Wireless videosurveillace over 802.15.4

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ABSTRACT

This paper presents a performance analysis of wireless image sensor networks for videosurveillance using the IEEE 802.15.4 wireless standard. The dependence of image quality and network throughput with JPEG image compression parameters and wireless protocol parameters has been investigated. The objective of the work is to give useful guidelines in the design of wireless videosurveillance networks over low cost, low power, low rate IEEE 802.15.4 wireless protocol.

Keywords: wireless communication, IEEE 802.15.4, SystemC, JPEG, videosurveillance

1. INTRODUCTION

The availability of low cost, low power, small dimensions sensors and wireless communication devices has resulted in the development of many applications of wireless sensor networks, such as infrastructure security, environment and habitat monitoring, health monitoring, industrial sensing and traffic control [1-4]. Videosurveillance is recently becoming one of the promising applications for wireless networks [5-18].

The main specifications to be considered in the design of wireless image sensor networks are the quality of the image to be transmitted, the number of images per second that can be transmitted, the power dissipated for image processing and transmission, the low sensitivity to noise in the channel. Image processing algorithms, image compression algorithms, sensor node architecture, wireless protocol from application layer to physical layer, network topology must be analyzed and all the parameters of the sensor network should be tuned in a system level simulation in order to optimize the performances of the complete system. Image compression in the sensor reduces data to be transmitted, but this causes a reduction in image quality and a greater sensitivity to channel noise. Conversely, image processing can be performed to improve quality before compression in the sensor, but the processing will increase the power dissipated by the sensor itself and the compression ratio will be reduced with a consequent increment in the transmission power and sensitivity to noise. Image processing on the receiver side, after compression, does not allow the same quality, but reduces power dissipation on the sensor node.

A great number of standards have been defined for wireless communications, each one for different applications and with different characteristics. Between them, widely used are the WiFi, Bluetooth(IEEE 802.15.1), Home-RF, ZigBee (IEEE 802.15.4), WirelessUSB, Certified Wireless USB. In this work we will study the performance of the IEEE 802.15.4, being one of the most promising protocol for low cost and low power applications, even if it is not suited for high throughput communications.

The IEEE 802.15.4 standard has been developed specifically for remote monitoring and control. IEEE 802.15.4 networks are designed to save the power of the slave nodes. For most of the time, a slave device is in deep-sleep mode and wakes up only for a fraction of time to confirm its presence in the network. The targets of 802.15.4 are low cost applications, where the battery cannot be changed (battery life time of 1-2 years) with limited requirements of bandwidth. Therefore the IEEE 802.15.4 protocol for videosurveillance can be used only if the data processing and compression is performed very carefully.

Recently, preliminary results on an hardware implementation of a 802.15.4 wireless monitoring system consisting in a single image sensor and a PC has been presented [19]. JPEG 2000 compression standard has been used in [20-22] and the image transmission over IEEE 802.15.4 networks has been considered.

In this work we will present a performance analysis of a wireless network of JPEG image sensor nodes using the low cost and low bandwidth 802.15.4 protocol. The SystemC design environment for a system level design of electronic system has been used. The JPEG standard described in C++ has been included in a SystemC module. The MAC and Physical layers of the 802.15.4 protocol and the wireless channel has been implemented in SystemC. The complete videosurveillance wireless network with up to 5 image sensor nodes has been modeled and simulated in SystemC. The optimization of the JPEG parameters (Q factor, use of restart marker ...) and of the 802.15.4 parameters as a function of the image dimensions and number of nodes has been performed. The performances considered are image quality, channel effective throughput, average time for sending the images, packet error rate due to collisions in the wireless channel.

Section 2 reports some details of the 802.15.4 wireless standard and of JPEG image compression standard. Section 3 reports the architecture of the wireless videosurveillance system described in SystemC and the results of the simulations.

2. IEEE 802.15.4 AND JPEG

2.1 IEEE 802.15.4 wireless standard

The IEEE 802.15.4 standard [23] has been developed specifically for low power and low cost applications, where the battery cannot be changed, with limited requirements of bandwidth. The supported over-the-air nominal data rate is 250 kbps for the 2.4 GHz band. The maximum payload size of each packet is 102 bytes. The 802.15.4 networks can be beacon-enabled or non beacon-enabled networks.

In non beacon-enabled networks, suited for low power applications and considered in this work, the nodes are not synchronized, a collision in the channel may occur when two or more nodes try to transmit at the same time. For the non beacon-enabled networks the 802.15.4 MAC layer uses the unslotted collision avoidance medium access (CSMA-CA) algorithm to access the channel and to reduce the collision probability. The CSMA-CA algorithm reduces the effective maximum information rate to about 125 kbps in case of a single node that uses the channel [24-25]. The effective channel throughput and the number of collisions in the channel depend on the number of devices in the network, on the size of the packet sent and on the frequency with which the devices try to access the channel[24].

802.15.4 networks may operate in two topologies: star topology or peer-to-peer topology. The architecture investigated in this work is a star topology. The devices send data to the Personal Area Network (PAN) coordinator, and the PAN coordinator responds with an acknowledge packet.

2.2 JPEG compression

The compression of the image to be transmitted is fundamental for a low data rate network: the dimension of a QCIF image of size 720x288 pixels is about 622kbytes in raw format, therefore the transmission of a single image in a channel with 125 bps data rate takes about 40 seconds: too much for a videosurveillance network with many sensors. An image compression must be performed to reduce the dimension of the image keeping the information content in order to reach a image rate of one image per second. JPEG[26] is a widely used image compression standard. A JPEG file can be encoded in various ways, the most common way is JPEG File Interchange Format (JFIF) encoding. The encoding process consists of several steps, as indicated in Figure 1:

1. The representation of the colors in the image is converted from RGB to YC_BC_R.
2. The resolution of the chroma data is reduced, considering that the human eye is less sensitive to color details than to brightness details.
3. The image is partitioned in blocks of 8×8 pixels and the discrete cosine transform (DCT) is applied to each block.
4. To compress data discarding a small amount of information, the compressor divides each DCT output value by a "quantization coefficient" and rounds the result to an integer. The complete quantization tables actually used are recorded in the compressed file, so that the decompressor knows how to reconstruct the DCT coefficients.
5. The resulting data for all the 8×8 blocks is further compressed with a lossless algorithm, the Huffman encoding.

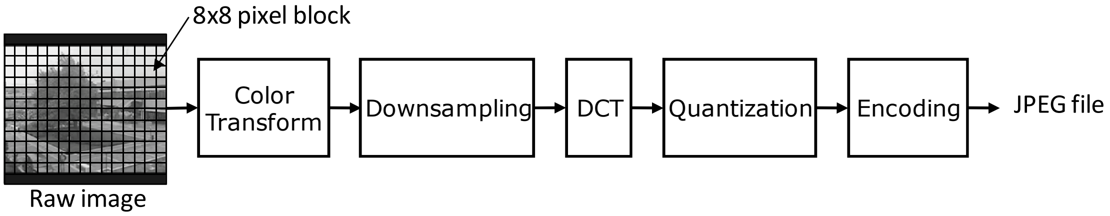

Figure 1. JPEG compression scheme.

A JPEG image consists of a sequence of segments, each beginning with a marker (2 bytes). Some markers consist of just those two bytes; others are followed by payload data and two additional bytes indicating the length of payload data. The first marker is the Start of Image (SOI) and the last one is the End of Image (EOI). The JPEG baseline markers are reported in Table 1.

The header of the JPEG file contains information on the image coding (for example the quantization tables and Huffman tables). The header consists of about 300 bytes, that can by contained in 3 packets of the 802.15.4 standard (maximum payload size is 102 bytes). If the header bytes are corrupted the image cannot be regenerated. In a wireless communication these information must be protected: they can be fixed and transmitted only in the beginning during the creation of the network in a secure way with protection in case of transmission errors, or retransmitted for each image in a secure way. Errors during transmission of the rest of the data cause a degradation of the reconstructed image.

Optional markers (DRI and RSTn) can be inserted in the data stream. DRI specifies the interval between the RST markers. They are used to partition the data in a numbered sequence of blocks so that, if a block is lost during the transmission, the decoder is able to understand in which part of the data stream data are lost and partially recover the information. The RST markers have been used, during the partitioning of the data stream in the packet size of the 802.15.4 standard (maximum payload size is 102 bytes).

Table 1. JPEG Baseline Markers.

name	**marker**	**Payload**	
SOI	0xFF, 0xD8	*none*	**S**tart **O**f **I**mage: At the beginning of the file
APP0	0xFF, 0xE*n*	*variable*	**App**lication Specific: Right after SOI marker, used to identify the JPEG FIF, length, identifier, version, units, Xdensity, Ydensity, Xthumbnail, Ythumbnail, (RGB)n
DQT	0xFF, 0xDB	*variable*	**D**efine **Q**uantization **T**able(s): Specifies one or more quantization tables.
DHT	0xFF, 0xC4	*variable*	**D**efine **H**uffman **T**able(s): Specifies one or more Huffman tables.
SOF0	0xFF, 0xC0	*variable*	**S**tart **o**f **F**rame: Indicates that this is a baseline DCT-based JPEG, and specifies the width, height, number of components, and component subsampling
DRI	0xFF, 0xDD	2 bytes	**D**efine **R**estart **I**nterval: Specifies the interval between the RST*n* markers.
RST*n*	0xFF, 0xD0 … 0xD7	*none*	**R**e**st**art
SOS	0xFF, 0xDA	*variable*	**S**tart **O**f **S**can: Begins a top-to-bottom scan of the image.
COM	0xFF, 0xFE	*variable*	**Com**ment: contains a text comment.
EOI	0xFF, 0xD9	*none*	**E**nd **O**f **I**mage

3. VIDEOSURVEILLANCE ARCHITECTURE AND SIMULATION RESULTS

The architecture investigated in this work is a star topology, reported in Figure 2. The SystemC model of the network is reported in Figure 3. The image sensors compress the image in a JPEG format, they partition the data in payload packets of the size of the 802.15.4 standard (from 8 to 102), and they continuously send images to the Personal Area Network (PAN) coordinator. Up to 5 sensor nodes are considered in the simulations.

In the 802.15.4 standard the effective maximum information rate is about 125 kbps in case of a single node in the channel, when many nodes use the channel the maximum data rate can be about 180kbps [24-25]. Therefore the ideal maximum data rate is 180/5= 36 kbps for each node, and consequently the image dimension should be less than 4,5kbytes to send 1 image per second to the PAN coordinator. The color (YCbCr) images coming from the camera are in CIF format (352x288) with a non compressed size of about 200kbytes, to reach a dimension of 4,5kbytes a compression of 97% must be used. The image size is reduced decreasing the JPEG quality parameter Q, as indicated in Figure 4 that reports image dimension reduction with respect to a JPEG compression with Q=100, as a function of the JPEG quality parameter Q. On the other hand, the quality of the image decreases decreasing the parameter Q.

The sensor nodes continuously send images to the PAN coordinator, and the PAN coordinator responds with an acknowledge packet to each data packet, as indicated in Figure 5. In a non beacon-enabled networks, the nodes are not synchronized and a collision in the channel may occur when the nodes try to transmit at the same time. For the non beacon-enabled networks the 802.15.4 MAC layer uses the unslotted collision avoidance medium access (CSMA-CA) algorithm to access the channel and to reduce the collision probability. When two nodes try to transmit at the same time, they create interference each other and the packets are lost even in absence of additional noise. CSMA-CA algorithm reduces the packet error rate (PER).

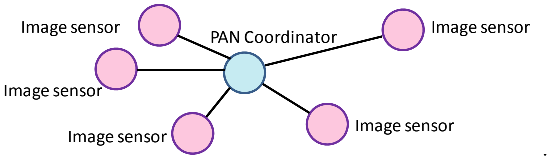

Figure 2. Star topology of the videosurveillance network

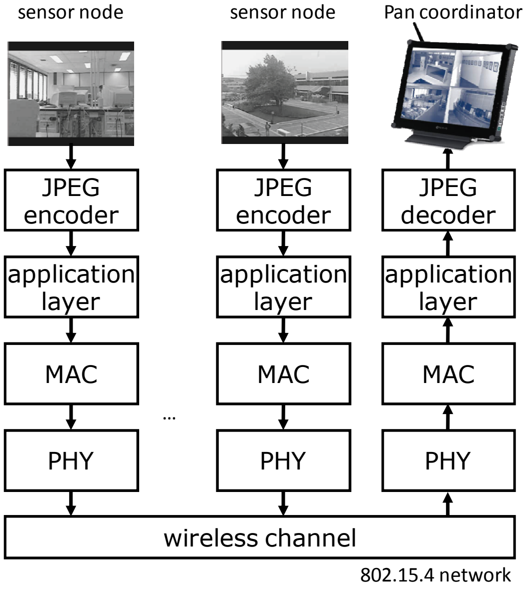

Figure 3. SystemC model of the videosurveillance network

When a collision occur, each device tries to retransmit after a random delay, as represented in Figure 6. If the MAC layer of the device does not receive the acknowledge from the PAN coordinator, due to a collision on the data or on the ack, it retransmits the data up to 3 times (following the 802.15.4 rules of the MAC layer), than the MAC gives up and sends other data. The application layer forces the MAC to retransmit only the header part of the JPEG image till the ack is received. We decided not to retransmit the complete codestream till the ack is received, since this causes an excessive overhead. In this way the image received can be corrupted.

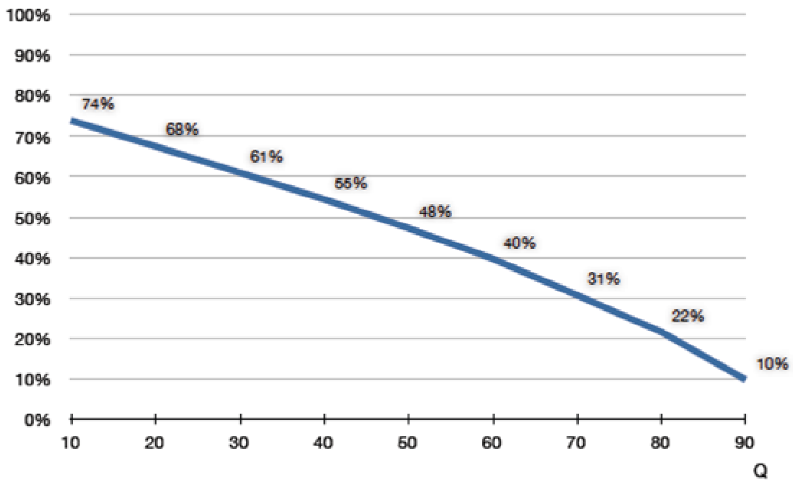

Figure 4. Image dimension reduction with respect to a JPEG compression with Q=100, as a function of the JPEG quality parameter Q.

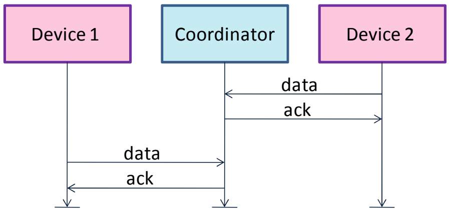

Figure 5. Communication between sensor nodes and PAN coordinator.

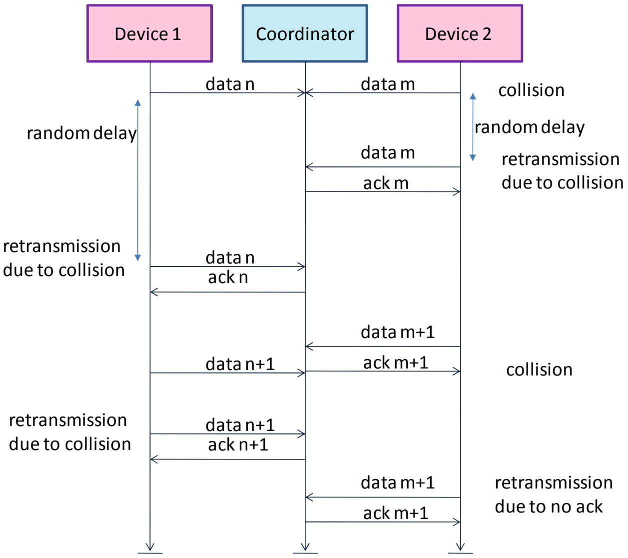

Figure 6. Collisions and retransmissions in the channel due to the CSMA-CA mechanism

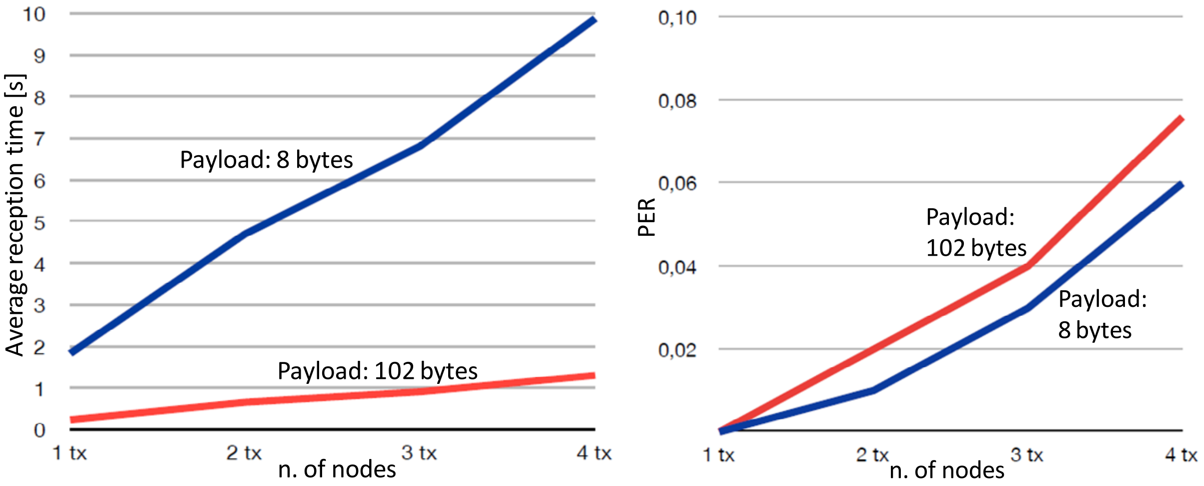

Figure 7. Average reception time and PER as a function of the number of sensor nodes in the device for different payload sizes of the 802.15.4 packet (8 and 102 bytes).

Figure 7 reports the average time for the reception of an image and the PER as a function of the number of sensor nodes in the network for different payload sizes of the 802.15.4 packet (8 and 102 bytes). The results are obtained with a simulation of a network in which all the nodes continuously transmit data with the minimum (8 bytes) and maximum (102 bytes) payload size allowed by the 802.15.4. Considering that a payload of 102 bytes must be used for an image transmission network, where a lot of data must be transmitted, the PER can be relevant and many packets of the image may be lost with a consequent high image corruption.

RST markers have been used, during the partitioning of the data stream in the 102 payload bytes of the packet size, in order to reduce the effect of the packet loss on the image quality. Figures 8-10 show the effect of the presence of RST markers. Figures 8A and 8B show two original images with compression factor Q=50. Figure 9A show image A, coded with restart marker, received by the PAN coordinator in a channel with PER = 3%. Figure 9B show image B, coded with restart marker, received by the PAN coordinator in a channel with PER = 10%. The corruption is evident but the image quality is still acceptable.

Figure 10A show image A, coded without restart marker, received by the PAN coordinator in a channel with PER = 3%. Figure 10B show image B, coded without restart marker, received by the PAN coordinator in a channel with PER = 10%. Compared with Figures 9, the image quality of Figures 10 is not acceptable.

Many simulations of different networks with 1, 2, 3, 4 or 5 sensor nodes have been performed. In the results reported in Figure 11a and 11b, the nodes send continuously images to the pan coordinator. Figure 11a shows the average reception time as a function of the number of network nodes for different JPEG compression factors (Q). Figure 11b shows the transmission efficiency defined as 1-PER.

A low quality factor Q reduces the dimension of the image, and therefore it reduces the time required for the transmission of the image. The increment of the number of nodes increases the traffic in the network, therefore it reduces the effective bandwidth for each node and it increases the Packet Error Rate with a consequent increment of the image corruption.

In previous results, the nodes send continuously images to the pan coordinator. The results shown in Figures 11c-11h have been obtained with networks of 1-5 nodes that send images with different Q values. The nodes insert a waiting time of 10, 20 and 30 ms before sending again a new image. This waiting time reduces the network congestion and therefore the PER. The PER is about 6% for 10 ms idle time, 3% for 20 ms, and 1% for 30ms. The waiting time increases lightly the average reception time, this effect is evident with only one node in the network. On the other hand it reduces the channel congestion and therefore the collisions and PER, this effect is evident increasing the number of nodes of the network.

Finally Figure 12 reports the average reception time as a function of the size of the image for different waiting time between transmissions in a network with 5 nodes. The continuous lines represent the best fitting linear model. The model can be used to make the choice of the Q parameter (that is related to the image dimension) and waiting time in dependence of the desired images per second and PER (related to the image corruption).

4. CONCLUSIONS

The implementation of a low power, low cost wireless 802.15.4 network of a video surveillance system is not simple due to the high bandwidth required by the application and the low bandwidth of the 802.15.4 network.

The proposed SystemC model enables the fast evaluation of the performances of a wireless network based on the IEEE 802.15.4 standard. In this work the performances of a non beacon-enabled network have been evaluated as a function of the number of devices, of the JPEG quality parameter Q and of the frequency with which the nodes try to transmit. The insertion of restart marker is fundamental to reduce the effect of the high PER in a network with a high number of nodes.

The solutions proposed allow the creation of a 802.15.4 wireless video-surveillance network with an acceptable number of images transmitted per second.

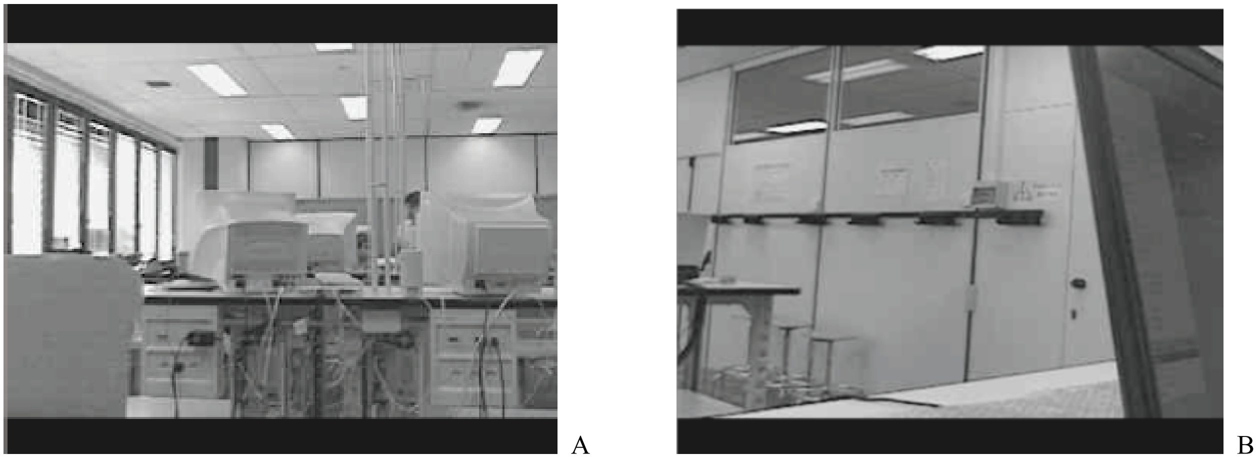

Figure 8. Original images A and B with compression factor Q=50

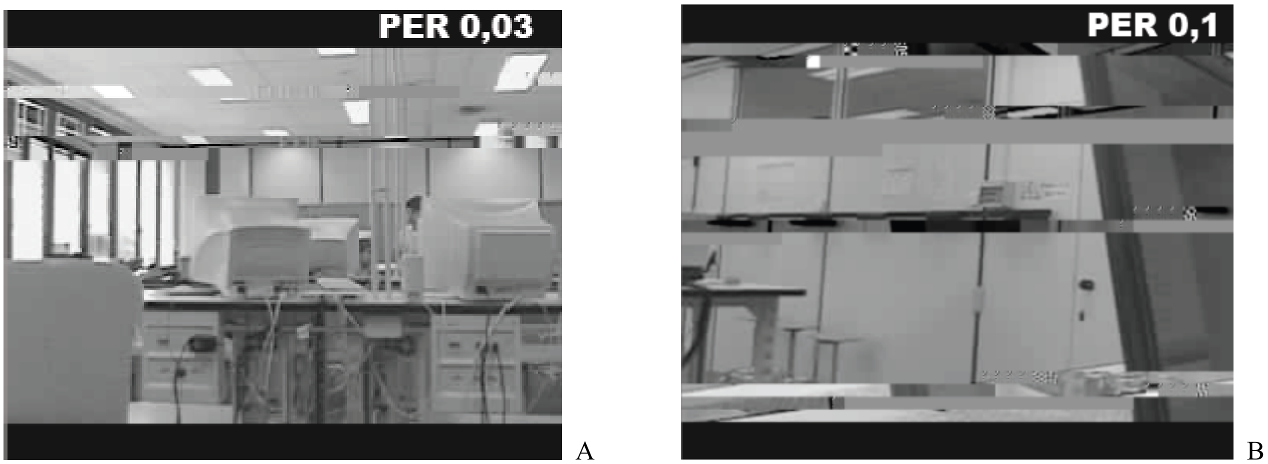

Figure 9. Image A with PER = 3% and image B with PER=10% with restart marker

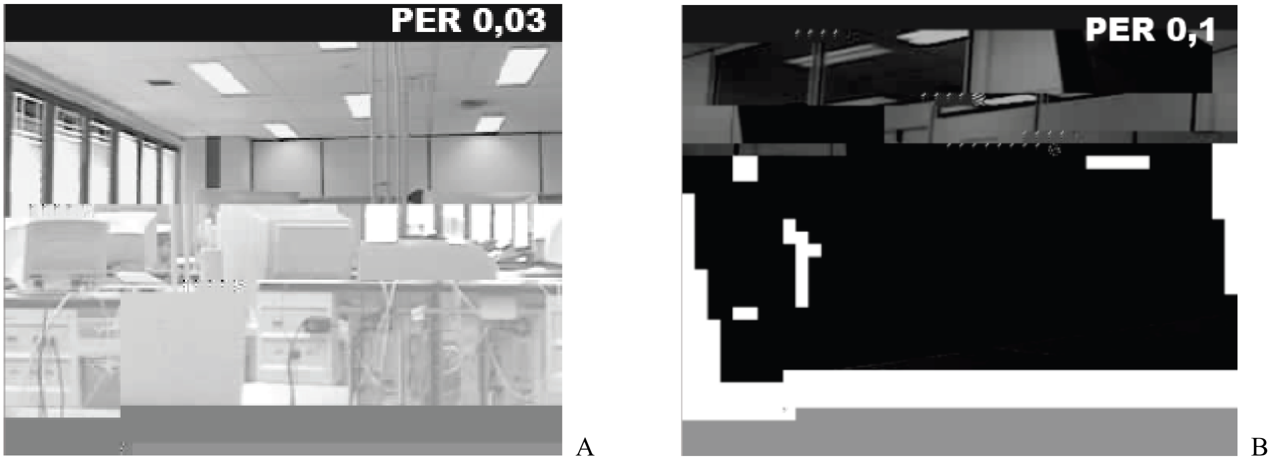

Figure 10. Image A with PER = 3% and image B with PER=10% without restart marker

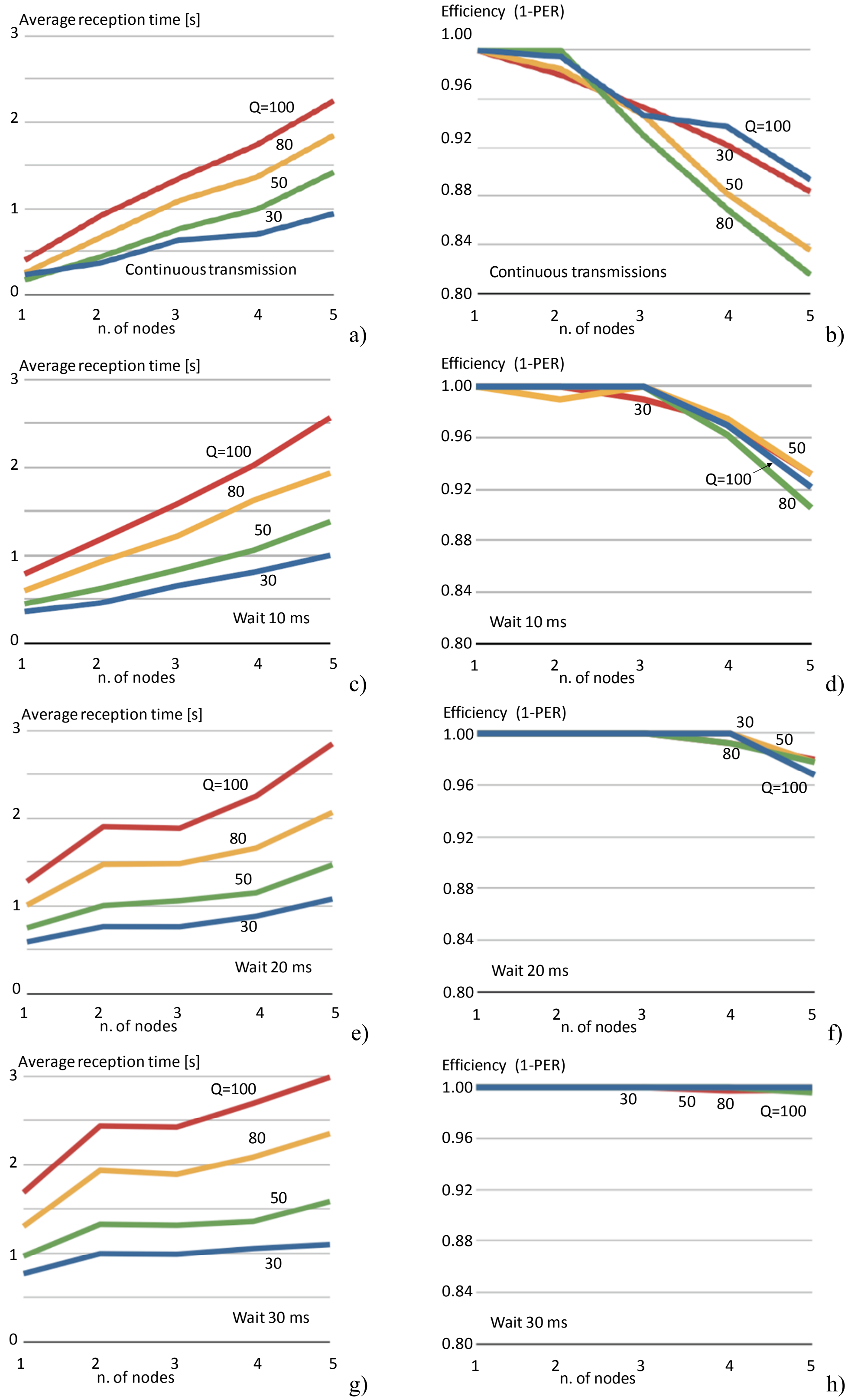

Figure 11. Average reception time and transmission efficiency as a function of the number of network nodes for different JPEG compression factors (Q) and different waiting time between transmissions.

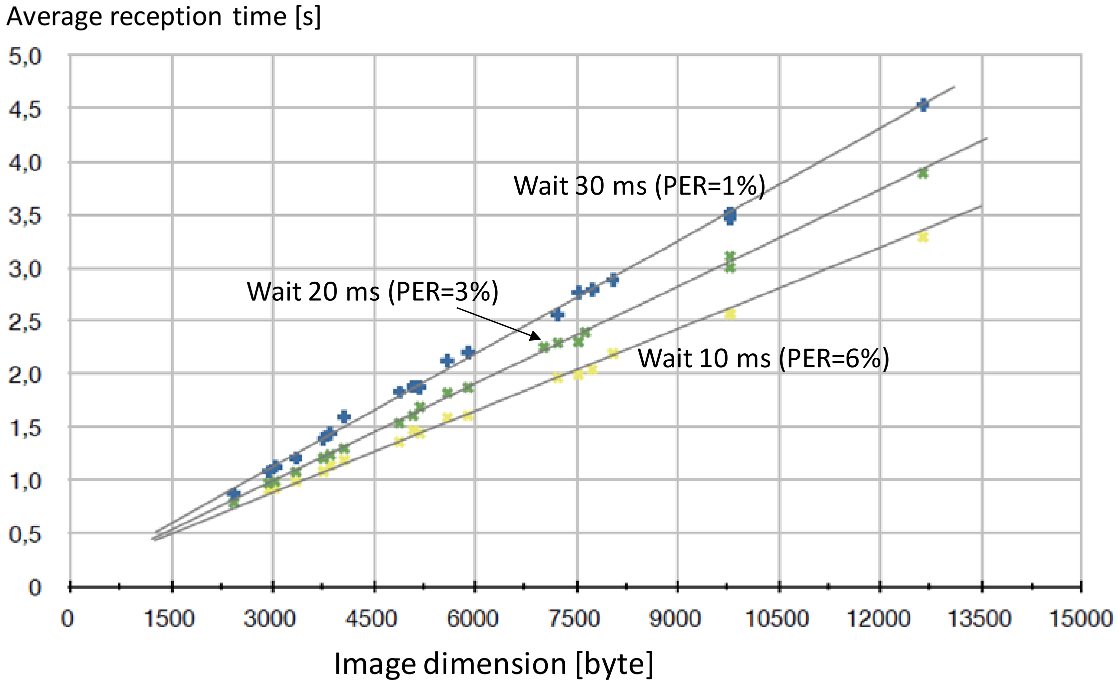

Figure 12. Average reception time as a function of the size of the image for different waiting time between transmissions in a network with 5 nodes.

REFERENCES

[1] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Capirci, " Wireless sensor networks: a survey", Computer Networks 38 (2002) 393–422

[2] Chee-Yee Chong; S. P. Kumar, "Sensor networks: evolution, opportunities, and challenges", Proceedings of the IEEE , vol. 91, n. 8, Aug. 2003.

[3] A. Chandrakasan, R. Min, M. Bhardwaj, S.H. Cho, and A. Wang, "Power Aware Wireless Microsensor Systems", keynote Paper ESSCIRC, Florence, Italy, September 2002.

[4] W. Ye, J. Heidemann, and D. Estrin, "An Energy-Efficient MAC Protocol for Wireless Sensor Networks", In Proceedings of the 21st International Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM 2002), New York, NY, USA, June, 2002.

[5] M.Conti, S.Orcioni, "Smart wireless image sensors for video surveillance", in the book "Intelligent Technical Systems" Springer series "Lecture Notes in Electrical Engineering", vol 38, R.Seepold, N.Martinez (Eds.), 2009, pp.3-16, ISBN-978-1-4020-9822-2.

[6] D.Marcozzi, M.Conti, "Image processing performance analysis for low power wireless image sensors", Proc. of the IEEE Fifth Int. Workshop on Intelligent Solutions in Embedded Systems WISES07, pp.3-14, Madrid, Spain, June 21-22, 2007. IEEE cat.n. 07EX1757, ISBN 978-84-89315-47-1

[7] A. Hampapur, L. Brown, J. Connell, A. Ekin, N. Haas, M. Lu, H. Merkl, S. Pankanti, S., "Smart video surveillance: exploring the concept of multiscale spatiotemporal tracking," IEEE Signal Processing Mag., vol. 22, no. 2, pp. 38--51, Mar. 2005.

[8] G. L. Foresti, C. Micheloni, L. Snidaro, P. Remagnino, T. Ellis, "Active video-based surveillance system: the low-level image and video processing techniques needed for implementation," IEEE Signal Processing Mag., vol. 22, no. 2, pp. 25--37, Mar. 2005.

[9] R. Kleihorst, A. Abbo, V. Choudhary, B. Schueler, "Design Challenges for Power Consumption in Mobile Smart Cameras," in Proc. COGnitive systems with Interactive Sensors (COGIS 2006), Mar. 2006.

[10] M. Rahimi, R. Baer, O. I. Iroezi, J. C. Garcia, J. Warrior, D. Estrin, M. Srivastava, "Cyclops: In Situ Image Sensing and Interpretation in Wireless Sensor Networks," in Proc. 3rd International Conference on Embedded Networked Sensor Systems (SenSys 2005), Nov. 2005, pp. 192-204.

[11] F. Dias Real de Oliveira, P. Chalimbaud, F. Berry, J. Serot, F. Marmoiton, "Embedded Early Vision Systems: Implementation Proposal and Hardware Architecture," in Proc. COGnitive systems with Interactive Sensors (COGIS 2006), Mar. 2006.

[12] I. Downes, L. Baghaei Rad, H. Aghajan, "Development of a Mote for Wireless Image Sensor Networks," in Proc. COGnitive systems with Interactive Sensors (COGIS 2006), Mar. 2006.

[13] Z.-Y. Cao, Z.-Z. Ji, M.-Z. Hu, "An image sensor node for wireless sensor networks," in Proc. International Conference on Information Technology: Coding and Computing (ITCC 2005), Apr. 2005, vol. 2, pp. 740--745.

[14] R. Kleihorst, B. Schueler, A. Danilin, M. Heijligers, "Smart Camera Mote with High Per-formance Vision System," ACM SenSys 2006 Workshop on Distributed Smart Cameras (DSC 2006), Oct. 2006.

[15] M. Bramberger, A. Doblander, A. Maier, B. Rinner, H. Schwabach, "Distributed embedded smart cameras for surveillance applications," in IEEE Computer Mag., vol. 39, no. 2, pp. 68--75, Feb. 2006.

[16] S. Hengstler and H. Aghajan, “WiSNAP: A Wireless Image Sensor Network Application Platform”, 2nd Int. Conf. on Testbeds and Research Infrastructures for the Development of Networks and Communities (TridentCom), March 2006

[17] S. Hengstler, D. Prashanth, S. Fong, and H. Aghajan, “MeshEye: A Hybrid-Resolution Smart Camera Mote for Applications in Distributed Intelligent Surveillance”, Information Processing in Sensor Networks (IPSN-SPOTS), April 2007.

[18] L. Brown, J. Connell, A. Hampapur, M. Lu, A. Senior, C.-F. Shu, Y. Tian, “IBM Smart Surveillance System (S3): A Open And Extensible Framework For Event BasedSurveillance”, Proc. of the Int. Conf. on Advanced Video- and Signal-based Surveillance September 2005.

[19] Yeong-Hyun Kwon, Dong-Ryeol Shin, “The security monitoring system using IEEE 802.15.4 protocol and CMOS Image Sensor”, Proc. of the International Conference on New Trends in Information and Service Science, 2009, pp.1197-1202.

[20] G.Pekhteryev, Z.Sahinoglu,P.Orlik, G.Bhatti, “Image transmission over IEEE 802.15.4 and ZigBee Networks”, Proc. of IEEE ISCAS 2005, Kobe, Japan. pp.3539-3542.

[21] Kyu-Yeul Wang , Seung-Yerl Lee , Byung-Soo Kim , Sang-Seol Lee , Jae-Yeon Song , Dong-Sun Kim , Duck-Jin Chung, “Robust JPEG2000 Image Transmission over IEEE 802.15.4”, Proc. of 4th IEEE International Symposium on Electronic Design, Test & Applications, 2008, pp.253-257.

[22] Pieretti Andrea, Cristiano Scavongelli, Simone Orcioni, Massimo Conti, “Performance analysis of JPEG 2000 over 802.15.4 wireless image sensor network”, Proc. of the IEEE 8th Int. Workshop on Intelligent Solutions in Embedded Systems WISES10, pp. 55-60, Heraklion, Crete, Greece, June 8-9, 2010. ISBN: 978-1-4244-5716-8

[23] ZigBee Specification. s.l. : available at www.zigbee.org, Jan. 2008.

[24] Emanuele Losavio, Simone Orcioni, Massimo Conti, “Performance analysis of 802.15.4 wireless standard”, Proc. of SPIE 2011 International Symposium on Microtechnologies for the New Millennium, Int. Conference VLSI Circuits and Systems.

[25] A.Mignogna, M.Conti, M. D’Angelo, M.Baleani, A.Ferrari, “Transaction Level Modeling and Performance Analysis in SystemC of IEEE 802.15.4 Wireless Standard”, Proc. of the 11th Euromicro Conf. on Digital System Design DSD08, Parma, Italy, Sept. 3-5, 2008

[26] JPEG: Reccomendation ITU-T T.81: Information Technology – Digital compression and coding of continuos-tone still images – Requirements and guidelines – 1992