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ENERGY HARVESTING AND RECHARGING FOR WIRELESS SENSOR NETWORKS

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Abstract

Minimizing energy consumption for wireless sensor networks lifetime is one of the main problems in wireless sensor networks. The problem is long term autonomous operation of wireless sensor networks. This implies harvesting and recharging the sensor nodes during it is operation by employing the energy harvesting method using the sunlight available. The optimized solar energy harvesting and recharging wireless sensor networks operate for an infinite wireless sensor networks lifetime. The simulation results indicate the highest stability for energy harvesting and recharging the wireless sensor networks that indicates good throughput.

Keywords: wireless sensor network; network lifetime; energy consumption; efficiency energy; energy harvesting.

1. Introduction

The generation of wireless technology is rapidly growing and concurrently demand for power consumption to maintain the network. The wireless sensor network (WSNs) is a self-organizing network and communication function. The WSNs has advantages (e.g., avoid wires, flexibility through physical partitions, easily to add new devices, free, accessible through centralized monitor etc.) The various researchers introduced algorithms and different methods which minimize amount of energy required by WSN during the network communication [1], [2]. Low latency, overcomes the limited factors of each and every sensor node in WSNs. Among suggestive algorithm are Power Efficient Gathering in Sensor Information System (PEGASIS), and energy efficiency using the genetic algorithms suggested [3], [4]. Furthermore, given scarcity of the research onto determinants of implementation in energy harvester and recharging literature [5], [6].

The main contributions of this article are energy harvesting from the available sunlight, recharging the sensor nodes and sensor nodes energy consumption

2. Related Works

The principal indication behind charging batteries for WSN based on energy harvesting technology is to Minimize and eliminate the need for maintaining lifetime for the sensor node. Thus, a common selling argument for energy harvesting is extended lifetime compared to batteries that in turn can enable otherwise, unsustainable network solutions. Recently, simultaneous wireless information and energy harvesting has increased its popularity in modern wireless networks. Energy harvesting has attracted a lot of attention, since it can prolong the lifetime of WSN under energy constraints [7]. Energy harvesting refers to a process by which energy is derived from the surrounding environment (e.g., wind, wave, vibration, solar, and thermal energy), captured, and stored for later use [8].

3. System model for energy harvesting using sunlight

A sensor node with an energy harvester and a small battery for temporary storage can operate indefinitely, in theory, by perpetually replenishing its battery using the harvested energy. The energy available to these nodes is intermittent and varying; making power management, i.e., transmit power and energy storage control, a crucial matter for efficient operation.

For energy harvesting nodes, an energy storage device is desirable to provide such a power policy. In practice, however, this storage device would have storage losses, leakage, and capacity fading. These in turn can affect the optimum transmission policy. The information transmission from the source node to the destination node is assumed to occur via several clusters of decode and forward relay nodes. The source and relay nodes have the ability to harvest energy from the environment and use that harvested energy to transmit and forward the information to the next hop. Under such an assumption, the objective is to improve energy optimization over a number of transmission frames subject to constraints on energy causality, battery overflow, and time duration for energy harvesting.

The block diagram of an energy harvesting and recharging sensor node is illustrated in Figure 1. The solar energy harvesting system provides a direct current (DC) power supply on a conversion system to the WSN node. This voltage is harvested from ambient sunlight by using solar panels [9].

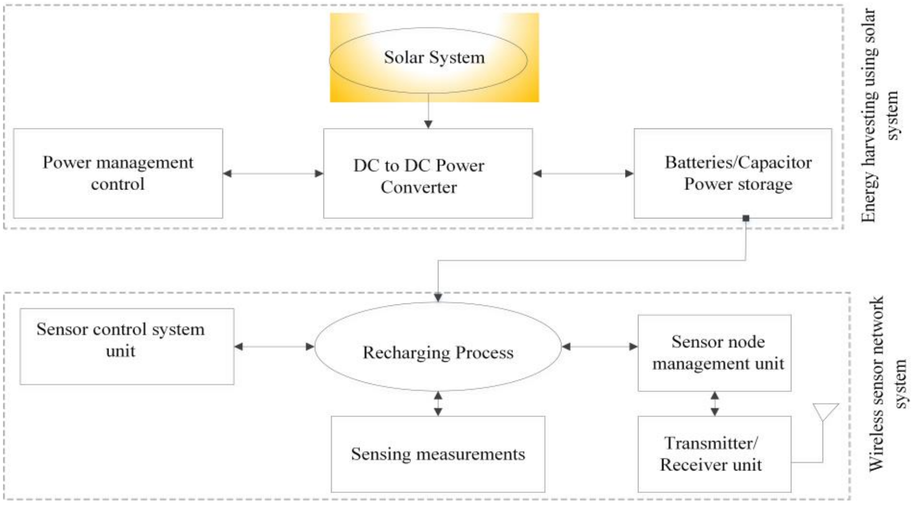

Fig. 1: Block diagram of the energy harvesting and recharging WSN

Furthermore, the technical implementation for the energy harvester and recharging system illustrated Figure 2, a cooperative WSN that consists of one source sensor node denoted as S_0, one destination node S_k and $k{-}i$ as a clusters of relay nodes. The energy harvested in each time frame sequence and recharging the sensor nodes when the energy is below threshold from the sensor nodes. The *kth* cluster is assumed to be composed as M_k relay sink nodes, S_{k1}, S_{k2}, S_{k3}, …., $S_{km}k$ $k = 1, 2, …., K - 1$.

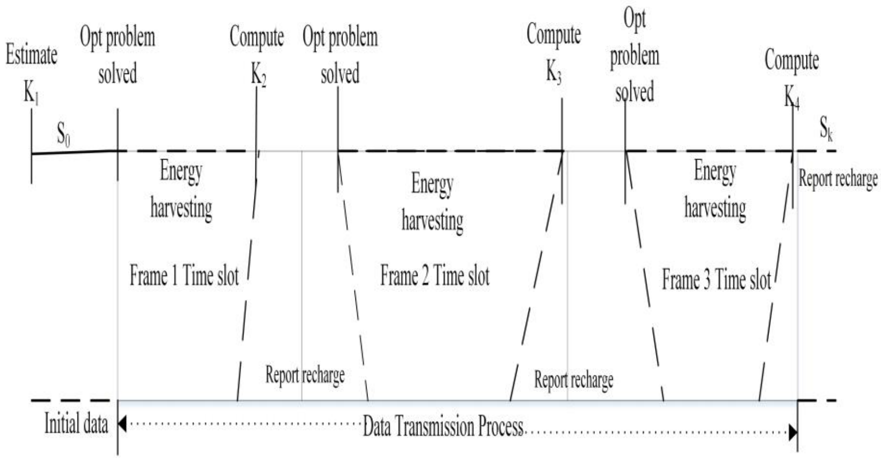

Fig. 2: Energy harvesting optimizing and data processing time frame for WSN

The *'k'* spans frames indexed by f = 1, 2,...,*F* meaning that a lifetime optimization event acts on groups of frames based on each frame time slots. The number of time or time frequency slots in a frame is defined to accommodate the planned number of sensor nodes in the network. The *'F'* is the optimization span. Low mobility or fixed WSN demand less frequent optimization events., large 0F 0, while WSN with high mobility nodes will need frequent optimizations, i.e., small 'f' or even $F = 1$.

The transmission of each node takes place over a time interval consisting of '*N'* transmission blocks frames. As illustrated in Figure 2, each node harvests energy for a fraction $0 \leq \alpha(i) \leq 1$ in the *ith* frame time slot. The remaining $(1-\alpha(i))/k$ fractional of the time slot is subdivided into 'k' hop relaying. First phase of operations S_0 sends data signals to all the relay nodes in the first cluster and each relay node decodes the data. Second phase, the selected relay forwards the decoded data to the relay nodes in the second cluster.

The process is repeated '*k'* times so that the data are delivered to the destination S_k Energy harvested at each node from the surrounding environment can be expressed as [10], [11]. The energy harvesting and recharging method has some parameters and variables for the system model which need to be defined as steps below illustrated:

- **Step 1** The number of sensor nodes is denoted by N, and they are indexed by $n = 1, 2,…,N$. A single sink node is assumed.
- **Step 2** Energy harvesting optimization is denoted by $k = 1, 2,...,k - 1$ as K spans number of frames indexed by $f = 1,2,...,F$, meaning that an energy harvesting and lifetime optimization event acts on groups of

frames as illustrated in Figure 2. The sensor nodes batteries associated with *k-th* optimization and are given by residual energy as $S_{(k)} = S1_{(k)}, S_{2k}, ... S_{F+1}(k)$.

- **Step 3** The recharge matrix is defined as shown Equation 1 representing the amount of energy delivered to the sensor nodes batteries during recharge process.

$$R(k) = [r_1(k), r_2(k)...R_{F+1}\ \varepsilon\ R^{N*F}] \quad (1)$$

- **Step 4** It is defined that the lifetime of a network is the time interval during which all sensor nodes are in full operation. In other words, the instant at which the first sensor node fails with a high probability or fails permanently due to insufficient energy will determine the network lifetime.

The estimated total energy consumption ($E_{consume}$) in amplification, reception, aggregation and data transmission by any sensor node is calculated using Equation (2)

$$\boldsymbol{E_{consume} = E_{Transmit} + E_{receive} + E_{circuit}} \quad \textbf{(2)}$$

whereas ($E_{Transmit}$) and ($E_{receive}$) is the amount of energy consumed during data transmission and reception respectively and ($E_{circuit}$) is the consumed energy by the electric circuitry of a sensor node. Thus, energy consumption by a node 0N0 within the time based on the frame, starting at time (1 − α) (*i*), in a round k_k+1 period is represented by Equations (3) and (4).

$$\boldsymbol{E_{Frameji}(k)} = \int_{Eiconsumei}^{(1-\alpha)i}(k)dk \quad \textbf{(3)}$$

$$\boldsymbol{E_{Framej}(k)} = \int_{\boldsymbol{Ereceivei}}^{(\boldsymbol{1}-\alpha)(\mathrm{i})}(\boldsymbol{k}) + \boldsymbol{E_{circuit}(k)dk} \quad \textbf{(4)}$$

3.1 **Problem formulation process**

The objective is to maximize total stability throughput over frame time slot transmission blocks. Based on the relay selection strategy, the capacity of the *kth* hop can be computed as illustrated in Equation (5). Firstly, *ith* frame slot the *kth* node except for the destination harvest energy with rate *δk. Bk(i)* be the energy available at the battery of the kth node. The total energy of the *(k−1)th* node at the beginning of the *ith* frame slot be equal to the remaining energy from the *(i − 1)*, plus the additional energy that node harvests during each frame time slot. However, the amount of energy at the kth node at the *(i−1)th* frame time slot and the updated value at the *ith* frame time slot have the relation as illustrated in Equation (6).

$$C_k(i) = max\log(1+\Gamma_{km})(i), (m\epsilon 1,2,3...,m_k) \quad (5)$$

$$B_{k-1}(i) = min(B_{k-i}(i-1) - \frac{(1-\alpha(i-1))T}{K} \quad (6)$$

$E_{k-1}(i-1) + \delta_{k-i}\alpha(i)T, B_{k-1}^{max}), k = 1,2,3...,K,$ whereas, (B_k^{max}) maximum capacity of the batteries at

the *kth* node. The total energy for each node must avoid battery overflows [12].

$$f(x) = \begin{cases} \sum_{i=1}^{n+1}(\frac{E_{max}-E_{circuit}}{E_{max}^{\delta}}E_{k-1}^{\delta}(i) + E_{circuit})\alpha(i)T \\ f(x) \leq B_{k-1}^{max}, k = 1,2,3,..K, n = 1,2,3,..N_1 \end{cases}$$

Comparing Equations (2,3,4,5, and 6) then formulating the energy optimizing problem as expressed hereunder;

$$E = \begin{cases} Max_{\alpha} = (\sum_{i=1}^{N}\frac{1-\alpha(i)}{K}min_{E_{k-1}}C_k(i)) \\ Subject \to to, \sum_{i=1}^{n}(\frac{E_{max}-E_{circuit}}{P_{max}^{\delta}}E_{k-1}^{\delta}(i) \\ +E_{circuit}) \leq \sum_{i=1}^{n}\delta_{k-1}\alpha(i) \\ k = 1,2,3,...,K, n = 1,2,3,..,N \\ \sum_{i=1}^{n+1}\delta_{k-1}\alpha(i)T - \sum_{i=1}^{n}(\frac{E_{max}-E_{circuit}}{E_{max}^{\delta}}E_{k-1}^{\delta}(i) \\ +E_{circuit})\alpha(i)T \leq B_{k-1}^{max} \\ k = 1,2,3,...,K, n = 1,2,3,..,N-1, \end{cases}$$

$$|\ where; 0 \leq \alpha \leq 1, i = 1,2,3,..,N \quad \&$$

$$0 \leq E_{K-1}(i) \leq E_{max}, k = 1,2,3,..,K.$$

3.2 Results and Analysis

Following Equation (7) total work required for only one *MICAz* is about 1.353*Joules*. Now for the WSN size with 500 sensor nodes will require about 6.7674*Joules*. Similar formulation calculation can be the same for the $eZ430_RF2500$ sensor node, which is about 6.041*Joules*. When considering the action operation is due every one hour for 24 *hours* a day for a network size, 500*sensornodes* is 162.410*Joules* and 144.960*Joules* for both sensor nodes, respectively. The clarification of formulation calculation is shown in Table I.

$$W(work) = F(force) * D(distance) \qquad (7)$$

The minimum energy which can be harvesting in an area of $1m^2$ per one day is approximately 48*Kilojoules*

Table I

Power utilizing wireless MICAz and $eZ430_RF2500$ sensor node

Type	Nodes	Distance(m)	P (mW)	P used (J)
MICAz	1	100	135.35	0.01
MICAz	500	100	67674	6.77
$eZ430_RF2500$	1	100	120.81	0.01
$eZ430_RF2500$	500	100	60405.75	6.04

and maximum approximately 84*kilojoules*.Therefore, the requirements for the operation of the wireless *MICAz* sensor is about 162.41*Joules* for the network size of 500 in one day,

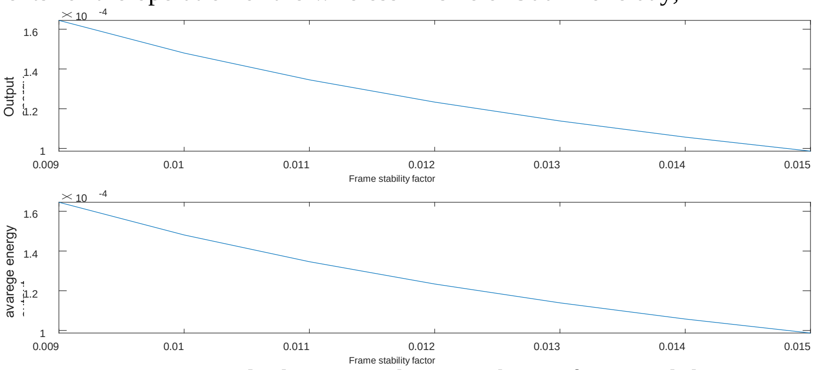

Fig. 3: Residual energy relation with time frame stability

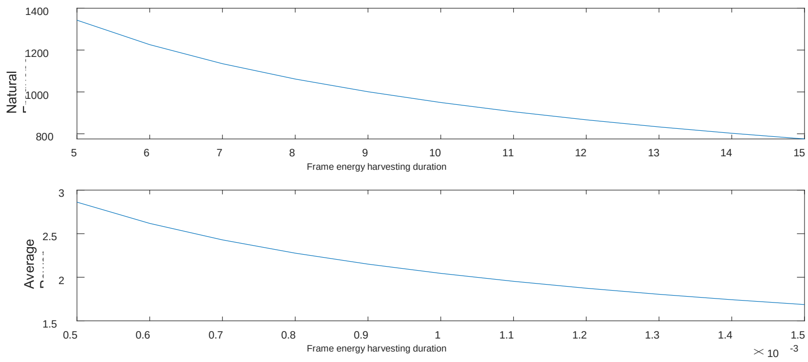

Fig. 4: Average energy harvesting

The distance from the source sensor node S_0 to the destination sink node S_k is denoted as d_0. Consider the cluster as 3 relays as the frame time and their distance is equal; thus, $dk = d, \forall k$ and energy harvesting for all sensor node;$\partial k = \partial, \forall k$. Energy harvesting and recharging for WSN lifetime, the algorithm indicates that the output energy against average energy for the sensor node are correlated based on the frame stability factor for the residual energy against time frame duration. The similar indicates on the natural available frequency based on the energy harvesting on the frame per time slot as illustrated on simulation results Figures 3 and 4. However, the good stability for threshold f_o the harvesting and recharging of the sensor nodes is illustrated in Figure 5.

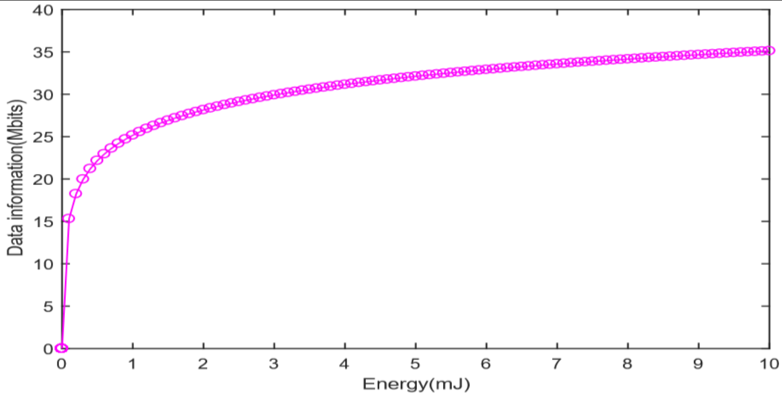

Fig. 5: Threshold energy relationship with data accumulation

Conclusion

The average energy harvesting indicates stable correlated with frame energy harvesting based on average power consumed and natural frequency as shown in Figure 4. Also, the residual energy with time frame stability against the average energy and output consumption energy indicates a decrease with the frames per time slot as shown in Figure 3. Regarding the energy harvesting and recharging investigation, the minimum energy which can be harvested in an area of $1m^2$ per one day is approximately 48 *Kilojoules* and the maximum approximately 84*kilojoules*. Therefore, the requirements for the operation of sample sensor nodes *MICAz* sensor is about 162.41*Joules* for the network size of 500 in one day.

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