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The Effect of Packets Relaying on the Implementation Issues of the Visual Sensor Node

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***Abstract*—Wireless Visual Sensor Networks (WVSNs) are used for the monitoring of large and inaccessible areas. WVSNs are feasible today due to the advancement in many fields of electronics such as CMOS cameras, low power computing platforms, distributed computing and radio transceivers. The energy budget in a WVSN is limited because of the wireless nature of the applications and the small physical size of the Visual Sensor Node (VSN). The WVSN covers a large area where every node cannot transmit its results directly to the server. Receiving and forwarding other node's packets consumes a large portion of the energy budget of the VSNs. This paper explores the effect of packets relaying in a multihop WVSN on the implementation issues of the VSN. It also explores the effect of node density in the multihop WVSN on the energy consumption, which in turn, has an impact on the lifetime of the VSN. Results show that the network topology does not affect the software implementation of the VSN because of the relatively high execution time of the image processing tasks on the microcontroller. For hardware implementation, network topology and node density does affect the architecture of the VSN due to the fact that communication energy consumption is dominant (because of the low execution time on FPGAs).**

***Index Terms*—Wireless sensor networks, low power electronics, embedded computing, image communication.**

I. Introduction

Typically Visual Sensor Nodes (VSNs) in Wireless Visual Sensor Networks (WVSNs) consist of an image sensor for acquiring images of the area of interest, Field Programmable gate Arrays (FPGAs) or, a microcontroller for performing image processing tasks, a radio transceiver for communicating the results to the server and an energy resource for providing power to all the other components. The VSN possesses capabilities in relation to performing complex image processing algorithms using limited energy resources due to the technological advancement in various fields of electronics such as Complementary Metal Oxide Semiconductor (CMOS) sensors, radio transceivers, low power computing, embedded systems and distributed computing.

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The WVSNs are suitable for applications having a limited availability of power and in those cases where it is inconvenient to modify the locations of the VSNs or to frequently change the batteries. The large amount of data generated at VSN requires a great deal of energy for processing at the VSN and communication to server.

Both on-board processing and communication influence the energy consumption of the VSN. In the literature, many authors have focused on two implementation strategies for performing image processing tasks either at the VSN or at the server. Some authors have designed a VSN which transmits the raw compressed images to the server for further processing [1]. In this case, the communication energy consumption is high because of the transmission of large chunks of raw compressed data.

On the other hand, some authors have considered performing all the image processing tasks at the VSN and to transmit the final results to the server. In this case, the communication energy consumption is low but the computational energy consumption is high because of the longer processing time of the VSN. An example, representing all the computation at the VSN, is presented in [2] where the authors implemented a distributed vision processing system for human pose interpretation on a wireless smart camera network. They discussed that the motivation behind employing distributed processing is to process the data in real-time and to also provide scalability for developing more complex vision algorithms. By performing local processing at the smart camera, they extracted critical joints of the subject in the scene in real time. The results obtained by multiple smart cameras are then transmitted wirelessly to a server for the reconstruction of the human pose.

Our previous work in [3]–[5] concludes that balancing the computational load between the VSN and the server reduces the overall energy consumption of the VSN. We concluded in [5] that using an FPGA for vision processing, a microcontroller integrated with a radio transceiver for communication and a server for particular vision tasks results in a longer lifetime for the VSN. In [3]–[5], we predicted the lifetime of the VSN for which we considered point to point communication between the VSN and the server.

In a multihop WVSN, each VSN must receive and forward other node's packets, which consumes a large portion of the energy budget and cannot be neglected in predicting the lifetime of the VSN. The effect of node density in a multihop WVSN on the implementation issues of the individual VSN require to be investigated.

This paper explores the effect of the packets relaying and the node density in a multihop network on the implementation issues and the lifetime of the VSN. The remainder of the paper is organized as follows. Section II presents the related work. Section III briefly discusses the suitable Intelligence Partitioning (IP) strategies and provides appropriate references for the detailed information. Section IV elaborates upon the packet relaying in a multihop network. Section V presents the results and Section VI discusses the implications of the results. Finally Section VII concludes the paper.

II. Related Work

In our previous work in [3]–[5], we assumed point to point communication between the VSN and the server and predicted the lifetime of the VSN. The strength of WVSN is to monitor a large and inaccessible area, where every VSN cannot directly transmit its packets to the server because of the limited wireless range of the wireless transceiver and the large area under observation. For such applications, the intermediate nodes receive/forward the packets of the other far away nodes. The energy consumed by the VSN in packet forwarding constitutes a significant portion of their total energy consumption [6], [7] and has an impact on the architecture of the VSN. Consequently, a mathematical model that can accurately predict the traffic load of a VSN is critical for designing reliable VSNs and for accurately predicting their lifetimes.

The authors in [8] described an analytical model which can accurately estimate the traffic load at the distant VSNs in the Wireless Sensor Network (WSN). They considered a typical scenario wherein, the sensor nodes periodically sense the environment and forward the collected samples to a server using greedy geographic routing. Their results show that, irrespective of the radio model, the traffic load generally increases as a function of the node’s proximity to the server.

The traffic load of a given sensor node depends on several factors. The first and, most important, is the relative distance of the sensor node to the server. In general, the closer the sensor node is to the server, the greater is its traffic load. This is because those sensor nodes which are closer to the server have to relay more data packets as compared to the far away nodes. The traffic load also depends on the routing protocol employed in the network because it determines the selection of the next hop sensor node involved in relaying the data towards the server. Lastly, the characteristic of the environment, which affects the radio communication behaviour of the sensor nodes also, has an impact on the traffic load.

In terms of the application, the authors in [8] focused on the periodic monitoring of applications, wherein the sensor nodes sample the environment periodically and forward the collected data to the server. With regards to the routing strategy, which is important for selecting the next-hop node, they have considered the popular greedy routing forwarding scheme [9], [10]. In greedy routing, a sensor node forwards its packets to a neighbour, which, when considering all other possible neighbours, is geographically closest to the server. In doing so, greedy routing can find an approximation to the shortest path in terms of hops between a sensor node and the server [9].

The assumptions made in [8] e.g. periodic sampling, greedy routing etc. are valid for most applications of a WVSN, so we have selected the equations in [8] for predicting the traffic load at the distant VSNs. Our aim is to analyse the effect of the traffic load on the lifetime and the implementation of the VSN. The authors in [8] have analysed two radio models, namely, an ideal radio model and a log normal shadowing model. They showed the traffic load for both the radio models and, by looking carefully at their traffic load plots, we observed that both radio models resulted in almost the same traffic load for all sensor nodes occurring at a distance of 30 meters or more from the server.

Usually, the sensor node are 30 to 40 meters away from the server, which means that either of the two models analysed in [8] could be used for the traffic load analysis in WVSN. We have selected the ideal radio model.

III. Suitable Intelligence Partitioning Strategies

Both local processing and wireless communication consume a large portion of the total energy budget of the VSN. Transmitting the results from the VSN without local processing reduces the processing energy consumption but, the consequence of this is, the higher communication energy consumption due to the transmission of large chunks of raw data. On the other hand, performing all the processing locally at the VSN and transmitting the final results, reduces the communication energy consumption but, the disadvantage of this is in relation to the higher processing energy consumption because of the increased processing at the VSN.

We analysed all the intelligence partitioning strategies based on Fig. 1 for the software implementation (based on SENTIO32) and hardware implementation (based on FPGA) of the VSN and presented the results in [4] and [5] respectively. The interested readers are referred to [4], [5] for an explanation and for the usage of the image processing tasks shown in Fig. 1 as well as for a detailed discussion of the intelligence partitioning strategies.

Thirty six IP strategies are analysed in [5]. Among the 36 strategies, we selected the four most suitable intelligence partitioning strategies for the analysis in the current work. The four selected strategies are to perform the vision processing tasks up to (and including) 1) segmentation, or 2) morphology, or 3) bubble removal or 4) labelling and features extraction at the VSN (the four IP strategies are shown by the dashed lines in Fig. 1). For the first three strategies, the compression is also performed at the VSN and the compressed images are transmitted to the server. In the last IP strategy, where the image processing task up to the labelling and features extraction are performed at the VSN, there is no need for the compression.

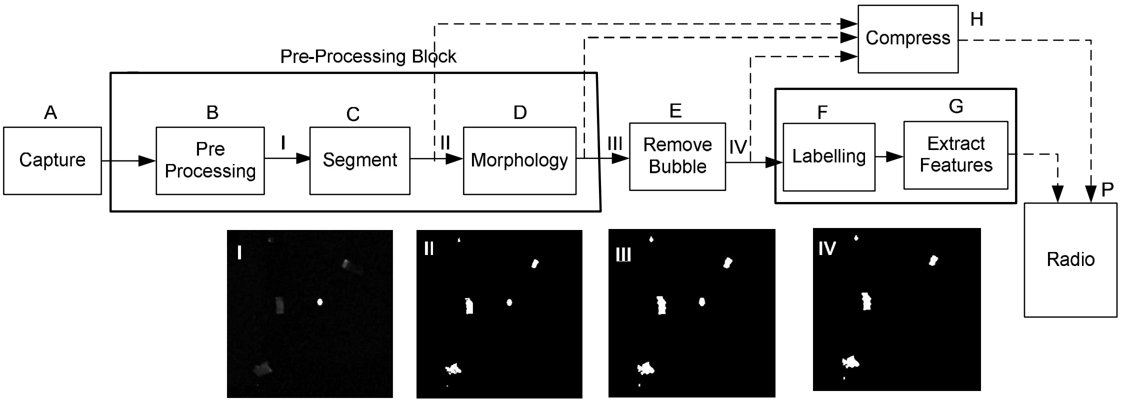


Fig. 1. The suitable intelligence partitioning strategies.

IV. PACKETS RELAYING IN A MULTIHOP NETWORK

In this section, our aim is to determine the traffic load at the distant VSNs in a multihop WVSN. We have also explored the effect of various node densities on the traffic load in the multihop WVSN. The traffic load f(d) of a VSN located at distance *d* from the server, can be calculated using (1) which is borrowed from [8]

$$f(d) = \left\{ \frac{S_t(d)}{\pi(2\mathrm{d} + \varepsilon)\varepsilon\rho} \right\} \frac{1}{(1-q)}, \tag{1}$$

where ε is the quantization interval, ρ is the node density (number of nodes per unit area), q is the packet loss rate in the multihop network and St(d) is given in [8]. Fig. 2 shows the traffic load at the VSNs lying inside a circular region of 200 meters (the assumed area of the WVSN, could be large or small in practical deployments). We determined the traffic load for three different node densities i.e. 0.019, 0.00039 and 0.00019 corresponding to 240, 50 and 25 nodes in the network respectively.

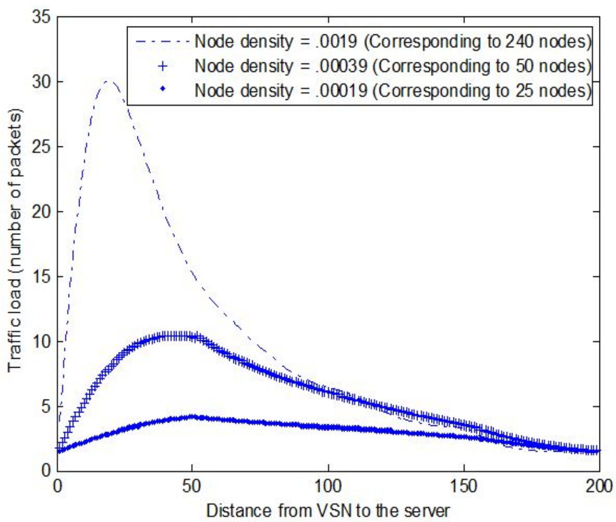


Fig. 2. Traffic loads at distant VSNs.

The lowest curve in Fig. 2 shows that, for a sensor node placed at a distance of 30 meters from the server, the traffic load is four packets. This means that all the sensor nodes at a distance of 30 meters from the server will have, on average, a traffic load of four packets. Relaying four additional packets, consumes energy, which is considered in the lifetime calculation of the VSN in Section V.

Similarly, the middle curve in Fig. 2 shows that for a sensor node placed at a distance of 30 meters from the server, the traffic load is ten packets for 50 nodes in the whole network, which means that all the sensor nodes at a distance of 30 meters from the server will have, on average, a traffic load of ten packets.

V. RESULTS

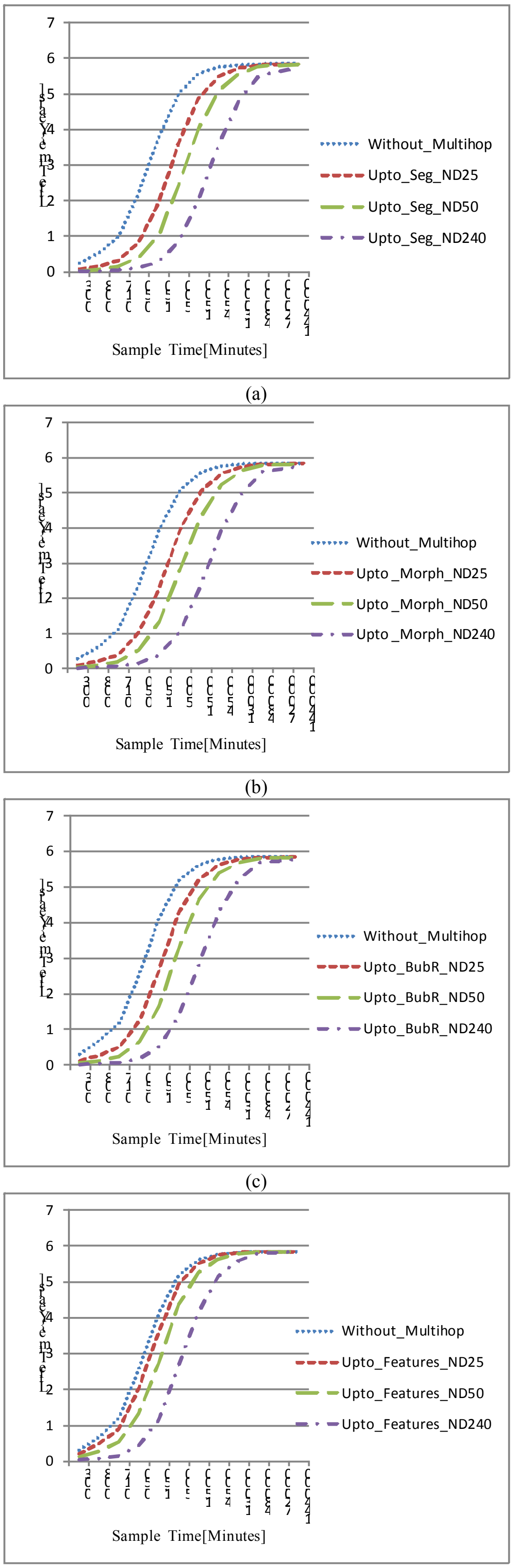
The material in this paper, including the results, form part of the licentiate thesis in [13], but have never been published in any journal/conference proceedings. The traffic loads for the various node densities in the multihop network from Section IV are used to estimate a more accurate lifetime of the VSN.

A. Hardware Implementation of the VSN

We determined the lifetime of the hardware implementation of the VSN for point to point communication between the VSN and the server and presented the results in [5] where we concluded that the best IP strategy is to transmit the compressed image after morphology. The lifetime of the VSN is 5.1 years for a sampling period of five minutes for this strategy.

Figure 3 shows the effect of traffic load in a multihop network with various node densities on the lifetime of the four selected IP strategies. Figure 3 (a) is the IP strategy in which the vision processing tasks up to and including segmentation are performed locally at the VSN and then the compressed image is transmitted to the server. Similarly, Fig. 3(b), Fig. 3(c) and Fig.3(d) are the strategies where the vision processing tasks up to the morphology, bubble remover and feature extraction are performed at the VSN respectively.

The top most curve in all parts of Fig. 3 shows the lifetime of the VSN when it is not a part of the multihop network. Thus, the nodes are not involved in relaying the packets of others nodes, which has resulted in a higher lifetime curve. The second and third top most curves in Fig. 3 show the lifetime curves for the VSN in a multihop network with 25 nodes and 50 nodes respectively. It should be observed that, as the number VSNs increases in the network, the traffic load also increases because an increased number of nodes will forward packets to other nodes. The result of this is an increase in the traffic load in the network, which, in turn, has resulted in a reduced lifetime for the VSN.



(d)

Fig. 3. The impact of node density on hardware-VSN.

Based on these results, we can conclude that packets relaying in a multihop network decrease the lifetime of the VSN. Furthermore, the node density in a multihop network affects the traffic load and hence a higher number of nodes further reduce the lifetime of the VSN. If the number nodes is increased from 25 to 50 in the entire network (for the best IP strategy and sampling period of 5 minutes), then the lifetime of the VSN is reduced from 4.3 years to 2.8 years.

B. *Software Implementation of the VSN*

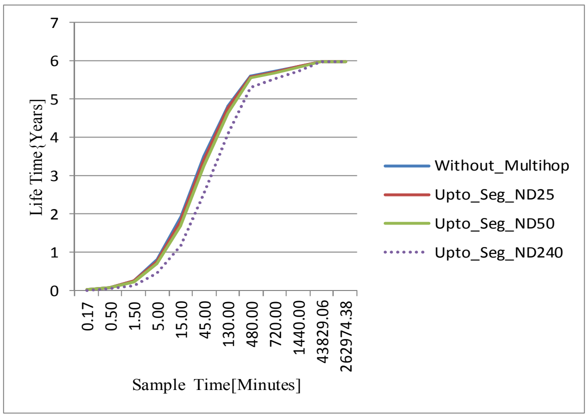
We determined the lifetime of the VSN for point to point communication between the VSN and the server for various IP strategies with regards to the software implementation of the VSN and presented the results in [3] where we concluded that the best IP strategy is to transmit the compressed image after segmentation to the server. The lifetime of the VSN is 4.22 years for a sample period of 15 minutes for this strategy. The difference in the lifetime (5.1 vs. 4.22) of the hardware and software implementations of the VSN must be observed along with the difference in the sampling rate (5 minutes vs. 15 minutes).

Fig. 4 shows the effect of traffic load in a multihop network with various node densities on the lifetime of the four selected IP strategies for the software implementation of the VSN.

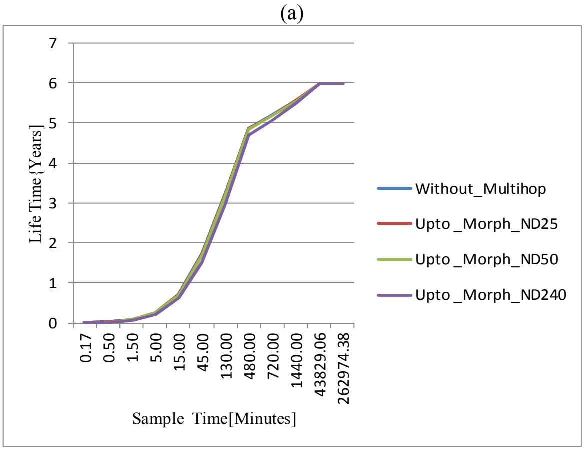
In addition to all the trends observed in Fig. 3, Fig. 4 has another trend namely that all the lifetime curves rest almost on top of each other. The reason for this is the higher processing time of the software implementation of the VSN. This higher processing time leads to higher processing energy consumption and hence the communication energy consumption in relaying other node's packets is comparatively lower. Hence all the curves contracted towards a single curve. This trend is more and more observable when we move from part (a) to part (d) in Fig. 4, because more and more vision tasks are performed at the VSN (up to feature extraction in Fig. 4(d)), which leads to a higher processing time and a dominant processing energy consumption.

We must note that the communication energy consumption is exactly the same in both the hardware and software implementations. However, it is dominant in the hardware implementation because of the low processing energy consumption (due to low processing time on FPGA). On the other hand, the processing energy consumption is dominant in the software implementation of the VSN because of the higher execution time of the image processing tasks on the microcontroller.

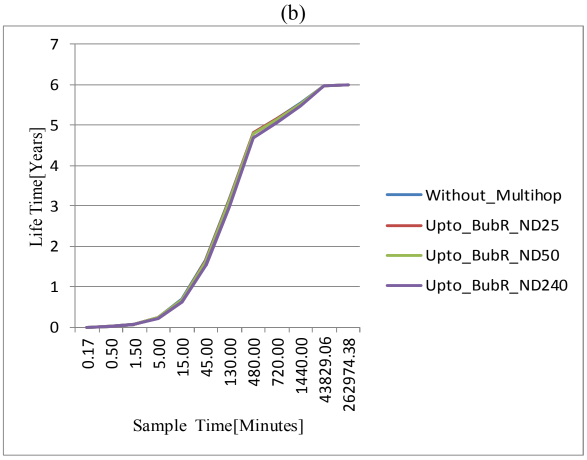
We observed that packet relaying has a severe impact on both the hardware and software implementation of the VSN. Because of the higher processing time of the software implementation of the VSN, the network effect is not dominant and hence implementation optimization is required for increasing the lifetime or the sampling rate. For the hardware implementation of the VSN, the processing time is low and hence the network effect is dominant. Thus, further data compression is necessary for increasing the lifetime or the sampling rate.



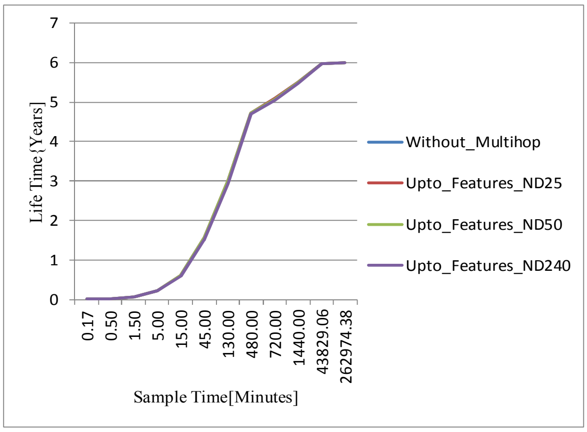
(a)



(b)



(c)



(d)

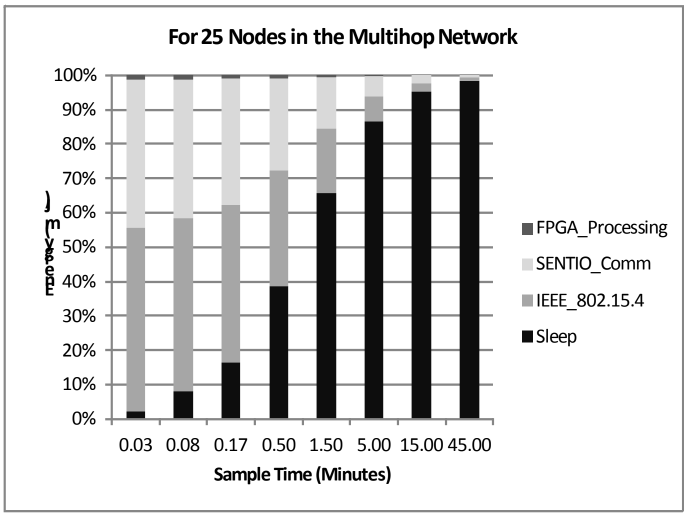
Fig. 4. The impact of node density on software-VSN.

VI. DISCUSSION

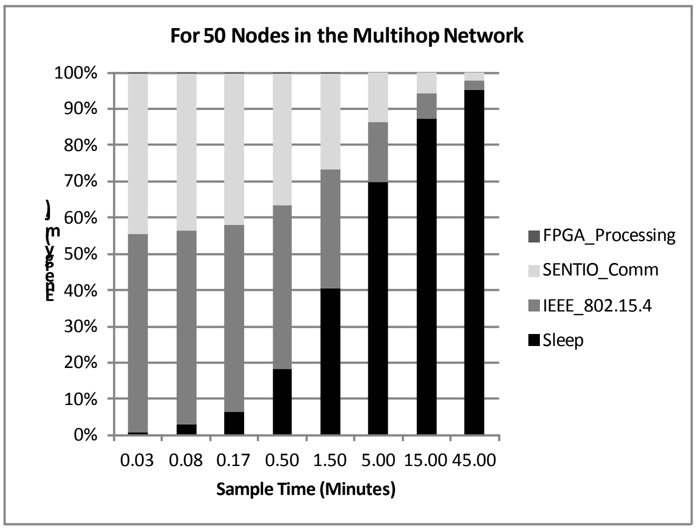
The energy vs. sample time for various components of the VSN for a fully hardware and fully software implementation are shown in Fig. 5 and Fig. 6 respectively. By fully hardware and fully software implementation, we mean to perform all the image processing tasks up to and including the features extraction at the VSN. The SENTIO_Comm and the IEEE_802.15.4 in both Fig. 5 and Fig. 6 is the energy spent by the SENTIO32 board and the radio transceiver for communicating the results to the server.

For the hardware implementation of the VSN, the processing energy consumption of the FPGA is small and the sleep energy is dominant for the higher sampling rate (Fig. 5). Also the communication energy consumption (Both SENTIO_Comm and the IEEE_802.15.4 in Fig. 5) is large compared to the processing energy consumption (FPGA_Processing). By increasing the number of nodes from 25 to 50 in the network (Fig. 5(a) to Fig. 5(b)), the communication energy consumption is increased due to the increased number of packets in the multihop network.

In Fig. 6, the sleep energy consumption is higher for a higher sample rate, but the dominant energy consumption is the SENTIO32_Proc. This is because of the higher processing time for the software implementation. To increase the sample rate and maintain a higher lifetime for the software implementation of the VSN, it is necessary to reduce the processing energy consumption.



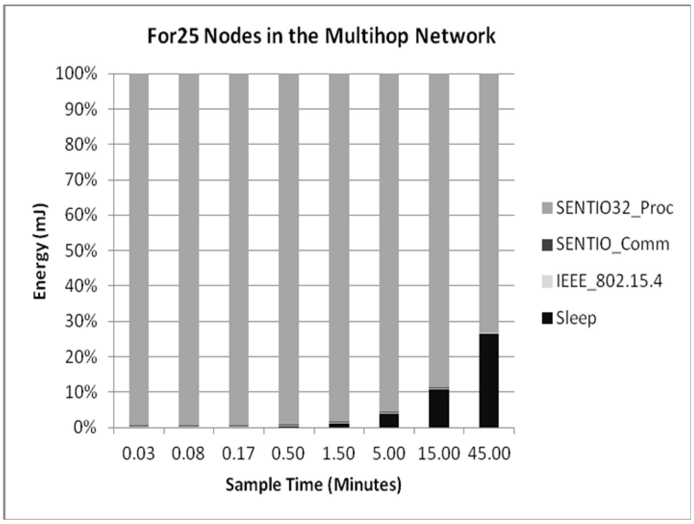
(a)



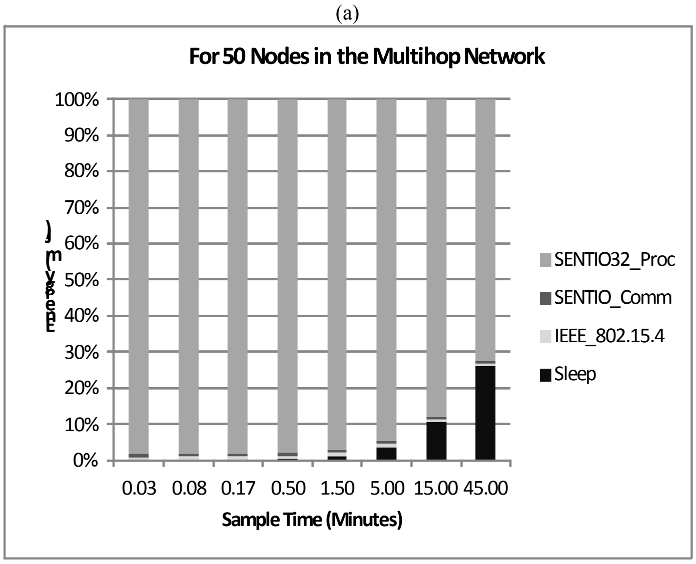
(b)

Fig. 5. The effect of node density on the hardware-VSN.

To increase the sampling rate and maintain a higher lifetime for the hardware implementation of the VSN, the communication energy consumptions must be addressed which mainly depends on the amount of data that is transmitted to the server. Thus, further data compression using some other methods must be investigated for reducing the amount of information and the communication energy consumption (SENTIO_Comm and IEEE_802.15.4).



(a)



(b)

Fig. 6. The effect of node density on software-VSN.

VII. CONCLUSIONS

We have investigated the effect of packet relaying and node density in a multihop network on the implementation issues of a VSN. In terms of lifetime, the hardware implementation proves to be significantly better than the software implementation of the VSN but, its disadvantage is in relation to the increased design and implementation cost. For software implementation of the VSN, the processing time is high because of the sequential execution of the image processing algorithms on the microcontroller. So, computation energy consumption is high and hence network effect is not dominant. For achieving higher lifetime or higher sampling rate for an application, algorithm optimization is recommended for the software implementation of the VSN. It is thus the case that the network topology and the node density do not significantly affect the architecture of the microcontroller based implementation of the VSN. For hardware implementation, the communication energy consumption is high and hence the overhead of the multihop network is dominant. Due to a particular set of constraints for the hardware (FPGA) implementation of the VSN, the selection of the intelligence partition strategy depends on the network topology and the number of hops. In order to increase the sampling rate (often required in surveillance applications) and to maintain a higher lifetime for the hardware implementation of the VSN, it is necessary to address the challenges involved in reducing the output data, so that the energy required for communicating the results to the server is reduced to as low a value as possible.

REFERENCES

[1] L. Ferrigno, S. Marano, V. Paciello, A. Pietrosanto, "Balancing computational and transmission power consumption in wireless image sensor networks", in *Proc. of the IEEE Int'l Conf. on Virtual Environments, Human-Computer Interfaces, and Measur. Syst.*, Italy, July 2005.

[2] W. Chen, A. Hamid, K. Richard, "Real-Time Human Posture Reconstruction in Wireless Smart Camera Networks", in *Proc. of the 7th Int. Conf. on Information processing in sensor networks IEEE Computer Society* (*IPSN 08*), Washington, DC, USA, 2008, pp. 321–331.

[3] K. Khursheed, M. Imran, M. O'Nils, N. Lawal, "Exploration of Local and Central Processing for a Wireless Camera Based Sensor Node", in *Proc. of the IEEE Int'l. Conf. Signal Elec. Syst.*, Gliwice, Poland, Sept. 7–10, 2010.

[4] K. Khursheed, M. Imran, A. W. Malik, M. O'Nils, N. Lawal, T. Benny, "Exploration of Tasks Partitioning Between Hardware Software and Locality for a Wireless Camera Based Vision Sensor Node", in *Proc. of the Int'l Symp. on Parallel Computing in Electrical Engineering PARELEC 2011*, 2011.

[5] M. Imran, K. Khursheed, M. O'Nils, N. Lawal, "Exploration of Target Architecture for a Wireless Camera Based Sensor Node", in *Proc. of the 28th Norchip Conf.*, Tampere, Finland, 2010.

[6] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, E. Cayirci, "Wireless sensor networks: a survey", *Computer Networks*, vol. 38, pp. 393–422, 2002. [Online]. Available: http://dx.doi.org/10.1016/S1389-1286(01)00302-4

[7] W. R. Heinzelman, A. Chandrakasan, H. Balakrishnan, "Energy efficient communication protocol for wireless micro sensor networks", in *Proc. of the 33rd Annual Hawaii Int. Conf. Syst. Sciences*, Hawaii, USA, 2000, vol. 8, p. 8020. [Online]. Available: http://dx.doi.org/10.1109/HICSS.2000.926982

[8] Q. Chen, S. S. Kanhere, M. Hassan, "Analysis of Per-node traffic load in multihop wireless sensor networks", in *IEEE Trans. on Wireless Communications*, vol. 8, no. 2, 2009.

[9] B. Karp, H. T. Kung, "GPSR: Greedy perimeter stateless routing for wireless networks", *in Proc. of 6th Annual Int'l Conf. Mobile Computing Networking*, Boston, MA, USA, 2000, pp. 243–254.

[10] Y. Yu, R. Govindan, D. Estrin, "Geographical and energy aware routing: a recursive data dissemination protocol for wireless sensor networks", UCLA Computer Science Department Technical Report, UCLA-CSD TR-01-0023, 2001.

[11] F. Shu, T. Sakurai, M. Zukerman, H. L. Vu, "Packet loss analysis of the IEEE 802.15.4 MAC without acknowledgements" *Communications Letters IEEE,* vol. 11, no. 1, pp. 79–81, 2007. [Online]. Available: http://dx.doi.org/10.1109/LCOMM.2007.061295

[12] L. Fredrik, C. Peng, B. Oelmann, "Analysis of the IEEE 802.15.4 standard for a wireless closed loop control system for heavy duty cranes", in *Proc. of the IEEE Second Int'l Sympo. on Industrial Embedded Systems (SIES 2007),* 2007.

[13] K. Khursheed, "Investigation of Intelligence Partitioning in Wireless Visual Sensor Networks". Thesis for the degree of Licentiate of Technology, Mid Sweden University Sundsvall 2011.

[14] K. Khursheed, N. Ahmad, M. Imran, M. O'Nils, "Detecting and Coding Region of Interests in Bi-Level Images for Data Reduction in Wireless Visual Sensor Network", in *Proc. of the IEEE 8th Int'l Conf. on Wireless and Mobile Comp., Net. and Comm. WiMob.*