SAÜ. Fen Bil. Der. 18. Cilt, 2. Sayı, s. 125-130, 2014 SAU J. Sci. Vol 18, No 2, p. 125-130, 2014

KAA ömür tahmini için basitleştirilmiş bir algılayıcı düğüm enerji tüketimi hesaplama yaklaşımı

Nükhet Sazak[1*], İsmail Ertürk[2], Etem Köklükaya[3]

[1*]Sakarya Üniversitesi, Mühendislik Fakültesi, Elektrik Elektronik Bölümü, Sakarya
[2]Turgut Özal Üniversitesi Mühendislik Fakültesi Bilgisayar Mühendisliği Bölümü, Ankara
[3]Gazi Üniversitesi, Mühendislik Fakültesi, Elektrik-Elektronik Mühendisliği, Ankara

06.12.2013 Geliş/Received, 08.04.2014 Kabul/Accepted

ÖZET

Kullanılabilirlik süresi (ömür), ağın ne zamana kadar işlevsel olarak çalışabileceği temel bilgisini verdiği için KAA uygulama tasarımındaki en önemli konulardan birisidir. Literatürde bir KAA'nın ömrünü belirleme ile ilgili çok sayıda araştırma makalesi olmasına rağmen kesin ve kullanışlı bir tanım üzerinde tam bir uzlaşma yoktur. Sonuç olarak, hepsi gerçekten en iyi tahmini KAA ömür değerini bulmayı amaçlayan bu çalışmalarda çeşitli matematiksel ifadeler verilmektedir. Bu makalede, literatürde yakın zamanda önerilmiş bir KAA ömür hesaplaması yöntemi için KAA ömür üst sınırı belirlemeyi nispeten daha basit ve kolay hale getiren önemli bir yaklaşım sunulmaktadır.

Anahtar Kelimeler: enerji, ağ ömür tahmini, KAA

A simplified sensor node energy consumption computation approach for WSN lifetime estimation

ABSTRACT

Lifetime is probably the most important issue in WSN application design since it gives the basic knowledge how long the network will operate functionally. Although there are many research papers related to determining lifetime of a WSN in the literature, there is not any consensus on a certain and useful definition. As a result, there are various mathematical expressions given in those studies, all genuinely aiming at finding the best estimated WSN lifetime value. In this presented study, we suggest an important revision on the computation of WSN lifetime bounds recently proposed in the literature so that determining upper bound of WSN lifetime becomes relatively simpler and easier.

Keywords: energy, network lifetime estimation, WSN

---

[*] Sorumlu Yazar / Corresponding Author *nsazak@sakarya.edu.tr*

1. INTRODUCTION (GİRİŞ)

Wireless Sensor Networks (WSNs) have a great application potential in various fields. A WSN is simply composed of a number of small and independent sensor nodes. Sensing unit, transceiver, processing unit and power unit are the basic components of a sensor node as depicted in Figure 1 [1]. The dashed components such as location finding system, mobilizer and power generator can also be added according to the specific WSN application requirements..

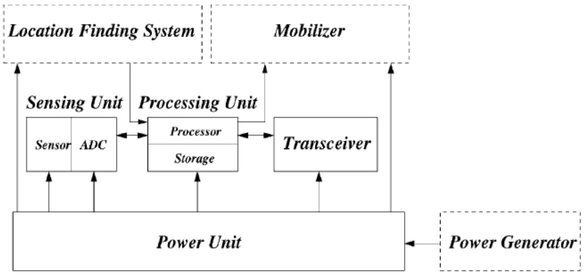


Figure 1. Components of a sensor node (Sensör düğüm bileşenleri) [1]

Batteries are usually used as power source, and recharging or changing them is quite difficult for almost all WSN applications. A sensor node with exhausted battery is regarded as "dead" node. Lifetime is the indicator of how long a WSN operates with full functionality, and knowing that duration has crucial importance. In this paper, we consider the sensor node energy consumption during data transmission to determine the WSN lifetime.

The paper is organized as follows. In section 2, we give a brief summary of WSN lifetime definitions found in the literature. Analytical approach and mathematical expressions for calculating sensor node energy consumption and estimating WSN lifetime are given in section 3. In section 4, a numerical analysis is realized with the help of an example WSN scenario. Finally, we present the conclusions of the study in the last section.

2. LIFETIME OF WSNS (KAA'LARIN ÖMÜRLERİ)

The required lifetime of a WSN may range from several hours to several years depending on the application and its usage. There is no unified definition for the lifetime of WSNs though some different proposals exist in the literature shortly given in this section.

[2] stated the WSN lifetime as "the time span from the deployment to the instant when the network is considered nonfunctional". The time when the network considered as nonfunctional is certainly application-dependent. For instance, it can be that the first sensor node dies [2], a percentage of sensors die [3] or the network partitions and/or the loss of coverage occur. According to [4] network lifetime definitions in the literature can be categorized into three classes. Class 1 includes the references in which lifetime is defined as the time to which percentage of failed sensor nodes exceeds a predefined threshold. Class 2 has the references in which lifetime is considered as the time to emergence of first partition in the network. Finally in Class 3, there are some references in that the lifetime is the time to which the packet delivery rate falls below a predefined threshold. In [4], it is stated that although the time from the instant the network starts operating to the first sensor node failure is the most commonly used definition, it seems too pessimistic. Indeed, considering redundancy of deployed nodes, self-organizing and fault tolerance capabilities of WSNs, the failure of a single node usually does not prevent the functionality of the rest of the nodes. This definition is the most popular one in the literature, and we also use it for our proposed work in the paper.

In this paper, also the lifetime is defined as "duration of the time from the initialization of the network till at least one of the nodes dies" as in [5].

3. A SIMPLIFIED ANALYTICAL SENSOR NODE ENERGY CONSUMPTION COMPUTATION APPROACH FOR WSN LIFETIME ESTIMATION (KAA ÖMÜR TAHMİNİ İÇİN BASİTLEŞTİRİLMİŞ BİR ALGILAYICI DÜĞÜM ENERJİ TÜKETİMİ HESAPLAMA YAKLAŞIMI)

As [5] does, we use the mathematical model for sensor node energy consumption, initially suggested by Alonso et al. [6]. This model considers continuous sensor networks in which sensor nodes read data values and send them in a multi-hop fashion to a centralized base station and then sleep until the next iteration. While the outer sensor nodes only send their data packets, the intermediate ones not only send their own data packets but also transmit the outer sensor nodes' packets. The sensor nodes are partitioned into different spheres (S_0, S_1,… S_k) as shown in Figure 2. Base station (B) is at the sphere 0, $S_0=\{B\}$. S_i represents the set of sensor nodes that can be reached from the base station (B) in i hops and there is no empty S_i. The term balls of radius i denoted B_i is given as $B_i=S_0 \cup S_1 \ldots \cup S_i$. Also $s_i=|S_i|$ and $b_i=|B_i|$ [6].

All sensor nodes are assumed to transmit at the same constant power. The energy consumed in unsuccessful attempts to acquire the channel or messages lost due to collision, bit errors and loss of connectivity is not considered in this basic model [6].

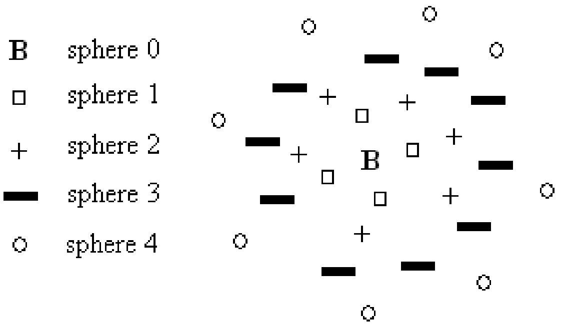


Figure 2. A sensor network partitioned in spheres (Alanlarda bölümlenmiş bir sensör ağı) [5]

E(receive) and E(send) are the energy consumed for receiving and sending operations, respectively. N is the total number of sensor nodes including base station. ($N-b_i$) term is the total number of nodes outside B_i and thus the total number of packets that the set of nodes in sphere S_i receive in each iteration. A lower bound on the energy consumption for a node in Si is calculated by:

$$m_i = \left(\frac{N-b_i}{s_i}\right) x E(\text{receive}) + \left(\frac{N-b_i+s_i}{s_i}\right) x E(\text{send}) \quad (1)$$

When the total number of packets received and transmitted is equally divided among the nodes in S_i, the minimum energy consumption is computed. After computing the minimum energy consumption for nodes in different spheres, the lower bound on the energy consumption of a node in the whole network is found by:

$$\max\{m_1,....m_k\} \quad (2)$$

At each iteration at a node, the total number of packets received cannot exceed N-s0-1 and the total number of packets transmitted cannot exceed $N-s_0$. The upper bound on the energy consumption of a node in the WSN is:

$$\begin{aligned} &E(\text{receive})(N-s_0-1)+E(\text{send})(N-s_0)= \\ &[(E(\text{receive})+E(\text{send}))x(N-s_0)]-E(\text{receive}) \end{aligned} \quad (3)$$

Each node has the same amount of energy that is represented by EE. T_{max} is the maximum number of iterations which a WSN can perform within its lifetime.

$$\begin{aligned} &\frac{EE}{[(E(\text{receive})+E(\text{send}))x(N-s_0)]-E(\text{receive})} \le T_{max} \\ &\le \frac{EE}{\max\{m_1,...m_k\}} \end{aligned} \quad (4)$$

Energy consumptions during unsuccessful attempts to acquire either the channel or messages lost due to collision, bit errors and loss of connectivity are not considered in this work. In unicast traffic, a sensor node overhears all traffic sent by nearby nodes and checks out whether the packet is sent to itself or not. If it is not the intended receiver of the packet, the data packet is discarded. In this presented study, energy consumption during this computation is also ignored as suggested in [5].

4. NUMERICAL ANALYSIS (SAYISAL ANALİZ)

In [5], Tmote Sky sensor motes were used for energy consumption measurement. A Tmote Sky mote [7] features the Chipcon CC2420 radio which is an IEEE 802.15.4 standard compliant radio. The simplified representation of data frame for IEEE 802.15.4 standard [8] is shown in Figure 3.

6 bytes	n bytes	11 bytes
Addressing Fields	Data Payload	Acknowledgement

Figure 3. Simplified version of IEEE 802.15.4 data frame structure (IEEE 802.15.4 veri çerçeve yapısı basitleştirilmiş versiyonu)

Addressing fields include destination PAN identifier (2-byte), destination address (2-byte), source PAN identifier (which is left empty) and source address (2-byte). Hence total length of addressing fields is 6-byte. Data payload is represented by n. Acknowledgement contains preamble sequence (4-byte), start of frame delimiter (1-byte), frame length (1-byte), frame control field (2-byte), data sequence number (1-byte) and frame check sequence (2-bytes). Thus total length of acknowledgement section is 11-byte and length of data frame in total is 17 + n bytes. Therefore,sending 17 + n bytes and receiving 11 bytes are required to transmit an n-byte packet. On the other hand, receiving 17 + n bytes and sending 11 bytes are necessary to receive an n-byte packet.

In [5], the measurement results were obtained for 18 + n bytes since TinyOS adds a TinyOS_IP field with 1-byte. The energy consumption values to receive 1 byte, 11 bytes and 18 bytes were measured as 0.12 mJ, 1.3 mJ and 2.13 mJ, respectively. On the other hand, energy consumption values to send 1 byte, 11 bytes and 18 bytes were measured as 0.12 mJ, 1.32 mJ and 2.16 mJ respectively [5].

By using these energy consumption values, the energy consumed by a sensor node during sending or receiving a packet were given as below [5]:

$$E(\text{send}) = 0.12 \text{ x } n + 3.54 \text{ mJ} \quad (5)$$

$$E(\text{receive}) = 0.12 \text{ x } n + 4.03 \text{ mJ} \quad (6)$$

Let us consider a WSN consisting of 29 Tmote Sky motes as shown in Figure 2. The number of sensor nodes in the spheres is 4, 6, 10 and 8 from inner to the outer. These sensor nodes send packets with 2-byte data payload (n) in every 10 seconds. The outermost sensor nodes send only their own packets. The other sensor nodes, closer to the base station (B), send their packets and also relay packets coming from the sensor nodes at the outer spheres. Tmote Sky motes use 2 AA batteries and this corresponds to 30,780 J energy.

By putting 2-byte as n value into the Equations (5) and (6), we get:

$$E(\text{send}) = 0.12 \text{ x } 2 + 3.54 = 3.78 \,\text{mJ} \tag{7}$$

$$E(\text{receive}) = 0.12 \text{ x } 2 + 4.03 = 4.27 \,\text{mJ} \tag{8}$$

$$s_1 = 4, \quad b_1 = 5, \quad m_1 = 52.08 \,\text{mJ} \tag{9}$$

$$s_2 = 6, \quad b_2 = 11, \quad m_2 = 27.93 \,\text{mJ} \tag{10}$$

$$s_3 = 10, \quad b_3 = 21, \quad m_3 = 10.22 \text{ mJ} \tag{11}$$

$$s_4 = 8, \quad b_4 = 29, \quad m_4 = 3.78 \,\text{mJ} \tag{12}$$

$$\max\{m_1, \ldots . m_k\} = m_1 = 52.08 \text{ mJ} \tag{13}$$

$$\frac{30780}{221.13 \text{x} 10^{-3}} \le T_{\max} \le \frac{30780}{52.08 \text{x} 10^{-3}} \tag{14}$$

$$139194 \le T_{\max} \le 591014 \tag{15}$$

As a result, considering the 10-second intervals for packet sending, the lifetime of WSN can vary between about 387 hours and 1642 hours.

Amiri [5] concludes that S_1 representing the sphere to determine the upper bound is the bottleneck in this example. It is also stated in [5] that the load of packet transmissions can be spread approximately equally on all the sensor nodes and thus the upper bound can be improved by means of better positioning the sensor nodes.

In this presented work, we change the deployment type of sensor nodes on the spheres and calculate the sensor node energy consumption values for the same values given in the above example. The total number of sensor nodes and the total number of spheres are kept constant for fair comparisons. We describe deployment type 1 as sensor node distribution with 4, 6, 8 and 10. The deployment type 2 includes the descending order sensor node distribution with 10, 8, 6 and 4. In the deployment type 3, the sensor nodes are distributed equally at the spheres as 7, 7, 7 and 7. Having computed the energy consumption values at the spheres for each deployment type, the results obtained are given in Table I.

In order to make the comparisons easy, the results given in Table 1 are also presented graphically in Figure 4. As it can be seen from the graphs, node energy consumption at the outermost sphere is same for all deployment types. The reason is that these sensor nodes only send their own packets no matter how many others at that sphere.

Table 1. Energy consumption values for different deployment types (Farklı dağıtım türleri için Enerji tüketim değerleri)

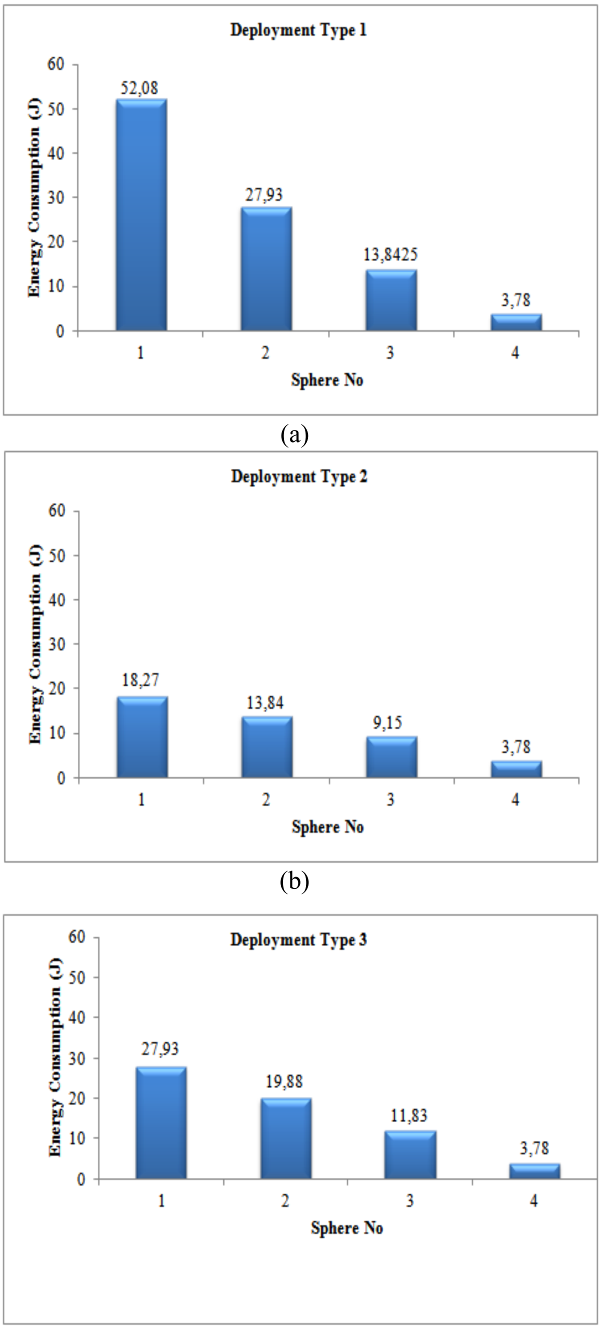
Deployment Type	Sphere No	Number of Sensor Nodes	Energy Consumption (J)
1	1	4	52.08
	2	6	27.93
	3	8	13.84
	4	10	3.78
2	1	10	18.27
	2	8	13.84
	3	6	9.15
	4	4	3.78
3	1	7	27.93
	2	7	19.88
	3	7	11.83
	4	7	3.78

There is yet another interesting point at the results. Although the node energy consumption values at the spheres change depending on the sensor node distribution, the energy consumed at the first sphere is the maximum for each deployment type as expected. Therefore, we conclude that computing only the node energy consumption at the first sphere is enough to determine the upper bound of the WSN lifetime. This result reflects the fact that there is no need to calculate the energy consumption values for all of the spheres then choose the maximum one of them as opposed to the claim in [5].

As one of the most important contributions of this study, we can consequently simplify the formula for obtaining the bounds of the WSN lifetime as given below:

$$\frac{EE}{[(E(\text{receive}) + E(\text{send}))\text{x}(N - s_0)] - E(\text{receive})} \le T_{\max} \le \frac{EE}{m_1} \tag{16}$$

Finally, it could be stated that data payload, total number of sensor nodes and the number of sensor nodes at single hop distance are fair enough to estimate the lifetime bounds of WSN.



(a)

(b)

(c)

Figure 4. Node energy consumption values for three deployment types (Üç dağıtım türleri için düğüm enerji tüketim değerleri)

5. CONCLUSIONS (SONUÇLAR)

In this paper, an improving and simplifying change is proposed for estimating the WSN lifetime by using the formula already known in the literature. Motivation of this presented work is that the computation of energy consumption at the first sphere is fairly adequate for determining the upper bound of the lifetime of WSN, which discarding unnecessary calculations. Therefore, based on our proposed simple approach there is neither need to know the number of sensor nodes at each sphere nor how the sensor nodes are distributed. It simply assures obtaining the same results presented in [5] only using the number of the sensor nodes at the single hop. The distribution of sensor nodes in ascending/descending order or equally has no effect at all on determining the upper bound of the WSN lifetime. Receiving and sending energy consumption values, total number of sensor nodes, the number of sensor nodes at the one hop distance and battery energy value of the sensor node are enough to determine the lifetime bounds of WSNs.

REFERENCES (KAYNAKLAR)

[1] Akyildiz, I.F., Su, W. and Sankarasubramaniam, Y., (2002) 'Wireless sensor networks: A Survey', Computer Networks, vol. 38, pp. 393-422.

[2] Chen, Y. and Zhao, Q., (2005) 'On the lifetime of wireless sensor networks', IEEE Communication Letters, vol. 9, no.11, pp. 976-978.

[3] Deng, J., Han, Y., Heinzelman, W. and Varshney, P. (2005) 'Schedule sleeping nodes in high density cluster-based sensor networks', Mobile Networks and Applications, vol. 10, no. 6, pp. 825-835.

[4] Mak, N. H. and Seah, W.,(2009) 'How long is the lifetime of a wireless sensor network?', International Conference on Advanced Information Networking and Applications, AINA'09, May, pp. 763-770.

[5] Amiri, M.,(2010) 'Evaluation of lifetime bounds of wireless sensor networks', Computer Research Repository (CoRR), vol. abs/1011.2103.

[6] Alonso, J., Dunkels, A. and Voight, T., (2004) 'Bounds on the energy consumption of routings in wireless sensor networks', In Modeling and Optimization in Mobile Ad Hoc and Wireless Networks, Cambridge, UK, March.

[7] Tmote Sky Datasheet, [Online], Available: http://sentilla.com/files/pdf/eol/tmote-sky-datasheet.pdf [03 Aug 2013].

[8] IEEE Std. 802.15.4-2003-Wireless Medium Access Control (MAC) and Physical Layer (PHY) specifications for Low Rate Wireless Personal Area Networks (LRWPANs), [Online], Available:

http://standards.ieee.org/getieee802/download/802.15.4-2003.pdf ,[15 Aug 2013].