This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the ICC 2008 proceedings.

# Adaptive Rate Control Low bit-rate Video Transmission over Wireless Zigbee Networks

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***Abstract*—The emerging IEEE 802.15.4 standard is designed for low data rate, low power consumption and low cost wireless personal area networks (WPANs). Video transmission over such networks is considered an issue since video traffic demands high data rates. In this paper, the TES (Transform-Expand-Sample) methodology is used to model low rate MPEG4 video. The performance of a surveillance video application is evaluated over wireless Zigbee networks. A rate control algorithm (RC-VBR) adapted to MPEG4 variable bit rate (VBR) video coders is studied over Zigbee networks. The algorithm avoids unpredictable rate variations of the VBR coding and removes the coding delay in constant bit-rate (CBR) coders. A region of interest (ROI) encoding is added to the rate control algorithm in order to capture the important parts of the frame which is suitable for IEEE 802.15.4 (Zigbee) networks. Zigbee networks will enable a large number of applications for surveillance networks. The ns-2 simulator is used to test and validate the MPEG4 real video and modeled video over ad hoc Zigbee networks and to test the different algorithms.***

***Keywords: Zigbee, IEEE 802.15.4, Ad hoc, TES, MPEG4***

## I. INTRODUCTION

Most of the attention on wireless standards, i.e. IEEE 802.11 and cellular networks, focus on high rate and long range applications. However, not until recently, some new WPAN standards were developed for low rate and low cost set of applications. IEEE 802.15.4 [1] is a standard for low rate wireless personal area networks (LR-WPANs) which is designed for low cost, low power and short range communications.

With the rapidly growing market for short range wireless communication systems, the support of security and surveillance related applications over sensor networks is becoming important. However, many challenges limit the design of efficient video communications in wireless sensor networks. Some of the challenges are caused by resource limitations such as limited power and processing capability and the error resilience capability of video compression techniques. In addition, the capacity and throughput provided by wireless channels is low because of the path loss, fading and interference.

In general, IEEE 802.11, Bluetooth and other technologies are more suitable for real time applications than IEEE 802.15.4 since they offer much higher data rates. However, the cost of video transmission will be lowered if IEEE 802.15.4 based devices are used. A number of reasons enable video to be transmitted over low data-rate networks. Some of them being advanced video compression techniques such as MPEG4 and H.264, advanced content based video segmentation and rate control algorithms. Wireless Zigbee networks [3] are low data rate networks that implement the IEEE 802.15.4 as their physical and MAC layers. It is believed that wireless Zigbee networks may become the most used standard for wireless sensor networks (WSNs).

The purpose of the paper is twofold: testing the validity of TES modeling over low bit-rate (Zigbee) video and studying the performance of a rate control algorithm for video surveillance networks. TES (Transform-Expand-Sample) processes [2] offer a versatile and fast methodology for video modeling. Nevertheless, other modeling techniques can still be used to generate video models. The goal of the paper is not to implement a streaming application that requires high data-rate. Rather, some video applications such as video surveillance and monitoring will be studied. The size of the network that can be supported over such networks will also be studied. Advanced video encoders, object based segmentation (region-of-interest) and rate control algorithms are implemented to make the video transmission over IEEE 802.15.4 Zigbee networks feasible.

Sachin Deshpande [4] used LQI (Link Quality Indication) to support an adaptive CBR (Constant Bit Rate) streaming. In [6], an investigation of TES modeling and multiplexing of MPEG traffic over ATM networks was performed. In [7] H.261 video compression were modeled using the TES methodology. In [8], TES modeling was used to generate models for high bit-rate MPEG4 traffic. However, TES modeling is still not validated for low bit-rate video traffic.

The paper is organized as follows: section II gives an overview of IEEE 802.15.4 networks. Section III describes the TES processes used in modeling the low bit-rate video and provide a model example. Section IV shows the rate control VBR (RC-VBR) algorithm and region-of-interest (ROI-RCVBR) enhancement study. Section V provides simulations to validate the video models, the proposed RC-VBR and ROI-RCVBR algorithms and compares them with previous proposals. Finally, section VI concludes the paper.

## II. OVERVIEW OF ZIGBEE (IEEE 802.15.4) PHYSICAL AND MAC LAYERS

IEEE 802.15.4 defines the physical layer and the MAC sublayer of the OSI Zigbee layers [1]. It supports devices that consume minimum energy and is designed for low rate, low cost applications over a short range of 30 to 100 meters.

The IEEE 802.15.4 defines three physical layers; the 2.4 GHz, 868 MHz and 915 MHz frequency bands. The unlicensed industrial scientific medical (ISM) 2.4 GHz band is available worldwide, while the 868 MHz and 915 MHz bands are available in Europe and North America respectively. A total of 27 channels with three different data rates are defined for the IEEE 802.15.4: 16 channels with a data rate of 250 kbps at the 2.4 GHz band, 10 channels with a data rate of 40 kbps at the 915 MHz band, and 1 channel with a data rate of 20 kbps at the 868 MHz band [1]. The 2.4 GHz frequency band is chosen for the video transmission since it supports the highest data rate and number of channels. Offset quadrature phase shift keying (OQPSK) is used as the modulation scheme in the band.

The IEEE 802.15.4 MAC sublayer is based on CSMA/CA (channel sense multiple access) with two modes of operation: the unslotted-CSMA (beaconless mode) and the slotted-CSMA (beacon enabled mode). The basic responsibilities for the MAC sublayer is transmitting beacon frames, synchronization and providing a reliable transmission between Zigbee devices. Link layer acknowledgments are optional in IEEE 802.15.4 which can provide extra link level reliability. For our simulations, the unslotted-CSMA is used as all video sources will be contending for the channel. Link layer acknowledgments are used in order to make the video transmission more reliable.

## III. TES Processes

### A. Overview of TES Processes

TES processes [2] [9] are autoregressive modulo-1 schemes which are easy to implement on a computer with low computational complexity. The TES methodology is versatile which can generate data that matches the stationary distribution and capture the effect of correlations of any set of given samples from a time series.

The derivation of TES models is done in two phases. The first phase considers forming correlated sequences (background sequences $U_n^+$ and $U_n^-$) which are uniformly distributed in [0,1).

$$U_n^+ = \begin{cases} U_0 & \text{if } x = 0 \\ < U_{n-1}^+ + V_n > & \text{if } n > 0 \end{cases}$$

$$U_n^- = \begin{cases} U_n^+ & \text{if n even} \\ 1 - U_n^+ & \text{if n odd} \end{cases}$$

$U_0$ is a uniform random variable in [0,1) and $\{V_n\}$ is a sequence of independent and identically distributed random variables called the innovation sequences with probability density function $f_v$. $U_0$ is independent of each element of $\{V_n\}$. The second phase is to generate the foreground sequence which is done by some transformation called the distortion D .

$$X_n^+ = D(U_n^+), X_n^- = D(U_n^-)$$

The sequences $\{X_n^+\}$ and $\{X_n^-\}$ are both correlated and identically distributed. Therefore, an empirical histogram is used to represent the marginal distribution of an empirical data.

TES modeling is done by first capturing the autocorrelation of the input time series using innovation density function $f_v$ and then applying a smoothing technique using the stitching transform ($\zeta$) [2].

This step results in a distorted background sequence which is then inverted to a foreground sequence using the inverse of the histogram distribution which always guarantees the matching of the marginals. The task of finding an appropriate innovation density that approximates the empirical autocorrelation is carried out via a heuristic search using TEStool [10].

### B. TES modeling of MPEG4 video

MPEG4 [5] uses both spatial (intra-frame) and temporal (inter-frame) redundancy encoding because of the similarities in the successive frames for the same scene. I-frames are the intra-frames in MPEG4 which do not depend on any frames and contain the most important part. In temporal redundancy, only the differences between successive frames are encoded using frame differencing, motion estimation and motion-compensated prediction [5]. P-frames depend on previous I or P-frames while B-frames depend on previous and successive I or P-frames. P-frames and B-frames are the intra-frames in MPEG4. The frames are arranged in Group of Pictures (GOP). A GOP consists of one I-frame, a number of P-frames that are related to it and optionally some B-frames between the I and P frames.

In this section, an MPEG4 traffic generation model using TES processes is developed. MPEG4 traces are generated by encoding an indoor surveillance video at a rate of 10 frames per second (fps) with different quantization parameters and a GOP of 12 frames between two consecutive I-frames.

The traffic model of the real video shown in this section is done with a quantization parameter of 7 (any other value could be chosen and would produce similar results). The quantization parameter determines the spatial resolution of the encoded picture, i.e. by increasing the Q value; the bit rate and image quality decrease.

Since the overall video sequence is not stationary as seen in figures 1-a and 1-b, and because of the periodic nature of the autocorrelation function, a TES model is applied for the I, P and B frames separately. A $TES^+$ model is applied for the I and B frame statistics and a $TES^-$ model is applied for the P frame statistics as was performed in [7].

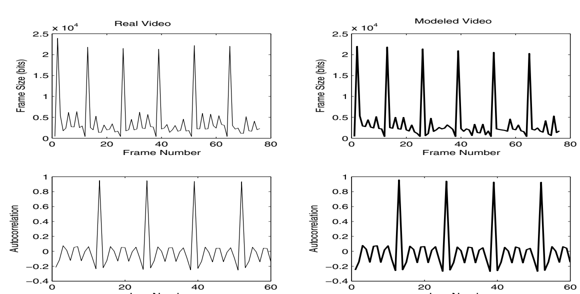


Fig. 1. a) Sample Size of the real video (Upper left figure) b) Autocorrelation of the real video (Lower left figure) c) Sample Size of the video model (Upper right figure) d) Autocorrelation of the video model (Lower right figure)

The steps for generating the TES models is only shown for the I-frames because of the space limitation. Figure 2a shows the TES model versus the frame size model of the I frames. Figure 2b shows an appropriate innovation density function $f_v$

that approximates the autocorrelation function of the I frames as much as possible. An appropriate innovation density that approximates the empirical autocorrelation was carried out via a heuristic search using TEStool [10].

As expected, it can be shown that the empirical and the modeled histograms always match while there are small differences in the autocorrelation function and the frame sizes. However, because of space limitations, only the frame size model of the I-frames was shown. The same steps were taken to generate the modeled P and B frames.

TABLE I
STATISTICS AND PARAMETERS OF THE MODELS

| | Mean (bits) | | Parameters | |
|---|---|---|---|---|
| | Original | Model | $U_0$ | $\zeta$ |
| I Frames | 20490 | 20146 | 0.460 | 0.60 |
| P Frames | 5573 | 5701 | 0.810 | 0.60 |
| B Frames | 2512 | 2556 | 0.590 | 0.40 |
| Overall(interleaved) | 4442 | 4499 | | |

Table I shows the mean of the original and modeled I, P, B and overall sequences as well as the parameters used for modeling.

After generating sample sizes from the TES models, the modeled MPEG4 video trace can be generated by interleaving the generated sample paths of the video frames individually. Figures 1-c and 1-d are the models of the real video. It can be shown that the real and modeled sequences are very similar. The generated TES models are validated to prove that real and modeled sequences produce similar queuing results.

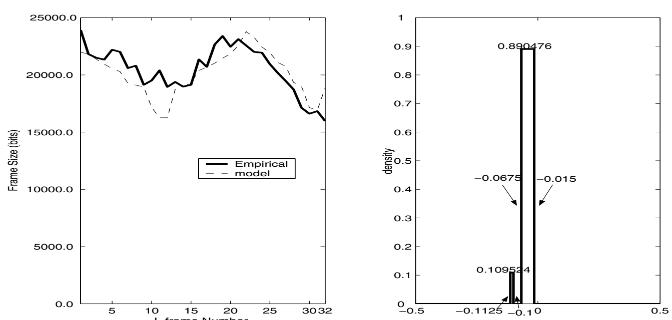


Fig. 2. a) Original and generated model of I frames (Left figure) b) Innovation density function of the I frames (Right figure)

Similar modeling results occurred when using different quantization parameters. By comparing the different quantization parameters, the autocorrelation function match closely while the frame size are different. However, the shape of the traces is similar with just a scaling factor difference. Hence, in order to generate a traffic model with a certain quantization parameter; it is not required to do it for every Q value (i.e. only one model of the video is required and the rest can be just multiplied by a scaling factor). This scaling factor is different for the I, P and B frames. Figure 3 illustrates the relationship between the bit rate per frame versus the quantization parameter knowing that the bit rate is normalized to the Q = 7 case.

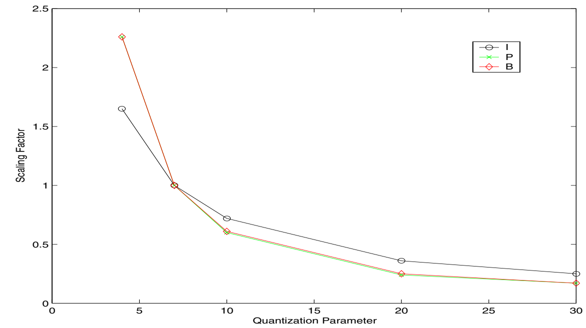


Fig. 3. Scaling Factor vs. Quantization parameter

## IV. RATE CONTROL MPEG4 VIDEO OVER WIRELESS ZIGBEE NETWORKS

There are two coding methods used in MPEG4: CBR and VBR coding. In CBR coding, the video is transmitted at a constant rate with bounded delay. CBR coding depends on changing the quantization parameter at the GOP level which is done by fixing the quantity of bits allocated to each GoP [11]. The major drawbacks of this technique are the continuous change in the video quality and the introduction of the smoothing buffer delay which role is to remove the rate variability. In VBR coding, the video is transmitted with rate variations (constant quality) which depends on the activity and complexity of the scenes. However, this results in a high burstiness in some cases because of the big difference between the intra-frame and inter-frame sizes.

To avoid the drawbacks of both techniques, a method that combines the benefits of both CBR and VBR coding is implemented which increases the video quality over Zigbee networks.

### A. *Rate Control VBR Algorithm*

The rate control VBR algorithm developed combines the benefits of both types of coding by using the queue to allow rate variability but at the same time keep a small restriction in the bit-rate.

Figure 4(a) shows the complete MPEG4 encoder when rate control VBR is used. No additional buffer is added to the encoder, resulting in an extra delay, that is known to occur in CBR coding. The rate controller is used to make sure that the buffer remains at a certain range by continuously checking the size of the queue. The output rate of the buffer is r (in packets per second) and the buffer size is b (in packets). The rate controller will keep a counter X representing the number of packets in the buffer. The counter increases or decreases to certain defined thresholds. The rate controller informs the encoder if these thresholds are reached so as to change the encoding parameters. The quantization parameter Q changes on a per GOP level. However, the rate change of Q is much less in RC-VBR coding than in CBR coding because of the introduction of the buffer size counter and the thresholds. This results in a consistent video quality with the addition of a rate controller.

RC-VBR functionality is similar to the one found in [13].

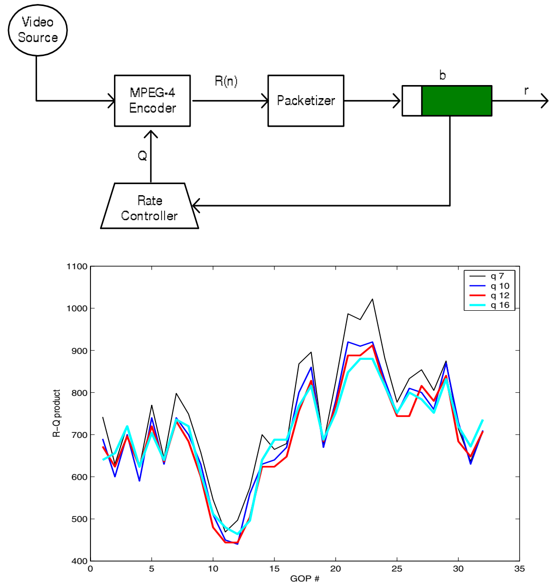


Fig. 4. a) RC-VBR algorithm (Upper figure) b) GOP Index vs. R-Q Product (Lower figure)

The number of packets in the buffer is kept as a counter X to make sure that the upper and lower thresholds are met ($0 \leq X \leq b$). R(n) is the number of packets generated, while Q(n) is the quantization parameter for the n-th GOP.

The RC-VBR algorithm makes sure that X is never close to 0 or b, by monitoring the packet size counter X and comparing it with a threshold. Therefore, if X is not close to 0 or b, the quality of the video remains unchanged. Whereas, if the X counter crosses the thresholds (i.e. becomes close to either 0 or b), the RC-VBR algorithm changes the video quality value by either increasing or decreasing it respectively.

The Q value will change for different reasons. One reason is the change in scene complexity, i.e an object appearing or disappearing in surveillance networks. Another reason could be a change in the number of hops or a change in the channel conditions. In the aforementioned cases, the quantization parameter values should be changed to make sure that the object can be tracked. A good measure for the scene complexity is the R-Q product [13].

Figure 4(b) shows the R-Q product versus the GOP number for different quantization parameters. From the figure, it is shown that the R-Q product of each GOP is almost the same for various Q values. The product difference between the various GOPs is due to the difference in frame complexity. However, the R-Q product for every GOP is a constant which represents the complexity of the scene. Let: $C(n) = R(n).Q(n)$ and from figure 4(b), it can be seen that C(n) is practically independent from Q. The full RC-VBR algorithm is summarized in figure 5.

### B. Region-of-interest Rate Control VBR Algorithm

In a conventional surveillance network, the static background regions in the video frames are encoded and transmitted over the network even if they do not contribute significant information. Video surveillance sequences contain long periods of inactivity and short periods of activity limited to a small region of the frame. Therefore, a method for object segmentation will reduce the video traffic over the network. Thus, this method is appropriate for low bit-rate networks such as Zigbee networks. The method can be produced by analyzing and encoding important regions of the frames and hence transmitting smaller frame parts, resulting in an increase of the topology size (i.e. number of video camera sources).

$Threshold1 \approx 0$, $Threshold2 \approx b$
$R_{VBR}(n)$: pkts in the $n^{th}$ GOP VBR coding
$if(X = 0)$
then RC-VBR coding = VBR coding
$if(X = b)$
then RC-VBR coding = CBR coding
$if(0 \leq X \leq Threshold1)$

then

$$R_{new} = max\{r, R_{VBR}(n)\}$$

$if(Threshold2 \leq X \leq b)$

then

$$R_{new} = min\{r, R_{VBR}(n)\}$$

$C_{new} = C(n)$ then $R_{new}$ x $Q_{new} = R(n)$ x $Q(n)$
$Q_{new} = Q(n)$ x $\frac{R(n)}{R_{new}}$

Fig. 5. RC-VBR algorithm

In [14], region-of-interest coding is used for JPEG2000 image transmissions over surveillance networks. In [15], a spatial-temporal segmentation technique was introduced to encode an MPEG-2 content based encoded video. The segmentation technique used in this paper is similar to the one in [15]. However, the segmented object (i.e. region-of-interest) frame is passed to the rate control VBR (RC-VBR) encoder instead of the MPEG-2 encoder to make sure the video output rate remains within certain boundaries. This algorithm is called the region-of-interest rate control VBR (ROI-RCVBR) algorithm. Figure 6a shows the original frame while figure 6b shows a segmented frame where only the person object is encoded.

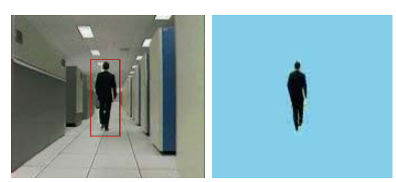

Fig. 6. a) Real video frame sample b) Video frame using video segmentation

## V. Simulation Results of Video Transmission over Wireless Zigbee Networks

Wireless Zigbee networks have additional challenges that limit the capability of video support. The small nominal rate, the small sized packets, among others.

The ns-2 simulator [18] is used throughout the simulation experiments. The Zigbee sensor cameras are simple nodes with low transmission range. This is because the camera sensors are distributed with limited (i.e. battery) power sources.

Two simulation metrics were used throughout the simulation: QoS metrics and Subjective metrics. The QoS metrics used are the frame loss percentage and average delay while the PSNR (peak signal-to-noise ratio) is calculated as follows:

$$\mathbf{PSNR}(s,d) = 20log\frac{V_{peak}}{\mathbf{MSE}(s,d)}[dB]$$

$V_{peak} = 2^k$, k is the bit color depth
$\mathbf{MSE}(s,d)$ =Mean Square Error of s and d
s (source frame) and d (destination frame)

While the PSNR is not a subjective metric, there is a direct mapping from the PSNR metric to MOS (mean-opinion-score). The aim of this paper is to produce a good or excellent video quality which means that the PSNR has to be greater than 30dB [12].

Throughout the simulations, losses due to the wireless channel are eliminated because of overhead. In addition, each data point collected is averaged over 5 simulation trials using a different random seed for each TES model generated.

### *A. Validity of video model transmission over wireless Zigbee networks*

Ns2 simulations are performed using both real MPEG4 video traces and TES models over wireless Zigbee networks [19] to test the validity of the TES models. The video consists of 415 frames in QCIF format (176x144 pixels); each of which is fragmented into a number of Zigbee packets of 127 bytes each (including the overhead). The GOP is IBBPBBPBBPBBI.. which consists of 12 frames. Zigbee networks allow single and multi-hop network topologies. In multi-hop (ad hoc) transmissions, the covering range is much higher than the single hop transmissions. However, the throughput is lowered whenever a hop count is increased which results in a lower video quality [16]. The simulations consider one and two hop transmissions with chain topologies where the only losses occur because of full buffers in the Zigbee nodes.

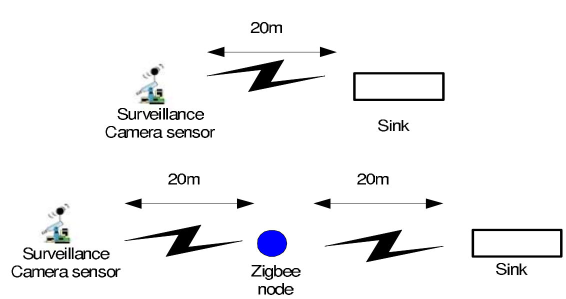


Fig. 7. a) One hop Zigbee video transmission. b) Two hop Zigbee video transmission.

Figure 8 shows the frame loss probability of the real video trace and the video model (generated over 5 trials) of the full video sequence. To understand the queuing performance, the buffer size of the Zigbee nodes are increased from 50 to 450 in 50-packet steps . The results in the graph include the one and two hop cases as shown in figure 7 with Q = 4 and 7 respectively. As shown in the figure, the video model generated closely matches the real trace and as the buffer size increases the frame loss decreases.

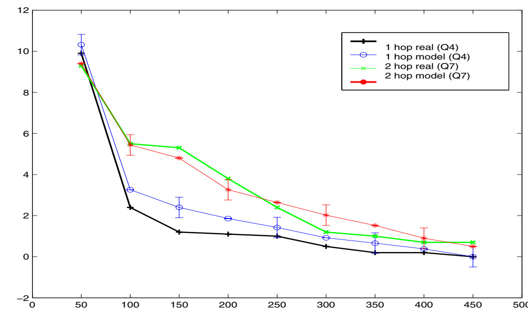


Fig. 8. Frame Loss vs. Buffer size (bytes)

Similarly, the average frame delay of the TES models closely matched the real video. However, the figure is not shown for space limitations.

### *B. Simulation results of RC-VBR algorithm over wireless Zigbee networks*

It is very important to choose the right parameters for the RC-VBR algorithm. For example, $b$ defines the buffer size used for the simulations and $r$ is the output buffer rate which directly impacts the video quality. For a reasonable video quality, $r$ should be set to a value greater than 30 kb/s.

The aggregation node as shown in figure 9 is a more complex node which aggregates data from different video sources to a single path and then to the destination. The aggregating node is connected to a power source. Hence, the transmission range is set to a higher value. The destination is the monitoring node where all videos are tracked and any suspicious act can be detected.

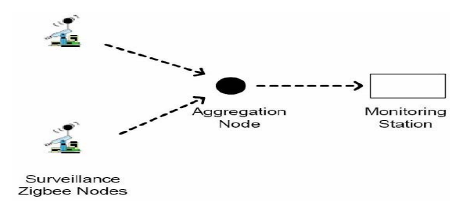


Fig. 9. Network Topology of the RC-VBR algorithm

Although Zigbee networks offer a nominal rate of 250kb/s (i.e. 240pkts/sec), this data rate is affected by the overhead and the number of hop counts. Various experiments were performed to show the throughput in packets/sec for 1, 2, 3 and 4 hops which were 175, 75, 48 and 42 pkts/s respectively. The data rate kept on decreasing drastically up to a certain number of hops (3 in this case) because of the hidden and exposed terminal problems [16] [17].

In order to get a good video quality over the Zigbee network for the two hop case in figure 9, we can provide a maximum of two video sources with about 35kb/sec (35pkts/sec) rate each. Table II shows all the simulation parameters used in the simulations.

TABLE II
SIMULATION PARAMETERS

| *Parameter* | *Value* |
|---|---|
| b | 50 packets |
| r | 35 packets/sec |
| $d_s$ (sources transmission distance) | 20 meters |
| $d_a$ (aggregating nodes transmission distance) | 80 meters |
| x-y topology coordinates | 100m x 100m |
| Transmission Model | Two-ray-ground model ($P_r \propto \frac{1}{d^4}$) |

In order to compare VBR with RC-VBR algorithms, a quantization parameter of 15 is used for the VBR because it produces an average output rate of 35kb/s. Figure 10 shows the PSNR using both the VBR and RC-VBR algorithms.

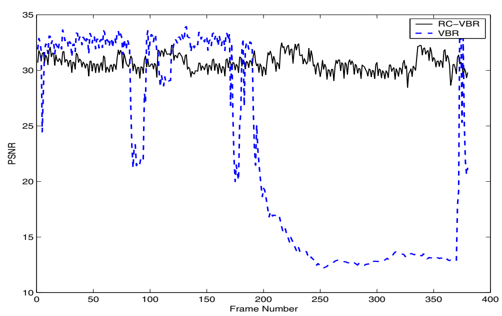


Fig. 10. Frame Number vs. PSNR

The PSNR metric is only shown for one of the video sources while the TES model was fed to the other source. The RC-VBR is implemented in the TES video model using the method shown in figure 3 where a scaling factor was used to obtain the frame sizes of the required GOP.

From the figure, it can be shown that RC-VBR algorithm outperforms the VBR algorithm. An important notice is that some of the times (especially at the beginning), the PSNR of the VBR encoding is higher than the RC-VBR. This is because initially the buffer is not full, hence packets can be queued without any loss. This difference is small and is not obvious. However, as the video sequence continues playing, the VBR encoding starts to loose a lot of packets because of the rate variability that it offers whereas in the RC-VBR case, the algorithm makes sure that the buffer occupancy stays within a certain boundaries.

Figure 11 shows a comparison between some parts of the real video, RC-VBR and VBR received videos. From the figure, the conclusions made to figure 10 can be proven visually (by looking at the arrows where the object cannot be observed) which shows that RC-VBR outperforms VBR for Zigbee networks.

To validate the previous results, 4 more video samples were taken for the same topology in figure 9. The average PSNR and the frame loss percentage are taken as the evaluation metrics. Table III shows the comparison of the video samples. The


Fig. 11. Comparison of i)Real video ii)RC-VBR algorithm and iii)VBR encoded sample frames

table shows that RC-VBR outperforms the VBR algorithm in all the cases.

TABLE III
COMPARISON OF THE PERFORMANCE METRICS OF VBR AND RC-VBR ALGORITHMS

| | RC-VBR algorithm | | VBR algorithm | |
|---|---|---|---|---|
| | $PSNR$ $(dB)$ | Frame Loss(%) | $PSNR$ $(dB)$ | Frame Loss(%) |
| Walking Person | 29.21 | 0.0 | 23.67 | 9.2 |
| Skater | 29.46 | 0.0 | 23.54 | 30.4 |
| Skier | 32.03 | 0.0 | 30.56 | 7.1 |
| Soccer Player | 26.37 | 0.0 | 24.29 | 26.1 |

### *C. Simulation results of ROI-RCVBR algorithm over wireless Zigbee networks*

Although RC-VBR produced good results, the maximum number of sources that were accommodated were small (two in our case) since IEEE 802.15.4 networks offer a very low data rate. Therefore, a combination of region-of-interest (ROI) coding with a source rate control VBR (RC-VBR) encoding is used, as developed in section IV. This is done by dynamically adapting encoding parameters for the region of interest in the different video frames. Hence, the number of video surveillance cameras that can be accommodated with a low loss rate over the Zigbee network are increased to four sources. A method for efficient energy consumption is needed since the Zigbee nodes are low power nodes (this can be done by using techniques such as low power video compression, edge detection where video frames are only decoded and transmitted when an object is detected).

Figures 12a and 12b illustrate a comparison between ROI-RCVBR encoding and ROI-VBR encoding using 4 video sources (walking person is used in this case). From the figures, the ROI-RCVBR algorithm resulted in an average decrease of 40% in the frame loss and an average increase of 2.5dB in the

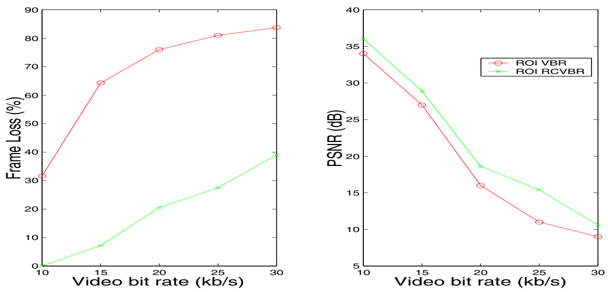


Fig. 12. a) Video bit-rate vs. Frame Loss b) Video bit-rate vs. Average PSNR

average PSNR. An important observation is that with ROI-RCVBR, a 10kb/s video bit rate produces 0% loss and very good video quality. This is because only important parts of the frames are transmitted, which means that this bit rate is suitable for wireless Zigbee networks.

TABLE IV
COMPARISON OF THE PERFORMANCE METRICS OF ROI-VBR AND ROI-RCVBR ALGORITHMS

| | ROI-RCVBR algorithm | | ROI-VBR algorithm | |
|---|---|---|---|---|
| | $PSNR$ $(dB)$ | Frame Loss(%) | $PSNR$ $(dB)$ | Frame Loss(%) |
| Walking Person | 35.96 | 0.0 | 34.20 | 32.0 |
| Skater | 27.03 | 17 | 20.01 | 71.7 |
| Skier | 35.0 | 0.0 | 22.67 | 56.0 |
| Soccer Player | 26.55 | 18.4 | 21.29 | 71.3 |

To validate the efficiency of the ROI-RCVBR algorithm, the same 4 video samples are taken. Table IV shows the average PSNR and frame loss percentage of the ROI-RCVBR and the ROI-VBR Zigbee video transmissions. It can be shown that the ROI-RCVBR algorithm results in a big difference in the performance that can enable the transmission of video in a Zigbee environment. An important observation from the table is the difference in the quality among the video sequences. For instance, the walking person and the skier result in the best performance in the ROI-RCVBR algorithm because the video object that is segmented takes the least amount of the original frame size which is the case for the surveillance video.

## VI. CONCLUSION AND FUTURE WORK

ZigBee is a promising protocol stack designed specially to facilitate low cost and low power communication running within a personal area network (PAN).

It is shown that TES processes offer a good modeling approach for low bit rate MPEG4 video traffic where the overall interleaved video model matched the original video sequence. The paper outlined a generation method of video models for the different quantization parameters without having to do all the steps of TES modeling. It was done by modeling the compressed video for a small number of quantization parameters, and then multiplying each frame type by a certain scaling factor that can be different depending on the type of the video. This enables the study of the performance of video over wireless Zigbee networks without the need for transmitting the real video since both the original and modeled traffic provide similar statistics.

The rate control variable-bit-rate (RC-VBR) algorithm is introduced and is shown that it outperforms video transmission over IEEE 802.15.4 using traditional techniques. The quantization parameter is changed adaptively for the different video sources by continuously monitoring the buffer occupancy. The performance metrics are calculated for the original MPEG4 source while all other sources are fed by the TES models. A combination of region-of-interest (ROI) and RCVBR is studies for improved video surveillance by adding more video sources to the network.

Future ongoing work is to use multiple channels and multiple interfaces over the IEEE 802.15.4 network.

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