-mean Gaussian RV with standard deviation $\sigma$. In our simulation, we define that $n = 4$, $\sigma = 3.84$, $PL(d_0) = 55\,dB$ and an output power of $0\,dBm$. Additionally, the MSs are deployed randomly within a cluster, where suppose that a cluster radius is equal to $20\,m$. Then, the channel capacity for each CH-MS pair will be different because each MS has different distance $d_i$ from the CH. There are two arbitrary value groups for signal to noise ratios of the MSs, that is, G1: (17.3 dB, 4.46 dB, 2.8 dB, 0.34 dB), G2: (17.3 dB, 7.03 dB, 5.04 dB, 3.66 dB), respectively.

Fig. 3 (a) and Fig. 3 (b) show the peak signal-to-noise ratio (PSNR) comparison between the proposed scheme and a conventional scheme. It is observed that the proposed algorithm provides higher PSNR values than a conventional algorithm. The gradual decrease of video quality in the proposed relaying algorithm is due to the delivery of more video packets with larger impact on video quality by packet loss.

## 5 Conclusion

We designed a novel distortion-aware cooperative relaying scheme for achieving the optimal video quality over WVSN. The proposed approach outperformed a conventional scheme in the performance comparison.


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