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Energy Consumption Modelling Of A Multisensor Node With Non-Uniform Sensors Data Capture Cycle Times

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Abstract—**In this paper, energy consumption modelling of a multisensor node with non-uniform sensors data capture cycle times is presented. In practice, the different sensor units in a multisensor node have their individual data capture duration and inter-data capture time or data capture repeat time. Sample multisensor node with six sensor units that have non-uniform sensor unit's data capture cycle times is used to present the approach. Requisite equations are presented along with the case study multisensor node time and current parameters. The case study multisensor node has cycle time of 1800 s, the active state time of 366.61 s and the sleep state time of 1433.39 s. The average current of 19.25 mA was obtained which for a battery with capacity 3000 mAh, gave battery lifetime of 156.0 hours. The approach presented in this paper helps to overcome the error in managing the non-uniform timeline in multisensor node.**

Keywords: Energy Consumption, Multisensor Node, Non-Uniform Sensors Data Capture Cycle Times, Battery Lifetime

1. INTRODUCTION

The current trend in wireless LoRa-based sensor application in Internet of things, as well as in smart technologies has prompted numerous researches on the issues that may affect such sensor operations [1,2,3,4]. Notably, energy consumption models have been developed for LoRa based sensor nodes to determine the average current drawn by the sensor in each cycle and the expected battery lifetime [5,6,7,8,9,10].

Several works on this topic have focused on LoRa sensor node with single sensor unit. However, in this paper, the focus is on multisensor node [11,12,13]. In such node, there are two or more sensor units in a single node. In such case, the different sensor units may have their unique data capture time and data capture repeat time. Specifically, a sensor unit may have more than one data capture activities in each sensor node cycle time. Such issue affect the energy consumption computation model which is required to account for the multiple activities per sensor node cycle. Accordingly, in this paper, an approach to effectively model the multisensor node with non-uniform sensor data capture cycle times is presented. The approach is applied to a case study multisensor node and the result is compared to that presented in existing study on similar multisensor node.

2. METHODOLOGY

2.1 The basic concepts for the model for computing the average current for multi-sensor node

In the multi-sensor node there are more than one sensors in the node for capturing the data and there is one transceiver that does the transmission and reception and also one microcontroller that controls the entire sensor node. In practice, the different sensor units in a multisensor node have their individual data capture duration and inter-data capture time or data capture repeat time. In this case, the first thing is to identify the total number of the Sensor Node Components (SNC), in the multisensor node that are going to be considered in the energy consumption model. Also, the number of states that each of the SNC in the node can have.

Let there be nx sensor node components (SNC) in the multisensor node, this includes the sensors, the microcontroller and the transceiver that are considered in the energy consumption model [14,15,15,16,17]. Also, let there be nst number of states the node undergoes. For instant, for a node that undergoes 13 states (hence nst =13 including the sleep state). Also, each of the nx components are modelled in each of the nst states of the nodes. The main task of the energy consumption model is to compute the average current, I_{avg} based on the normalised average current $I_{Navst(k)}$ per cycle and the SNC specific cycle time $\boldsymbol{t_{Ncy(k)}}$ in each of the node state k, and where the normalization parameter is the duration of sensor node cycle time, t_{cycl} where,

$$I_{avg} = \frac{(I_{Navst(k)})(\boldsymbol{t_{Ncy(k)}})}{t_{cycl}} \quad \text{for k = 1,2,3,…nst} \qquad (1)$$

2.2 Sample multisensor node with non-uniform sensors data capture cycle times

Sample multisensor node with non-uniform sensors data capture cycle times is used to present the approach for determining the average current and battery lifetime for multisensor node with non-uniform sensors data capture cycle times. Specifically, the multisensor node with 6 sensors, a microcontroller and a transceiver presented in the work by Bhattacharjee, et.al [18] is considered. The transceiver can be in three states, transmit, receive and sleep or standby state. The microcontroller can be in active and standby (sleep) states while each of the six sensors can be in two states active (or measure data) and standby (sleep) states. The data on the current consumption of the multisensor node components are given in Table 1. According to the Iavg computation presented in [18] the current drawn by the microcontroller is ignored, the standby or sleep current drawn by the components of the sensor node in any of the active states is ignored. However, all the sleep current in the sleep state by all the components are lumped together and given a value of 0.25.

Table 1 The data on the power consumption of the multisensor node components (Source: [18])

Component	*Current consumption*
MCU idle: CPU off Peripherals on	5.8 μA
Sleep mode	0.1 μA
Radio transmit at 0db output power	21.2 mA
Radio receive at 0db output power	13.3 mA
Temperature sensor DS18S20	4mA
Light sensor TSL235R	3mA
Humidity sensor module	2mA
Carbon Monoxide sensor MQ-4	80mA
Methane CNG Gas Sensor MQ-7	155mA
Hydrogen and Carbon Monoxide sensor TGS2600	65mA

In this case, there is a total number of 8 components, (that is nk = 8) in the multisensor node that are going to be considered in the energy consumption model, where there is 6 sensor, a microcontroller and a transceiver. Also, based on the description of the multisensor node operations in [18], the number of states, nst that the various nk components in the node can consume energy are identified as follows:

State 1: Measure data state which involves only the 6 sensors with six sub-states

State 2: Transmit data state which involves only the transceiver

State 3: Receive data state which involves only the transceiver

State 4: Standby state which involves all the components but the current is lumped together and given a value of 0.25 mA and the time will be computed from the cycle time, t_{cycl} and active time of the node

2.3 Model for computation of the average current and battery lifetime for a multisensor node with non-uniform sensors data capture cycle times

The input parameters for computation of the average current of each sensor node component (SNC) and each state in the multi-sensor node are shown in column 1, 2, 3, 4 and 5 of Table 2. In Table 2 the sensor node cycle time is 1800 s. Now, if nx is the number of sensor node components that are present in the node state k, then the given cycle time for each component x in k state, $t_{cy(x,k)}$, the given time duration of activity for each component x in k state, $t_{st(x,k)}$ and the given current drawn by each component x in k state, $I_{st(x,k)}$ are used to compute the average current, $I_{avst(x,k)}$ drawn by each component x in state k as follows;

$$I_{avst(x,k)} = \frac{(I_{st(x,k)})(t_{st(x,k)})}{t_{cy(x,k)}} \quad \text{for x = 1,2,3,…nsx and k = 1,2,3,…,nst} \qquad (2)$$

The normalising time, t_{cycl} for all the SNC is selected as the sensor node cycle time, 1800s and the normalised average current, $I_{Navst(k)}$ for each state k with respect to t_{cycl} is computed as follows;

$$I_{Navst(k)} = \frac{(I_{avst(x,k)})(t_{cy(x,k)})}{t_{cycl}} \quad \text{for k = 1,2,3,…,nst} \qquad (3)$$

Therefore, the required current and time for modelling the node average current, I_{avg} is given as;

$$I_{avg} = \sum_{k=1}^{k=nst} (\boldsymbol{I_{Navst(k)}}) \quad \text{for k = 1,2,3,…nst} \qquad (4)$$

Once I_{avg} is known, the battery lifetime in hours, t_{Lh} is computed as;

$$t_{Lh} = \frac{C_{bat}}{I_{avg}} \qquad (5)$$

The state chart shown in Table 2 is used to visualise the multisensor node states and the components involved in each of the states. The data on the current drawn by each components and the duration they spend in each state are extracted from the following operation specifications presented in [18], and shown in Table 1 and Table 3 which is as follows;

- When sensing data by the sensors (MQ-7, MQ-4 and TGS2600) they spend 3 minutes,, 1.5 minutes, 1.5 minutes, respectively in every 30 minutes,
- When sensing data by the sensors (TSL235R, DS18S20, and Humidity sensor) they spend 10 ms, 15 ms, 50µs respectively in every 15 s.
- The transceiver transmits data for 15 ms in every 15s and it receives data for 15 ms in every 10s
- The overall standby or sleep current for the entire sensor node is 0.25 mA

Table 2 The state chart used to visualise the multisensor node states and the components involved in each of the states.

Component number, x	Component name	State 1 [Measure data]	State 2 [Transmit data]	State 3 [Receive data]	State 4 [Standby or Sleep]
1	MQ-7	Measure data	-	-	-
2	MQ-4	Measure data	-	-	-
3	TGS2600	Measure data	-	-	-
4	TSL235R	Measure data	-	-	-
5	DS18S20	Measure data	-	-	-
6	Humidity Sensor	Measure data	-	-	-
7	Transceiver Transmit data	-	Transmit data	-	-
8	Transceiver Receive data	-	-	Receive data	-
9	Microcontroller and all the components in sleep state	-	-	-	Sleep

Table 3 The parameters for computation of the average current of each component in the multi-sensor node

1	2	3	4	5
Component, x	**Component name**	**Current of component x in mode state k,** $(I_{st(x,k)})$	**Duration of component x in state k,** $(t_{st(x,k)})$	**Cycle time of component x in state k,** $(t_{cy(x,k)})$
1	MQ-7	80	180	1800
2	MQ-4	155	90	1800
3	TGS2600	65	90	1800
4	TSL235R	3	0.01	15
5	DS18S20	2	0.015	15
6	Humidity Sensor	4	0.00005	15
7	Transceiver transmit	21.2	0.015	15
8	Transceiver receive	13.3	0.015	10
9	Microcontroller	0.25	1613.88	1800

The data and results for the; computation of $I_{Navst(k)}$ and $t_{Ncy(k)}$ for node state 1, the Measure data state are given in Table 4. Now, in Table 4, the column 5 is obtained using Equation 2. For instance, for the MQ-7 sensor $I_{st(x,k)}$= 80 mA, $t_{st(x,k)}$ = 180 seconds and $t_{cy(x,k)}$ = 1800 seconds , then $I_{avst(x,k)} = \frac{(80)(180)}{1800} = 8$. Similarly, in Table 4, the column 8 is obtained using Equation 3. For instance, for the MQ-7 sensor $I_{avst(x,k)}$= 8, $t_{cy(x,k)}$= 1800 and t_{cycl} =1800 then $I_{Navst(k)} = \frac{(8)(1800)}{1800} = 8$.

In order to determine the sleep or standby duration for the standby state, the duration of the active time of the node in the other states need to be determined. In this case, merely getting the sum of the states in the other states is not a good option. A series of assumption must be made. One, the sensor sensors can carry out their sensing operations simultaneously. The transceiver can either be in transmit mode or receive mode. In addition, the sensor node will not carry out any two states simultaneously. So, the active state times in Measure data state, transmit data state and receive data state can be added to get the total active state of the sensor node. The time taken in each cycle by each of the sensor node components, x, except the microcontroller is determined used as follows;

$$t_{stcyl(xx,k)} = \frac{(t_{cycl})(t_{st(xx,k)})}{t_{cy(xx,k)}}$$ for xx = 1,2,3,…nsx and k = 1,2,3,…,nst (6)

Where xx is the sensor node component that is used to determine the cycle time of the sensor node state k. Consequently, in Table 4, the column 7 is obtained using Equation 6. For instance, for the DS18S20 sensor $t_{st(xx,k)}$ = **0.015**, $t_{cy(x,k)}$= **15** and t_{cycl} =1800 then $I_{Navst(kt_{stcyl(xx,k)}} = \frac{(1800)(0.015)}{15}$ = 1.8. The same approach is used for the rest of the sensor node components shown in column 7 of Table 4.

The computation for the sleep current is given as, t_{slp} where ;

$$t_{slp} = t_{cycl} - \sum_{k=1}^{k=nst-1}(t_{stcyl(k)}) \quad (7)$$

Now, in Table 4, the sum of the time in column 7, $\sum_{k=1}^{k=nst-1}(t_{stcyl(k)})$ =366.61, then using Equation 7 the sleep current t_{slp} = 1800 − 366.61 =1433.39.

Table 4 The data and results for the computation of $I_{Navst(k)}$ and $t_{Ncy(k)}$ for node state 1: Measure data state

1	2	3	4	5	6	7	8
Sensor Node Component	**Current of component x in state k, ($I_{st(x,k)}$) in mA**	**Duration of component x in state k, ($t_{st(x,k)}$) in seconds**	**Cycle time of component x in state k,** ($t_{cy(x,k)}$) in seconds	**Average current of component x in state k,** ($I_{avst(x,k)}$) in mA	**Normalised cycle time of component x in state k,** ($t_{Ncy(x,k)}$) in seconds	**Normalised state time** $t_{stcyl(xx,k)}$ in seconds	**Normalised average current of component x in state k,** ($I_{Navst(x,k)}$) in mA
MQ-7	**80**	**180**	**1800**	**8**	**1800**	180	**8**
MQ-4	**155**	**90**	**1800**	**7.75**	**1800**	90	**7.75**
TGS2600	**65**	**90**	**1800**	**3.25**	**1800**	90	**3.25**
TSL235R	**3**	**0.01**	**15**	**0.002**	**1800**	1.2	**1.67E-05**
DS18S20	**2**	**0.015**	**15**	**0.002**	**1800**	1.8	**1.67E-05**
Humidity Sensor	**4**	**0.00005**	**15**	**1.33E-05**	**1800**	0.006	**1.11E-07**
Transceiver (transmit)	-	-	-	-	-	-	-
Transceiver (receive)	-	-	-	-	-	-	-
Microcontroller	-	-	-	-	-	-	-

3 RESULTS AND DISCUSSION

The summary of the results of the computation of the normalised average current, I_{avg} are given in Table 5 where I_{avg} 19.25 mA. The value obtained in [18] for the average node current is 19.29 mA. The error is 0.04 mA (that is 19.294 -19.25) and the percentage error is 0.2 %. The error is due to the assumptions made in [18] in arriving at the average current for the states with repeat time less than the sensor node cycle time. For a battery with capacity 3000 mAh , the battery lifetime in hours is given in Equation 5 as ; $t_{Lh} = \frac{C_{bat}}{I_{avg}} = \frac{3000}{19.2244576} =$ 156.0511364 hours.

In all, the approach used in this paper identified the error made in the work by [18] in the computation of the average.

Table 5 The summary of the results of the computation of the average current I_{avg}

1	2	3	4	5	6	7	8
Sensor Node Component	**Current of component x in state k,** $(I_{st(x,k)})$ in mA	**Duration of component x in state k,** $(t_{st(x,k)})$ in seconds	**Cycle time of component x in state k,** $(t_{cy(x,k)})$ in seconds	**Average current of component x in state k,** $(I_{avst(x,k)})$ in mA	**Normalised cycle time of component x in state k,** $(t_{Ncy(x,k)})$in seconds	**Normalised state time** $t_{stcyl(xx,k)}$ in seconds	**Normalised average current of component x in state k,** $(I_{Navst(x,k)})$ in mA
MQ-7	**80**	**180**	**1800**	**8**	**1800**	180	**8**
MQ-4	**155**	**90**	**1800**	**7.75**	**1800**	90	**7.75**
TGS2600	**65**	**90**	**1800**	**3.25**	**1800**	90	**3.25**
TSL235R	**3**	**0.01**	**15**	**0.002**	**1800**	1.2	**1.67E-05**
DS18S20	**2**	**0.015**	**15**	**0.002**	**1800**	1.8	**1.67E-05**
Humidity Sensor	**4**	**0.00005**	**15**	**1.33E-05**	**1800**	0.006	**1.11E-07**
Transceiver (transmit)	**21.2**	**0.015**	**15**	**0.0212**	**1800**	1.8	**0.000177**
Transceiver (receive)	**13.3**	**0.015**	**10**	**0.01995**	**1800**	1.8	**0.000111**
Microcontroller	**0.25**	**1800**	**1800**	**0.25**	**1800**	**-**	**0.25**
					Iavg	**366.61**	**19.25**

4. CONCLUSION

An approach for computing the average current and battery life time for a multisensor node that has different timelines for the various sensor node components is presented. The study is particularly suitable for the present day sensor network applications where sensor node with multiple sensor units are used to capture various ambient parameters. In this paper, the details of the application of the sensor node state chart and the analytical expressions used to determine the normalised time and current values for the multisensor node components are presented. Sample multisensor node presented is used to compare the results with some existing approach used by some authors. The findings in this work showed that the author cited made some mistakes in the computation of the average current due to wrong application of the multisensor node components timelines.

REFERENCES

1. Pagano, A., Croce, D., Tinnirello, I., & Vitale, G. (2022). A Survey on LoRa for Smart Agriculture: Current Trends and Future Perspectives. *IEEE Internet of Things Journal*, *10*(4), 3664-3679.
2. Tao, W., Zhao, L., Wang, G., & Liang, R. (2021). Review of the internet of things communication technologies in smart agriculture and challenges. *Computers and Electronics in Agriculture*, *189*, 106352.
3. Sinha, B. B., & Dhanalakshmi, R. (2022). Recent advancements and challenges of Internet of Things in smart agriculture: A survey. *Future Generation Computer Systems*, *126*, 169-184.
4. Awan, S. H., Ahmad, S., Khan, Y., Safwan, N., Qurashi, S. S., & Hashim, M. Z. (2021). A Combo Smart Model of Blockchain with the Internet of Things (IoT) for the Transformation of Agriculture Sector. *Wireless Personal Communications*, *121*(3), 2233-2249.

5. Das, P., Ghosh, S., Chatterjee, S., & De, S. (2022). A low cost outdoor air pollution monitoring device with power controlled built-in PM sensor. *IEEE Sensors Journal*, *22*(13), 13682-13695.
6. Ragnoli, M., Leoni, A., Barile, G., Ferri, G., & Stornelli, V. (2022). LoRa-Based Wireless Sensors Network for Rockfall and Landslide Monitoring: A Case Study in Pantelleria Island with Portable LoRaWAN Access. *Journal of Low Power Electronics and Applications*, *12*(3), 47.
7. Dimitrievski, A., Filiposka, S., Melero, F. J., Zdravevski, E., Lameski, P., Pires, I. M., ... & Trajkovik, V. (2021). Rural healthcare IoT architecture based on low-energy LoRa. *International journal of environmental research and public health*, *18*(14), 7660.
8. Sherazi, H. H. R., Grieco, L. A., Imran, M. A., & Boggia, G. (2020). Energy-efficient LoRaWAN for industry 4.0 applications. *IEEE Transactions on Industrial Informatics*, *17*(2), 891-902.
9. Sherazi, H. H. R., Grieco, L. A., Imran, M. A., & Boggia, G. (2020). Energy-efficient LoRaWAN for industry 4.0 applications. *IEEE Transactions on Industrial Informatics*, *17*(2), 891-902.
10. Fahmida, S., Modekurthy, V. P., Rahman, M., Saifullah, A., & Brocanelli, M. (2020, October). Long-lived LoRa: Prolonging the lifetime of a LoRa network. In *2020 IEEE 28th International Conference on Network Protocols (ICNP)* (pp. 1-12). IEEE.
11. Reyana, A., & Vijayalakshmi, P. (2021). Multisensor data fusion technique for energy conservation in the wireless sensor network application “condition-based environment monitoring”. *Journal of Ambient Intelligence and Humanized Computing*, 1-10.
12. Ferrer-Cid, P., Barcelo-Ordinas, J. M., Garcia-Vidal, J., Ripoll, A., & Viana, M. (2020). Multisensor data fusion calibration in IoT air pollution platforms. *IEEE Internet of Things Journal*, *7*(4), 3124-3132.
13. Rachman, F. Z., & Hendrantoro, G. (2020, June). A fire detection system using multi-sensor networks based on fuzzy logic in indoor scenarios. In *2020 8th International Conference on Information and Communication Technology (ICoICT)* (pp. 1-6). IEEE.
14. Kim, T. Y., & Cho, S. B. (2019). Predicting residential energy consumption using CNN-LSTM neural networks. *Energy*, *182*, 72-81.
15. Strubell, E., Ganesh, A., & McCallum, A. (2019). Energy and policy considerations for deep learning in NLP. *arXiv preprint arXiv:1906.02243*.
16. Millward-Hopkins, J., Steinberger, J. K., Rao, N. D., & Oswald, Y. (2020). Providing decent living with minimum energy: A global scenario. *Global Environmental Change*, *65*, 102168.
17. Min, M., Xiao, L., Chen, Y., Cheng, P., Wu, D., & Zhuang, W. (2019). Learning-based computation offloading for IoT devices with energy harvesting. *IEEE Transactions on Vehicular Technology*, *68*(2), 1930-1941.
18. Bhattacharjee, D., Kumar, S., Kumar, A., & Choudhury, S. (2010). Design and development of wireless sensor node. *International Journal on Computer Science and Engineering*, *2*(07), 2431-2438.