International Journal of Multimedia and Ubiquitous Engineering
Vol.9, No.1 (2014), pp.153-162
http://dx.doi.org/10.14257/ijmue.2014.9.1.15

Adaptive Video-Data Quality Control for Solar-Energy-Harvesting Wireless Sensor Networks

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Abstract

Since solar energy can be harvested periodically, using solar power in wireless sensor networks (WSNs) requires a different approach to energy consumption from typical battery-based WSNs. Meanwhile, it is also challenging to supply enough energy required for heavy operations such as video data encoding and transferring in battery-based WSNs. Therefore, we address the problem of determining the quality of encoding sensory data on the solar-powered sensor node. Based on a simple energy model of the solar-powered node, proposed scheme controls the quality of encoding data adaptively in the way of using the harvested energy maximally. Experimental results demonstrate the efficiency of our scheme.

Keywords: *wireless sensor networks, energy-harvesting, solar energy, QoS*

1. Introduction

Recently environmental energy has emerged as a feasible supplement to battery power for wireless sensor systems in which manual recharging or replacement of batteries is not practical. Especially, solar energy has a power density of about 15mW/cm^3, which compares very favorably with other renewable energy sources. This high power density makes it reasonable to shift the focus in designing a WSN from the minimization of energy consumption to more positive issues of performance. In this paper, we look specifically at the issue of the video quality of the sensory data as a contributor to the performance of WSNs.

As the sensor applications are getting diverse, some WSNs should treat multimedia data such as sound or video. When a sensor node gathers the sound or video, the node should encode the raw data to the promised data format using the standard codec. Generally, multimedia codec consumes more amount of energy to produce higher-quality-data. Moreover, the higher-quality-data tends to be heavier. This fact is very critical in WSNs because the node should send more amounts of data to the neighbors, which means consuming more amount of energy. Therefore, typical battery-based WSNs trade off network-lifetime against the high-quality-data. By using the solar energy recharged periodically, we can address this problem from a different angle.

Our goal is to design a localized algorithm that efficiently determines the encoding quality on each node adapting the residual energy available in that node. This algorithm is operating in the way of using the harvested energy maximally, and thus making the best contribution to the enhancing quality of sensory data gathered from the WSNs. In more detail, our scheme makes each node operate in energy-saving mode (called as ES-node) if that node's residual

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ISSN: 1975-0080 IJMUE

energy is lower than the threshold. In energy-saving mode, the node generates low-quality data, in order to save energy and to minimize blackout time. If a node has more energy than the threshold, it operates in high-quality mode (called as HQ-node) and produces/transfers high-quality data. The interesting fact is that all operations in a high-quality mode do not affect the network-lifetime since they use only the extra energy. Figure 1 shows the overview of our approach.

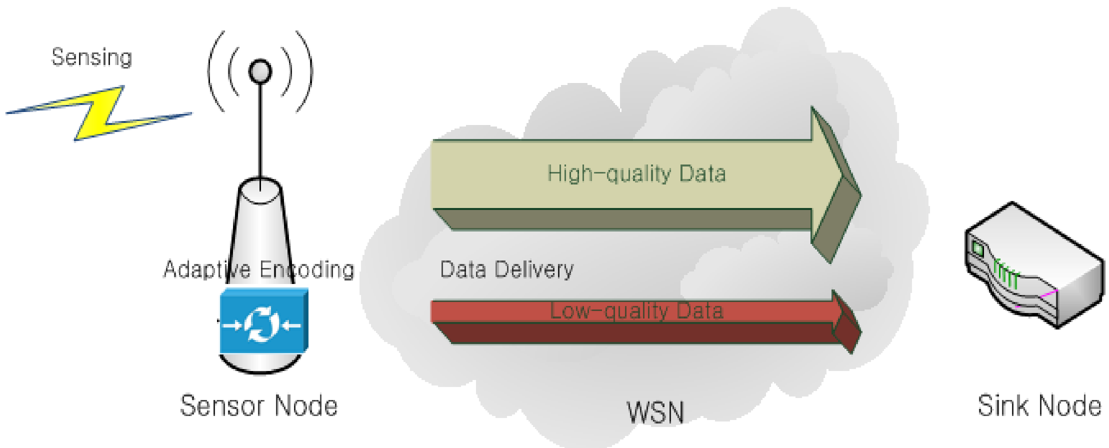

Figure 1. Overview of the energy adaptive video encoding

The rest of this paper is organized as follows: In the next section we review some existing schemes for adaptive video QoS control in WSNs and introduce solar-powered WSNs. We describe how to determine the energy threshold in Section 3, and in Section 4 we explain our energy-aware video-quality control scheme. We then evaluate the performance of our algorithm in Section 5, and draw conclusions in Section 6.

2. Related work

2.1 Solar-powered WSNs

Figure 2 [1] shows power density versus service lifetime for batteries and environmental energy sources. The operating time of a node can be extended indefinitely using energy-harvesting techniques, due to the reusable nature of environmental energy. Among them Solar cells are very popular due to their low cost and high efficiency. However, most research has focused only on hardware design or on prototype solar-powered nodes, rather than on the software services such as data collection or file distribution which are suitable for solar-powered networks. For example, Vijay *et al.*, [2] describe the key issues and tradeoffs which arise in the design of a solar energy harvesting, wireless embedded system and presents a prototype called Heliomote. Cesare Alippi and Cristian Galperti [3] propose a low-power maximum power point tracker (MPPT) circuit specifically designed for wireless sensor nodes to optimally convey solar energy into rechargeable batteries. Nico *et al.*, [4] developed a simple algorithm for ns-2 to simulate energy harvesting for wireless sensor networks. This algorithm is implemented in the energy module of the ns-2 simulator which has not yet contained energy harvesting algorithm. However all above are hardware designs and considerations that have different focuses from this work. A few researchers [5-7] have considered network-wide issues, such as end-to-end latency and throughput, in solar-powered

WSNs; but, to the best of our knowledge, we are the first to look specifically at video-encoding control for enhancing QoS in solar-powered WSNs.

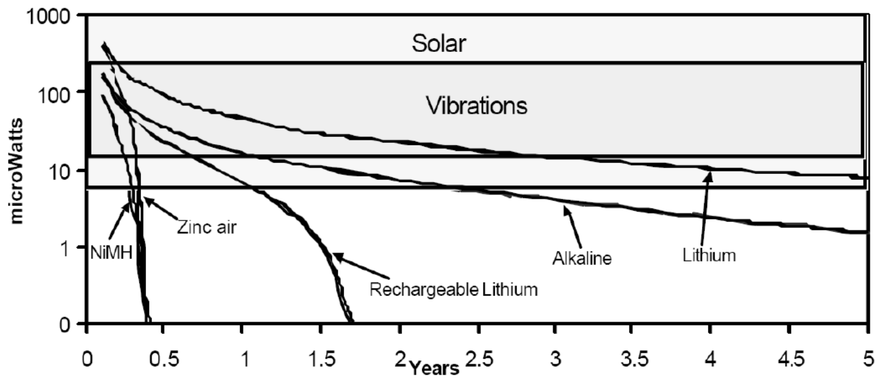

Figure 2. Power density vs. lifetime of different power source

2.2 Adaptive video encoding

According to the [8], "Publication of the first draft versions of DASH specification prompted efforts toward optimization of adaptive HTTP streaming. Most of the publications propose models for better control of network parameters and are concerned exclusively with performance related to underlying network. Proposed solutions include better adaptation logic on client side that implements enhanced bandwidth estimation [9], using specific codecs, namely H.264 Scalable Video Coding extension (SVC) for content preparation instead of H.264 Advanced Video Coding (AVC) in order to allow better caching performance of underlying network and hence better hit ratio [10, 11]. In [12] authors proposed fast estimation of available bandwidth that can be implemented in adaptation logic at the client. All of these proposed solutions either require significant additions to common workflow or they require client side modifications. While the advantages of these approaches were clearly shown in respective publications, content encoding was not addressed." Our work addresses the problem of video encoding to optimize the bitrates used in sensor nodes.

3. Energy Threshold Determination

We use the simple but effective energy model for a solar-powered system, which was suggested in our previous work [7]. Let P_{solar} be the average solar charging rate of the node, and let P_{sys} be its average energy consumption rate. If the residual energy is $E_{residual}$, the expected time when the battery will be full from $E_{residual}$ can be expressed as follows:

$$T_{full}(E_{residual}) = \frac{C-E_{residual}}{P_{solar}-P_{sys}}, \quad (1)$$

where C is the battery capacity.

Note that the battery will only charge when $P_{solar} > P_{sys}$, meaning that the average rate at which the system consumes energy must be less than the average solar power. Otherwise the system will be shut down. Therefore, we assume $P_{solar} > P_{sys}$.

Even though the availability of solar energy varies from day to night and from one day to another, no blackout time is expected between now and the next time the battery is full

($T_{full}(E_{residual})$), as long as the residual charge in the battery at the start of this period satisfies the following condition:

(a) Quantization interval 4 (a) Quantization interval 16

Figure 3. Comparison of video quality for the different quantization

$$E_{residual} \geq P_{sys} T_{full}(E_{residual}). \tag{2}$$

This is true even in the worst case, in which all solar energy charging occurs at the very last instant. From Equations (1) and (2), we obtain $E_{residual} \geq (P_{sys}/P_{solar})C$. This means that the system can run constantly in any environment if it has at least $(P_{sys}/P_{solar})C$ energy. We will call this value the energy threshold $E_{threshold}$. To restate,

$$E_{threshold} = \frac{P_{sys}}{P_{solar}} C. \tag{3}$$

If $E_{residual}$ falls below $E_{threshold}$, then the system can no longer be guaranteed to run without an unexpected shutdown, and a node in this situation needs to concentrate on saving energy. But when $E_{residual}$ exceeds $E_{threshold}$, it starts to allocate energy to enhance video quality.

4. Adaptive Data Quality Control

We use H.263+ [13], which is the famous video encoding protocol, to encode sensory video data. H.263+ can control the compression rate and the quality of video by configuring quantization interval, IP frame rate or motion estimation scheme. Among these, we decide to configure quantization interval [14] to control the video quality. Quantization interval is inversely related to the quantization frequency. Therefore when quantization interval gets larger, the loss of raw data increases, but consumes less energy. The qualities of the video for different quantization interval are shown is Figure 3.

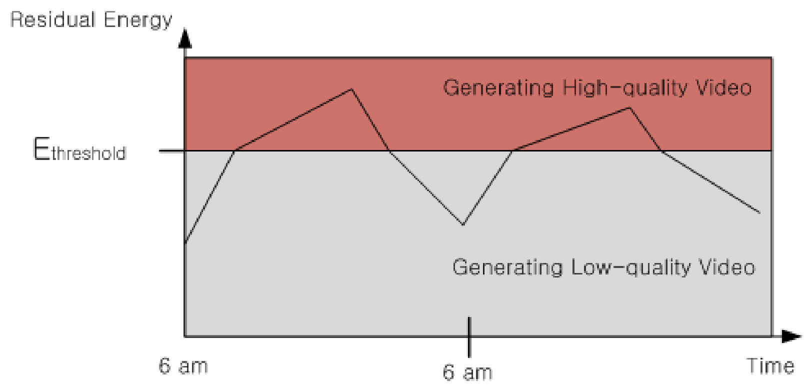

Figure 4. Illustration of the energy adaptive video encoding

For the present, we measure the amount of energy consumption for encoding data ($E_{consume}^{encoding}$) with different quantization intervals. We choose the Asus EEE PC [15] (attached with Linksys router) as the sensor node to support a high-performance sensing application such as video data streaming. An EEE PC is equipped with an Intel 900MHz CPU, 1GB DDR2 and 20GB solid static disk. This consumes only about 10W under moderate load and 15W when heavily loaded (namely, 0.8 A and 1.2 A respectively drained from the 12V rechargeable battery). We measure the current by phidget current sensor [16] from rechargeable battery to the system to calculate the amount of energy consumption. Additionally since the data transfer is one of the main sources of energy consumption in wireless sensor node, we also measure the file size generated by H.263+ encoder varying the quantization interval. The results are summarized in Table 1

According to Table 1, we decide to use the quantization interval 1 for the HQ-nodes and 20 for the ES-nodes, since higher quantization interval than 20 results in an awful quality of video. In detail, then $E_{residual} > E_{threshold}$, the node encodes data using encoder with the quantization interval 1 in order to generate high-quality of video since it has the extra energy. On the contrary, if $E_{residual} < E_{threshold}$, the node encodes data with the quantization interval 20 to preserve the energy for enhancing the network lifetime. Fig. 4 illustrates this operation. For the dynamic adaptation, the node checks the $E_{residual}$ periodically and then invokes the decision process.

Table 1. Energy consumption for encoding data and encoded file size with varying the quantization interval

Quant. Interval	1	4	8	12	20
$E_{consume}^{encoding}$ (mAH)	37	33	29	26	22
File Size (KB)	23100	6360	3725	2028	1196

5. Performance Evaluation

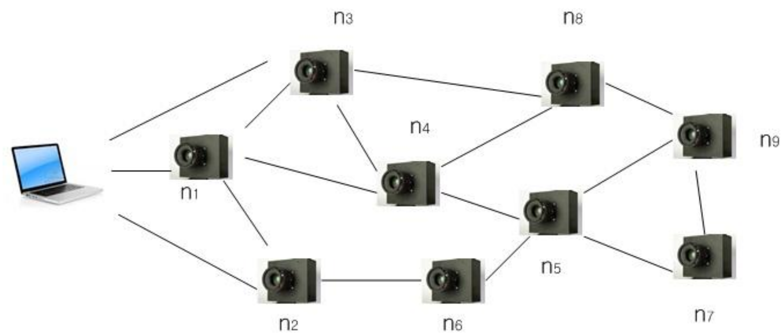

Figure 5. WSN topology deployed for the performance test

We set up indoor testbed for a solar-powered sensor network, which is the same as the one described in the previous publications [7]. The topology we use for the experiment is described in Figure 5. We used the solar-energy data obtained by our outdoor testbed [17] in Urbana, Illinois, during 10 days from OCT. 24th to Nov. 4th, 2011, as shown in Figure 6. The average energy harvested by one node during this period was 30.7Ah at 12V.

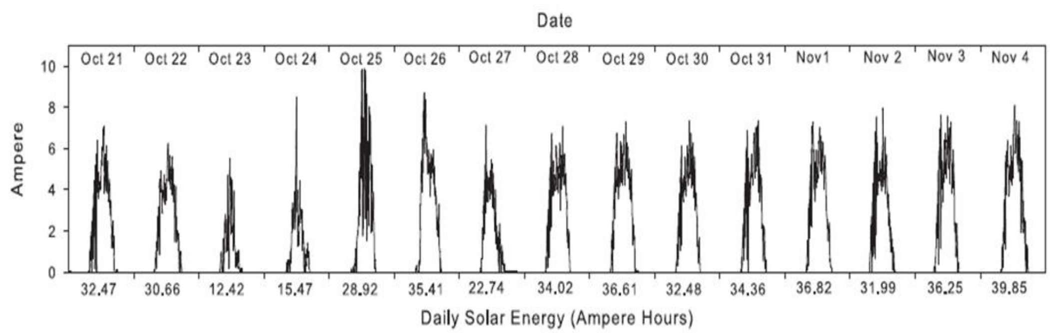

Figure 6. Energy harvested from a node in the outdoor testbed

Figure 7 shows how the residual energy ($E_{residual}$) and the energy threshold ($E_{threshold}$) vary under our scheme in the node n_5. Start with a low residual energy in its battery. For first five days, the residual energy is always below the threshold due to the low rate of energy harvest and the low residual energy. Thus, node n_5 is in a energy-saving mode and produces low-quality video (encoded with the quantization interval 20). In each of the following days, there are always a few hours when $E_{residual}$ is larger than $E_{threshold}$, and thus the node works as a high-quality mode during only these periods of time.

Figure 8 shows the average blackout time of the WSN and the average PSNR of the data gathered from WSN, for the different quantization interval. When the quantization interval is fixed to 1, every node produces and transfers high-quality data. Thus the PSNR, which indicates the quality of the image, is relatively good, but the blackout time is awful. This result is not good for the WSN since it means the WSN is not working stably. When the quantization interval is fixed to 20, the blackout time is nearly zero, which is good for the stable WSN. But the PSNR is the problem. In our adaptive approach, however, the blackout time is nearly zero while gathering relatively nice quality of data.

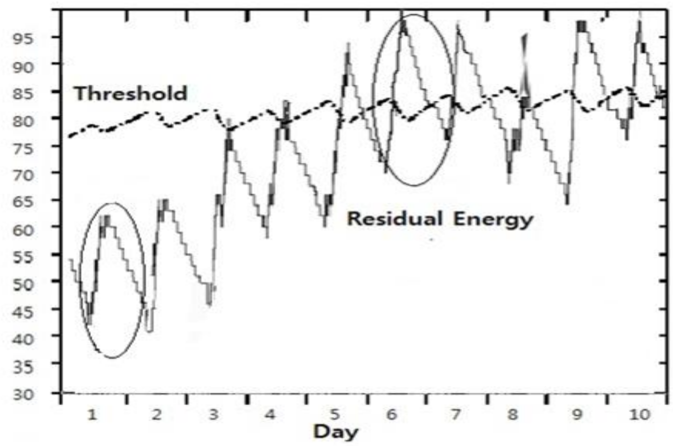

Figure 7. Important values related on the energy in a sample energy-harvesting sensor node (n_5)

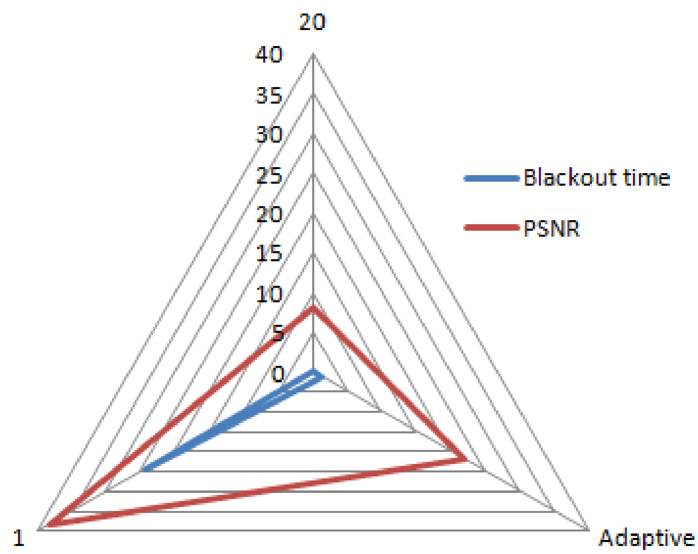

Figure 8. Comparison of the blackout time and PSNR for the different quantization interval

6. Conclusion

Harvesting solar energy is a viable way of supplementing battery power for many remote sensing applications, but it is not easy to make good use of solar energy since its availability depends on the weather and season. Therefore, based on the previous work [7] on effective solar-energy scheme which is independent from these factors, we designed a localized scheme for adaptive control of video quality in this work. This scheme produces high-quality video data only on energy-rich nodes, so as to maximize the utilization of the harvested energy. On the other hand, energy-poor nodes provide low-quality data, so as to minimize the unexpected blackout time of each solar-powered sensor, leading to stable operation. The experimental results demonstrate these contributions.

Acknowledgements

This research was supported partly by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2011-0012996), partly by Industrial Strategic Technology Development Program funded by the Ministry of Knowledge Economy(MKE, Korea)(10039239).

References

[1] S. Roundry, B. Otis, Y. H. Chee, J. Rabaey and P. Wright, "A 1.9GHz RF transmit beacon using environmentally scavenged energy", International Symposium On Low Power Electronics and Design, **(2003)** August 25-27; Seoul, Korea.

[2] V. Raghunathan, A. Kansal, J. Hsu, J. Friedman and M. Srivastava, "Design considerations for solar energy harvesting wireless embedded systems", Information Processing in Sensor Networks, **(2005)** April 25-27; UCLA, Los Angeles, California, USA.

[3] C. Alippi and C. Galperti, "An adaptive system for optimal solar energy harvesting in wireless sensor network nodes", IEEE Transactions on Circuits and Systems, vol. 55, no. 6, **(2008)** July, pp. 1742–1750.

[4] N. N. Encarnacion and H. Yang, "A simple energy harvesting algorithm for wireless sensor networks", Journal of Information and Communication Convergence Engineering, vol. 10, no. 4, **(2012)** December, pp. 359–364.

[5] D. Noh, D. Lee and H. Shin, "QoS-aware geographic routing for solar-powered wireless sensor networks," IEICE Transactions on Communications, vol. E90-B, no. 12, **(2007)** December, pp. 3373–3382.

[6] D. Noh, I. Yoon and H. Shin, "Low-latency geographic routing for asynchronous energy-harvesting wsns", International Journal of Networks, vol. 3, no. 1, **(2008)** November, pp. 78–85.

[7] Y. Yang, L. Wang, D. K. Noh, H. K. Le and T. Abdelzaher, "SolarStore: enhancing data reliability in solar-powered storage-centric sensor networks", The 7th Annual International Conference on Mobile Systems, Applications and Services, **(2009)** June 22-25; Krakow, Poland.

[8] V. Adzic, H. Kalva and B. Furht, "Optimizing video encoding for adaptive streaming over http", IEEE Transactions on Consumer Electronics, vol. 58, no. 2, **(2012)** May, pp. 397–403.

[9] C. Liu, I. Bouazizi and M. Gabbouj, "Rate adaptation for adaptive http streaming", Proceedings of the second annual ACM conference on Multimedia systems, **(2011)** February 23-25; San Jose, California, USA.

[10] Y. la Fuente, T. Schierl, C. Hellge, T. Wiegand, D. Hong, D. D. Vleeschauwer, W. V. Leekwijck and Y. L. Loudec, "idash: improved dynamic adaptive streaming over http using scalable video coding", Proceedings of the second annual ACM conference on Multimedia systems, **(2011)** February 23-25; San Jose, California, USA.

[11] J. -H. Lee and C. Yoo, "Scalable roi algorithm for h.264/svc-based video streaming", IEEE Transactions on Consumer Electronics, vol. 57, no. 2, **(2011)** May, pp. 882–887.

[12] S. -C. Son, B. -T. Lee, Y. -W. Gwak and J. -S. Nam, "Fast required bandwidth estimation technique for network adaptive streaming", IEEE Transactions on Consumer Electronics, vol. 56, no. 3, **(2010)** August, pp. 1442–1449.

[13] I. -T. SG11, "H.263+ public domain codec(tmn3.2)", University of British Comumbia, **(1998)**.

[14] S. Mohapatra, R. Cornea, H. Oh, K. Lee, M. Kim, N. Dutt, R. Gupta, A. Nicolau, S. Shukla and N. Venkatasubramanian, "A cross-layer approach for power-performance optimization in distributed mobile systems", 19th International Parallel & Distributed Processing Symposium, **(2005)** April 3-8 Denver, Colorado.

[15] "Asus EEE PC 900", http://eeepc.asus.com/global.

[16] "Phidget current sensor", http://www.phidgets.com/products.php?product id=1119.

[17] L. Wang, Y. Yang, D. K. Noh, H. K. Le and T. Abdelzaher, "Adaptsens: an adaptive data collection and storage service for solar-powered sensor networks", The 32nd IEEE Real-Time Systems Symposium, **(2011)** November 29 – December 2; Vienna, Austria.

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