Video Streaming in Wireless Sensor Networks with Low-complexity Change Detection Enforcement

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***Abstract*—Video streaming applications in wireless sensor networks are attractive for enabling new pervasive high value services. The reduced amount of available bandwidth in such networks imposes the transmission of small size video frames at very low frame rates. Moreover, when compression techniques cannot be applied, due to constrained computational capabilities of sensor nodes, and uncompressed video frames must be sent through the network, lower image sizes and frame rates must be adopted. In such a scenario, when higher frame rates are required or multiple video streams must be enabled the required transmission bandwidth of each stream must be reduced. In this paper we present a low-complexity algorithm based on change detection which reduces the transmission bandwidth of a video stream based on raw images. Performance results show how the proposed technique can reduce the transmission bandwidth up to 87.22% and 66.78%, with respect to a flat video stream transmission, when low and high changes are experienced in the monitored scene.**

***Keywords*-Change Detection; Video Streaming; Wireless Sensor Networks; IEEE802.15.4.**

I. Introduction

Wireless Sensor Networks (WSNs) have experienced a rapid growth in the last several years due to the increasing efforts of both research community and private stakeholders in developing this technology. WSNs have been recently adopted in a wide range of applications, where they replace old wired and wireless systems which are more expensive and hard to setup because of their necessity of power and connection cables. A reduced set of WSN applications include climatic monitoring [1], structural monitoring of buildings [2], [3], human tracking [4], military surveillance [5], and, more recently, multimedia related applications [6]–[8].

Multimedia applications in wireless sensor networks have been mainly fostered by a new generation of low-power and very performant microcontrollers, able to speed-up the processing capabilities of a single wireless node, as well as the development of new micro-cameras and microphones imported from the mobile phones industry. Among all the possible multimedia applications in the WSNs scenario one of the most promising and challenging is the video streaming. If from one hand video streaming services in pervasive wireless sensor networks can be successfully adopted for high value applications, such as pervasive video surveillance, on the other hand they require to address several problems. Considering wireless sensor networks based on the IEEE802.15.4 [9] standard, a very big issue is that of matching with a transmission bandwidth lower than 250 Kbps at physical layer. This limitation implies the transmission of small size video frames (e.g., 320x240, 160x120) at a very low frame rate to avoid network congestion [10]. Furthermore, in case of image compression, since popular techniques cannot be applied due to their computational complexity, raw images must be sent, thus reducing again the image size, the frame rate or both of them. As matter of example, considering the transmission of a video flow in which 160x120 gray scale raw pictures are sent through a network compliant with the IEEE802.15.4 standard, only a video stream can be enabled with a maximum allowable frame rate lower than 2 fps. If multiple video streams are enabled or higher frame rates are considered, the amount of information transmitted in each video frame must be reduced.

In this work we address the problem of uncompressed video streaming applications in case of transmission in WSNs composed by low-end devices with reduced computational capabilities. More in particular, we propose a computer vision based algorithm aiming at reducing the video flow transmission bandwidth occupancy while preserving as much as possible the carried information content. The algorithm can detect and send only the portion of an image in which a change in the scene has occurred, thus considerably reducing the bandwidth occupancy.

The rest of the paper is organized as follows: in Section II we present related works in the research area concerning to video streaming in WSNs, while emphasizing the contribution of the presented work with respect to previously proposed approaches. In Section III we first discuss the information content carried by a single video frame, then we present the developed change detection based algorithm which aims at selecting and sending only the part of an image in which a change in the scene has been detected. The performance evaluation of the proposed algorithm is presented and discussed in Section IV, conclusions follow in Section V.

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II. Related Work

In traditional video streaming applications high-end devices are used to compress and send multimedia contents by means of of state-of-the-art video encoders, such as MPEG-2 [11] and H.264 [12], so that the best trade-off between video quality and bandwidth reduction is achieved. The aforementioned standards rely on time-consuming and on demanding processing algorithms which are not supported by WSNs devices, characterized by low processing power, reduced memory availability and limited energy budgets. In such a scenario, proposed video compression techniques are based on simple image compression schemes with possible optimizations based on a differential coding [13]. In [14] the use of JPEG and JPEG2000 standards with a fixed point Discrete Cosine Transform (DCT) implementation, instead of the commonly used floating point, has been preliminarily investigated in respect to the image quality and node energy consumption. The paper shows as a fixed point DCT implementation permits, in the case of JPEG standard, to lower the energy consumption in the image compression process, thus showing as it is possible to adopt the JPEG compression in a WSNs context. An improvement of this work is presented in [15] where a video compression solution based on a change detection approach specifically developed for JPEG compression is adopted. The use of JPEG and JPEG2000 standards in IEEE802.15.4 networks has been addressed in [16] where both compression schemes have been tested in a real scenario, while highlighting network limitations and evaluating transmission performance in terms of Peak Signal to Noise Ratio (PSNR) and byte error rate parameters. A JPEG-lossless coding in IEEE802.15.4 network is analyzed in [17] where it is shown how it is able to reach better PSNR with respect to JPEG in case of an enhanced device node architecture for acquiring and processing images is adopted. The use of a JPEG-like compression technique targeted to video streaming applications in IEEE802.15.4 networks has been investigated in [18] where a new hybrid DPCM/DCT coding scheme is proposed and adopted to achieve an acceptable compression gain with a low computational complexity.

The use of the JPEG compression standard in tiny mote devices has been experimentally evaluated in [19], where the JPEG implementation provided by the Independent JPEG Group (IJG) has been implemented on the Imote2 [20] platform equipped with the Imote2 Multimedia Sensor Board. In case of a 320x240 gray scale images, and a working clock frequency of 13 MHz, the compression algorithm requires up to 500 ms to compress the image for any quality factor, thus allowing up to 2 fps in the video stream. Better compression performance has been reached in [18], where on the same platform up to 2.7 fps can be enabled. Moreover, considering the transmission bandwidth limitations of the IEEE802.15.4 standard the maximum allowable frame rate decreases in both cases to values lower than 1 fps. This last value has been obtained without considering the use of channel coding schemes, such as forward error correction (FEC) or erasure correction (EC), necessary to overcome data losses in DCT coefficients at the cost of further reducing the frame rate.

In case of sensor devices with lower computational capabilities are adopted for video streaming purposes a JPEG or JPEG-based compression may result unfeasible to meet frame rate constraints (up to 500 ms for compressing a single image) and the transmission of raw images must be considered. In this case an image size reduction can be considered with a joint implementation of advanced low-complexity techniques able to lower the transmission bandwidth occupancy, thus avoiding to reduce the frame rate due to the lack of compression techniques. In this work the problem of enabling video streaming applications based on raw images in WSNs is addressed by proposing a low-complexity change detection algorithm aiming at detecting and sending the portion of an image in which a change in the scene has occurred with respect to a reference image. The algorithm is based on computer vision techniques and it is designed to be used with raw images, although it can be applied as general change detection solution before applying compression.

III. Video information and change detection

A. Image information content in streaming applications

In case of video streaming applications aiming at realizing high values applications, such as video surveillance, the main goal is that of preserving as much as possible the information content of the video stream while reducing the required network bandwidth occupancy. To address this main problem, which is at the basis of each video streaming application, several strategies based on the deletion of imperceptible information contents have been proposed and developed. If we consider state-of-the-art compression standard mentioned in the previous section the data reduction is achieved by deleting the information content who is not perceptible at human eyes (e.g., high spatial frequencies), thus adopting a non-semantic approach that requires high computational capabilities. In this work we address the problem of reducing the transmission bandwidth of a video streaming application proposing a low-complexity compression algorithm based on

Algorithm 1 Change detection based algorithm.

```
Frame_id = 0;
while 1 do
    get_image(image);
    Frame_id = Frame_id+1;
    if (Frame_id mod N) == 0 then
        send_image(image);
        bgnd = set_background(image);
    else
        diff = background_sub(image, bgnd);
        blob = segmentation(diff);
        send_blob(blob, parameters);
    end if
end while
```

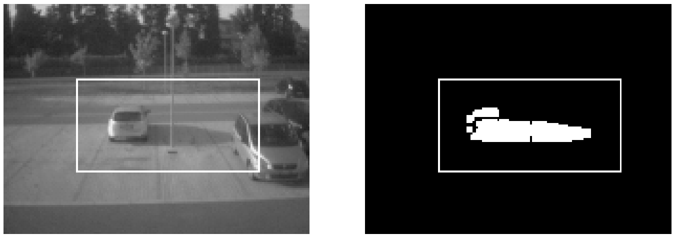


Fig. 1. Background differencing effects and bounding box identified.

Height	Width	x	y	Image data
2 bytes	2 bytes	2 bytes	2 bytes	(Width*Height) bytes

Fig. 2. Bounding box parameters and image data organization.

a semantic approach. For each video frame the sub-set of pixels characterized by a high information content is detected and transmitted through the network. Considering a classical video surveillance scenario in which the camera is in a fixed position the information content of each video frame is related to the amount of the detected changes with respect to a static situation. Starting from this consideration it is possible to divide a video frame in two main components: *background* and *foreground*. The background is the static component of an image and it contains only few information about the events inside the monitored scene. The foreground is the dynamic component of an image and it contains the largest amount of information regarding the events inside the monitored scene. While the background changes slowly among successive video frames (e.g., luminosity variations, once-off changes in the static situation) and can be sent sporadically, the foreground has a high dynamic and must be detected and sent for each frame. The bandwidth reduction algorithm proposed in this work is based on the background/foreground classification and it has been developed with the aim of detecting and sending the sub-set of an image in which a change in the scene is detected, while updating periodically the image background.

B. The change detection based algorithm

The developed change detection-based transmission algorithm has been reported as pseudo-code in Algorithm 1. It is divided in two parts: the first one is in charge of upgrading the background for reacting to luminosity variations and once-off changes, while the second one is in charge of detecting, for each foreground image, possible changes in the scene.

The background variation compensation is applied every N video frames, when a full image is sent. The period between two background refreshing is called in the following of the paper as *background refreshing period*. Regarding the logic implemented in the change detection part of the algorithm, this is based on the background subtraction approach, a technique widely used in computer vision applications. To each acquired image the background is subtracted applying a filtering threshold used to filter luminosity variations and camera noise, then, the blob containing a change in the scene is detected and included in a rectangular bounding box to be sent through the network together with a set of parameters useful for the image reconstruction at the receiver side. The full process of background differencing and rectangular bounding box identification is depicted in Fig. 1, where in the left side the acquired image when a car just parked is reported, while in the right side the detected bounding box obtained starting from the difference image followed by a tresholding and binarization procedure is represented. The full proposed algorithm is targeted to low-complexity; in fact, only simple operations are performed on each image, avoiding transformations in other domains or heavy compression procedures.

The use of a rectangular bounding box for containing the pixels in which a change in the scene has been detected fulfills the low-complexity approach both in identifying the video frame information content and in reconstructing the image at the receiver side, where only a few amount of additional bytes must be sent for a correct positioning of the box. The reconstruction procedure is summarized in terms of pseudo-code in Algorithm 2: it only requires to copy the box to the right position of the last received background. The additional parameters to be sent with each bounding box for its correct positioning within the background image at the receiver side are: height, width and left corner position values. The total amount of additional bytes is equal to 8, as depicted in Fig. 2, where the transmission data organization for both bounding box parameters and image data is reported.

Algorithm 2 Reconstruction algorithm.

```
Frame_id = 0;
while 1 do
  receive_data(buffer);
  Frame_id = Frame_id+1;
  if (Frame_id mod N) == 0 then
    bgnd = set_background(buffer);
  else
    image = rec_image(bgnd, buff);
  end if
end while
```

IV. PERFORMANCE EVALUATION

The performance of the developed algorithm has been evaluated by means of simulations in terms of video stream bandwidth occupancy and received video quality as a function of the background refreshing period, indicated with the N parameter in Algorithms 1 and 2. In each simulation no packet loss has been considered to evaluate in isolation the effects of the adopted compression scheme. The metric selected for evaluating the video quality is the Peak Signal-to-Noise Ratio, based on a comparison between the original images and their reconstructed versions at the receiver side. In the performed simulations the IPERMOB Data Set (IPERDS) [21] has been used as input, while low and high motion scenarios have been considered for a fair performance evaluation comparison.

A. The IPERDS dataset

The dataset adopted in this work is the IPERDS, created within the IPERMOB project [22]. IPERDS is basically a collection of images related to traffic and parking lots conditions. Each cataloged set of images is a video trace of more than 5 minutes with a frame rate equal to 1 fps. The dataset is composed of images with a size equal to 160x120 and 320x240 pixels, in gray scale. All the images composing the dataset have been collected by using real wireless sensor network devices equipped with a low-cost camera, hence they have all the necessary characteristics to prototype video streaming and computer vision algorithms targeted to low-end devices.

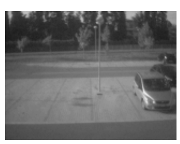
B. Low motion scenario

The performance evaluation of the proposed algorithm in a low motion scenario has been executed adopting a set of IPERDS images with a size of 160x120 pixels in which several parking lots are monitored. An example of the adopted images with the result of the differencing and reconstruction processes is depicted in Fig. 3, while the simulation results obtained by varying N from 1 to 100 are reported numerically in Table I and graphically in Fig. 4. In case of a background refreshing period equal to 1, no change detection is applied, the background is updated every frame, the bandwidth occupancy of the video stream is maximum, 153.60 Kbps, and the PSNR is theoretically infinite. When the developed change detection based algorithm is applied, N values bigger than 1 are adopted, the required bandwidth occupancy of the video stream rapidly decreases. Considering N equal to 10 the bandwidth occupancy reduction is 87.22% while the PSNR shows good quality levels. The same video quality and transmission bandwidth is reached in [18] where JPEG-like compression is applied. Lower bandwidth occupancy values can be reached increasing the background refreshing period, at the cost of decreasing PSNR figures. Considering the maximum transmission bandwidth provided by the IEEE802.15.4 standard approximately ten video streams at 1 fps, or a video stream at 10 fps, can be enabled by adopting the developed algorithm, instead of the one at 1 fps ensured by a plain video transmission.

From the data reported in Table I, two main behaviors can be noticed in the bandwidth occupancy trend. When N is in

TABLE I
LOW MOTION SCENARIO PERFORMANCE EVALUATION RESULTS.

N	Bandwidth occupancy [Kbps]	PSNR [dB]
1	153.60	inf
10	19.63	38.05
20	13.02	37.42
30	10.02	36.74
40	9.68	36.60
50	9.33	36.11
60	9.23	35.84
70	9.01	35.92
80	9.02	35.84
90	9.06	35.36
100	10.01	35.38



(a) Background

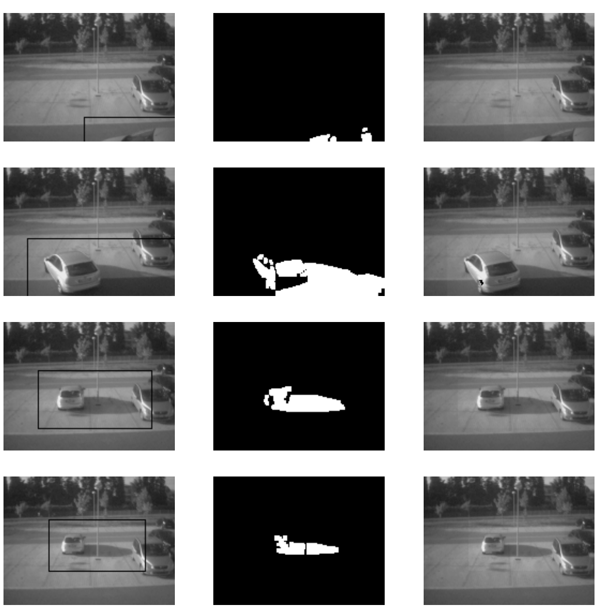
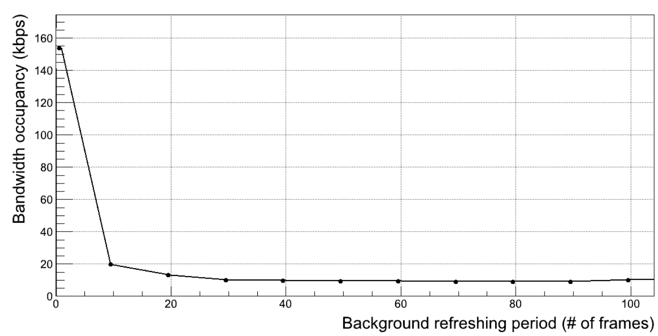
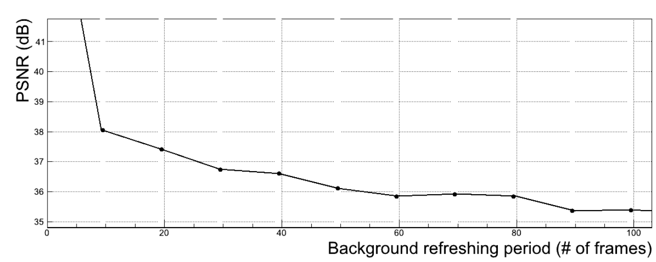


Fig. 3. Low motion scenario: sequences of original, difference and reconstructed images.



(a) Bandwidth occupancy vs. background refreshing period



(b) PSNR vs. background refreshing period

Fig. 4. Bandwidth occupancy and PSNR in the low motion scenario.

the range between 10 and 70 the bandwidth occupancy slowly decreases, while it starts to raise after a background refreshing period equal to 70. The described behavior cannot be noticed in the PSNR trend, where after a background refreshing period equal to 70 the PSNR values still decrease with some fluctuations. The described behaviors are not uncorrelated and their are due to light changes between the background and the current image. When light variation occurs, due to weather changes (e.g., clouds passing in front of the sun) or internal camera parameters variations (e.g., auto-exposure camera algorithm instability), the difference between the current image and the background results in bigger bounding boxes and bigger differences in the reconstructed images, thus increasing the required bandwidth and lowering the PSNR.

C. *High motion scenario*

In the high motion scenario the performance evaluation has been carried out adopting a set of images with a size of 160x120 pixels in which a view of road and the pedestrian walk is monitored. An example of the adopted images with the result of the differencing and reconstruction processes is shown in Fig. 5, while the whole simulation results are reported numerically in Table II and graphically in Fig. 6. For a fair comparison with respect to the low motion scenario the same background refreshing period values have been adopted.

The proposed algorithm shows its benefits in bandwidth occupancy reduction also in this scenario. Considering a value of N equal to 10 the bandwidth reduction with respect to a no change detection based procedure is 66.78%. When higher background refreshing period values are adopted the bandwidth occupancy and PSNR values experience some fluctuations. In this case, in fact, to the light variation effect previous described, a new effect related to the high mobility must be added, introducing a sudden invalidation of the reference background image. Even if in this scenario the bandwidth reduction is lower than the low motion case, approximately four video streams at 1 fps, or a video stream at 4 fps can be supported in an IEEE802.15.4 network, instead of the one at 1 fps ensured by a plain raw image based video transmission.

TABLE II
HIGH MOTION SCENARIO PERFORMANCE EVALUATION RESULTS.

N	Bandwidth occupancy [Kbps]	PSNR [dB]
1	153.60	inf
10	51.02	30.93
20	48.86	30.67
30	48.02	29.80
40	51.84	29.70
50	47.67	29.72
60	50.54	29.67
70	56.53	29.68
80	55.53	29.32
90	56.06	29.22
100	60.99	29.64

(a) Background

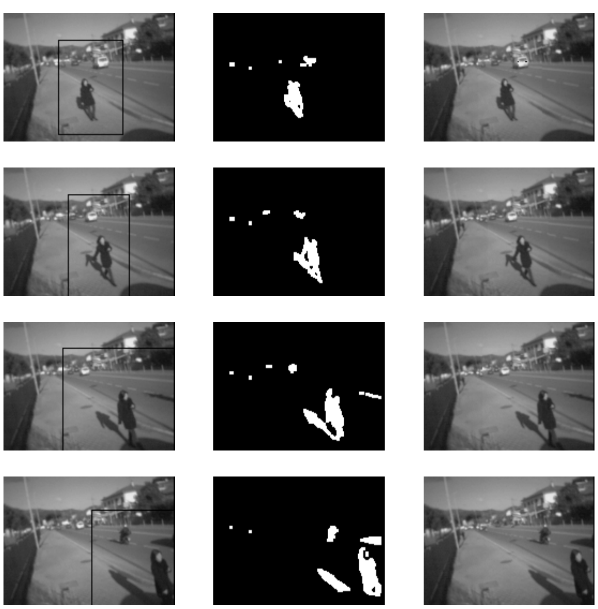
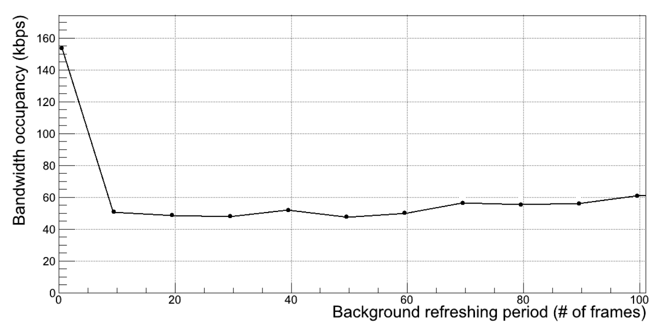
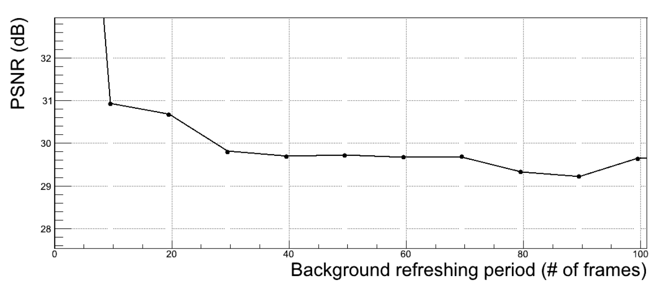


Fig. 5. High motion scenario: sequences of original, difference and reconstructed images.



(a) Bandwidth occupancy vs. background refreshing period



(b) PSNR vs. background refreshing period

Fig. 6. Bandwidth occupancy and PSNR in the high motion scenario.

D. Low motion and high motion performance comparison

In both analyzed scenarios the proposed change detection based video streaming algorithm shows its benefits with respect to a raw images based video transmission in which no data reduction is applied. Considering a background refreshing period equal to 10 the bandwidth reduction is 87.22% in the low motion scenario and 66.78% in the high motion scenario. In the former scenario the video quality and required transmission bandwidth is the same reported in [18] where JPEG-like compression is applied. The difference between the two percentages is bigger than 20%, showing as in case of high motion a bigger amount of data must be sent to preserve the information content of each image. Due to the different images adopted in evaluating the performance of low and high motion scenarios a fair comparison among PSNR values is not possible. In any case the highest PSNR has been obtained for lower background refreshing periods, N equal to 10, while an acceptable slight decrease in video quality has been experienced for N equal to 20. In both scenarios the best background refreshing period to be adopted is 10, while a proper trade-off between a further bandwidth reduction and video stream quality is reached for N equal to 20.

V. Conclusions

In this paper a low-complexity change detection based algorithm aiming at reducing the required transmission bandwidth of video streaming applications based on raw images in a wireless sensor networks scenario is presented. Starting from the consideration that it is possible to divide a video frame in background and foreground components, the proposed algorithm detects and sends, for each frame, only the foreground part of an image in which a change in the scene has occurred, while updating the background at every periodic background refresh. Performance results in low and high motion scenarios show the benefits of the proposed algorithm, with respect to a video stream in which no change detection based transmission is applied, in terms of saved transmission bandwidth. In case of a background refreshing period equal to 10 video frames the gain in bandwidth occupancy is 87.22% in the low motion scenario and 66.78% in the high motion scenario, while preserving a good video quality level in terms of PSNR. The huge bandwidth occupancy reduction reached by adopting the proposed algorithm permits the effective deployment of pervasive video surveillance systems based on WSNs. Considering the maximum transmission bandwidth provided by the IEEE802.15.4 standard, 250 Kbps at physical level, approximately ten video streams at 1 fps can enabled in case of low motion and four in case of high motion, or one video stream at 10 and 4 fps respectively, instead of the single stream at 1 fps ensured by a plain raw image based video transmission.

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