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Design of a Network with wireless sensor applied to data transmission based on IEEE 802.15.4 standard

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Abstract

The problem of data transmission in wireless sensor networks (WSN), with real time guarantees, is an issue that has important references in the international scientific community, but that still does not have a solution that can completely satisfy this requirement [1]. Therefore, real time data transmission with WSN is considered an open issue with many possibilities of improvement. In this sense, this document presents a new procedure to ensure this type of transmission with WSN, particularly from the planning of the resources available for data transmission in the network, taking as a reference the IEEE 802.15.4 standard.

Keywords: Data transmission; Wireless sensor networks (WSN); Static planning.

1. Introduction

This document presents a planning method (algorithm) for real-time data transmission with wireless sensor networks (WSN) [2], based on static planning techniques and applied to time-slot networks. The planning algorithm

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that was developed, called static planning with mathematical techniques (SPMT), Maximum Common Divisor (MCD) and Minimum Common Multiple (MCM) [3], starts with a feasibility assessment of the number of nodes participating in a WSN, the size of the packets to be transmitted, the transmission periods and the amount of resources available at the MAC layer. The SPMT design is based on the super-frame concept defined by the IEEE 802.15.4 standard [4] and, in particular, on the Guaranteed Time Slots (GTS) mode of operation, which establishes a mechanism for the reservation of time-slots for data transmission [5].

SPMT was compared with other solutions mentioned below, in order to establish similarities and differences with them. It was also designed in pseudocode and programmed in SCILAB [6], which is a free software mathematical analysis program, so the results presented are based on the simulation of cases of real situations. On the other hand, SPMT bases its calculations on the variables of the superframe handled by the IEEE802.15.4 standard. The structure of the document starts with the comparison of some previous existing algorithms versus the SPMT algorithm, then the operation of the algorithm is explained from an example that was simulated and ends with the results and conclusions of the research [7].

2. SPMT algorithm operation

SPMT takes the features of a WSN as inputs with a finite number of nodes and a network coordinating node, connected in star topology. It also assumes that the WSN coordinator did the previous synchronization process and has the variables that the algorithm works with, which correspond to [8][9][10]: N, which defines the number of nodes; P, which is the size of the packets that the nodes send; and T, which are the periods in which the nodes must transmit the data to the coordinator. The variables Rts and Nts correspond to the time-slot range (time-slots that are assigned in the transmission, indicating the beginning and end in the super-frame) and maximum number of timeslots, respectively, as values that will depend on the standard being worked with.

For the case of IEEE 802.15.4, which has been the example used for the proposed solution, they correspond to Rts = [3, 4 ...16] and Nts = 13. On the other hand, BSFD (Minimum time-slot size) is equal to 960 symbols and in time to 0.01536 sec. When there is a WSN with seven or less nodes, SPMT mainly validates the time-slot size and looks for the values that allow the assignment of GTS to each of the sensors that make up the network, according to the proposed planning. But when there are more than seven sensors in the WSN, SPMT looks for a planning that guarantees the transmission in real time. For these cases, the beacon interval and the data transmission ratio of each sensor are analyzed in order to find a possible value of BO and SO that fits the requirements of the application [11] [12].

In the two previous cases SPMT seeks to determine whether or not real time transmission is feasible. On the other hand, one of the aspects that SPMT controls, corresponds to verify that the number of time-slots does not exceed the value of 13 per super-frame and that the GTS is a maximum of seven. In cases where the WSN is composed of more than seven nodes, their behaviour is evaluated until they reach the network macro-circle. If in that time the number of time-slots exceeds 13 or the 7 GTS, the value of BO [13] is reduced by 1, as long as SO is lower. When this process is done, BI is decreased and other intervals are available to assign the periods of the WSN sensors. If a feasible option is found in this assignment, WSN is said to be feasible for real time, otherwise it is not feasible [14] [15].

3. Results

3.1. Step-by-step application of the Algorithm

SPMT Step 1: The first thing that SPMT does is to obtain the BO and SO values of the proposed WSN, which allows to know the BI and SD respectively. In order to understand the process, an example will be taken, in which a WSN is composed of 10 sensors. In Table 1, the initial data can be observed.

Table 1. Initial WSN Data Proposal.

Nodes	**UmBSFD (Units of periodic time in terms of the super-frame**	**Package Size (P) - Bits**
1	4000	44
2	5000	1044
3	6000	44
4	3000	1044
5	5000	1044
6	8000	1044
7	10000	44
8	12000	1044
9	11000	44
10	24000	44

After applying step one, the following results are obtained, see Table 2:

Table 2. Results of the first simulation

Variable	**Obtained Value**
BSFD	0,02514
BO	12
SO	1
BI	17.47 sg
SD	7682 Bits
Time-slot size	482 Bits
Time-slots available	14

Step 2: With the previously calculated and recorded data in Table 2, the algorithm proceeds to calculate the necessary amount of time-slot per sensor node and evaluates the feasibility of transmitting in real time with the assignment of maximum 7 GTS per superframe. Table 3 shows the calculation.

Table 3. Time-slot calculation per node

Nodes	**Number of Time-slot required by superframe**
1	1
2	3
3	1
4	3
5	3
6	3
7	1
8	3
9	1
10	1
Total	20

Step 3: As it can be seen, according to the values obtained and recorded in Table 3, the WSN with 10 nodes will require 20 time-slots at most at a given time to be able to transmit in real time, a situation that is not feasible according to the parameters of the IEEE 802.15.4 standard, which only allows 13 time-slots [16]. Table 4 shows the changes made by SPMT in this step.

Table 4. Values of second iteration Simulation

Variable	**Initial Value**	**Proposed change SPMT**
BO	12	10
SO	1	2
BI	7.47 sg	6.89 sec
N	A single group of 10 nodes	Two groups of 5 nodes

Step 4: When the change proposed in step 3 is made, SPMT evaluates the feasibility of meeting the requirements of the change in order to transmit in real time. In this case, the goal is to transmit a maximum of 7 GTS and 13 time-slots in each generation of superframe. In order to validate this requirement, the iterations of the BI are executed until the Macrocycle is fulfilled. If, in this process, it is found that, in each BI, the superframes handle up to 7 GTS and a maximum of 13 time-slots, the WSN is said to be feasible for real-time transmission; otherwise, the BO is again reduced, as long as the SO remains lower. In the case of the 10-sensor WSN, the corresponding decreases were made until BO = SO was reached, and the requirement was not met, so a new step was taken. In Table 5, the iterations made by SPMT can be seen [16][17].

Table 5. SPMT Validation Conditions: The number of time-slot exceeds the maximum allowed

Iteration	**BO value**	**SO**
Two groups of sensors - 1	10	3
Two groups of sensors - 2	9	3
Two groups of Sensors - 3	8	3
Two groups of sensors - 4	7	3
Two groups of sensors - 5	6	3
Two groups of sensors - 6	5	3
Two groups of Sensors - 7	4	3
Two groups of sensors - 8	3	3
Two groups of sensors - 9	2	3

Step 5: Due to the fact that the requirement of the standard was not achieved in the previous step, SPMT, in a new step, divides the set of sensors in three groups, where the first group works with the initially programmed period, the second group works with the displacement in one BI unit and the third group with the displacement of two BI units, is validated again according to the macro cycle of the periods of the set of sensors that constitute the WSN. It was

obtained that the network is feasible for the transmission in real time when BO = 9, but working with three groups of sensors. In Table 6, the result obtained can be seen.

Table 6 shows that there is a first column with the iterations made by SPMT in the validation process of the BO and SO values to make the transmission in real time feasible. The second column shows BI, which is the network's beacon interval and, in the case that it has been taken, corresponds to 7.86 seconds. Then there are the columns for the sensors from S1 to S10, where the number of time-slots required to transmit the data they capture is located, which in turn constitute the GTSs used by WSN to transmit in real time.

As mentioned above, the ten-node WSN sensors were organized into three groups: Group 1 (S1, S2, S3), Group 2 (S4, S5, S6) and Group 3 (S7, S8, S9, S10), which transmit in their corresponding BI, keeping Group 1 unchanged, but for Group 2, a displacement of one unit was made in what corresponds to the iteration (itera) and for Group 3, a displacement of two units was made, which prevented all the sensors from transmitting in the same BI with the 20 time-slots they require, but on the contrary, groups that do not exceed 13 time-slots, nor the 7 GTS needed for real-time transmission will be handled. When this solution is validated, it determines that the WSN must work with BO = 9 and SO = 1, in a subdivision of three groups of sensors.

Table 6. SPMT Final Result

Itera	**BI (sg)**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**
0	0	2	4	1	1	0	1	0	1	1	1
1	7,47	0	0	0	1	2	2	0	0	0	0
2	16,1	0	1	0	0	0	0	2	2	0	2
3	20,4	2	0	0	2	0	0	0	0	0	0
4	29,1	0	3	0	1	1	1	1	0	1	0
5	38,1	1	0	1	0	2	0	0	1	0	0
…	…	…	…	…	…	…	…	…	…	…	…
41198	325147,2	0	1	0	2	3	1	1	1	0	1
41199	328963,1	0	0	0	1	1	0	2	0	1	0
41200	**319896,9**	**2**	**0**	**0**	**0**	**0**	**3**	**0**	**0**	**0**	**0**

4. Discussion and Conclusions

Wireless sensor networks (WSN) provide structural support for new technologies, such as the Internet of Things (IoT) or cyber-physical systems (CPS), where one of the important requirements is real-time data transmission. Standards for WSN are supported by access mechanisms to the medium such as statistical multiplexing (e.g. CSMA/CA), time division multiplexing or frequency division multiplexing. However, the statistical multiplexing model does not allow to satisfy real-time requirements due to the non-deterministic latency introduced by the media access mechanism.

For this reason, research in this area focuses on the use of multiplexing methods as mechanisms to provide real time guarantees. However, the review of the state of the art showed that the methods available in the literature are still very limited in terms of providing feasible solutions using the limited resources of the network and, in terms of their ability, to scale the system when high numbers of sensors are required. This paper addressed these problems in the specific context of WSN, where sensor requirements are expressed in terms of transmission periodicity and minimizing transmission latency, eliminating the need for containment mechanisms for access to the medium through a coordinated planning scheme.

For this purpose, a planning algorithm called SPMT was designed, which takes as inputs the requirements of a set of sensors and the restrictions of the technology used for the implementation of the WSN, for determining a feasible planning scheme if possible, or reports the non-feasibility of the instance of the problem. Finding a feasible solution makes the deployment of the application possible, ensuring the requirements of the sensors and the compliance with the restrictions of the network infrastructure. In this case, the scheme is not feasible since SPMT provides information that allows the application designer to review its features, so that it becomes a tool that helps to adjust the system design to make it feasible.

The planning algorithm was verified through a set of real and synthetic test cases that allow demonstrating the feasibility or non-feasibility of the obtained planning scheme. This process was carried out by adjusting the algorithm to the restrictions of a specific technology case for the implementation of WSN networks, the 802.15.4 standard. Likewise, the benefits of the planning scheme were implemented and tested in prototype networks based on this standard. The synthetic cases allowed validating that the scheme allows to scale the sensor network without making changes to the standard, one of the most frequent limitations identified in the state of the art.

References

[1] Huang, R., & Zaruba, G. V. (2007, March). Static path planning for mobile beacons to localize sensor networks. In Fifth annual IEEE international conference on pervasive computing and communications workshops (PerComW'07) (pp. 323-330). IEEE.

[2] Kaur, R., Gupta, A., & Goyal, R. (2020). Analysis of Coverage Hole Problem for Detection and Restoration in Wireless Sensor Networks. Advanced Science, Engineering and Medicine, 12(3), 403-408.

[3] Tsilomitrou, O., Tzes, A., & Manesis, S. (2017, July). Mobile robot trajectory planning for large volume data-muling from wireless sensor nodes. In 2017 25th Mediterranean Conference on Control and Automation (MED) (pp. 1005-1010). IEEE.

[4] Renold, A. P., & Ganesh, A. B. (2019). Energy efficient secure data collection with path-constrained mobile sink in duty-cycled unattended wireless sensor network. Pervasive and Mobile Computing, 55, 1-12.

[5] Alomari, A., Comeau, F., Phillips, W., & Aslam, N. (2018). New path planning model for mobile anchor-assisted localization in wireless sensor networks. Wireless Networks, 24(7), 2589-2607.

[6] Alomari, A., Comeau, F., Phillips, W., & Aslam, N. (2018). New path planning model for mobile anchor-assisted localization in wireless sensor networks. Wireless Networks, 24(7), 2589-2607.

[7] Zygowski, C., & Jaekel, A. (2020). Optimal path planning strategies for monitoring coverage holes in Wireless Sensor Networks. Ad Hoc Networks, 96, 101990.

[8] Han, G., Yang, X., Liu, L., Guizani, M., & Zhang, W. (2017). A disaster management-oriented path planning for mobile anchor node-based localization in wireless sensor networks. IEEE Transactions on Emerging Topics in Computing.

[9] Rezazadeh, J., Moradi, M., Ismail, A. S., & Dutkiewicz, E. (2014). Superior path planning mechanism for mobile beacon-assisted localization in wireless sensor networks. IEEE Sensors Journal, 14(9), 3052-3064.

[10] Magadevi, N., Kumar, V. J. S., & Suresh, A. (2018). Maximizing the Network Life Time of Wireless Sensor Networks Using a Mobile Charger. Wireless Personal Communications, 102(2), 1029-1039.

[11] Ma, M., Yang, Y., & Zhao, M. (2012). Tour planning for mobile data-gathering mechanisms in wireless sensor networks. IEEE transactions on vehicular technology, 62(4), 1472-1483.

[12] Subramanian, C. B., & Balakannan, S. P. (2017, March). Optimized trajectory planning for mobile anchors in wireless sensor networks. In 2017 IEEE International Conference on Intelligent Techniques in Control, Optimization and Signal Processing (INCOS) (pp. 1-5). IEEE.

[13] He, X., Fu, X., & Yang, Y. (2019). Energy-Efficient Trajectory Planning Algorithm Based on Multi-Objective PSO for the Mobile Sink in Wireless Sensor Networks. IEEE Access, 7, 176204-176217.

[14] Xia, F., Wang, L., Zhang, D., Zhang, X., & Gao, R. (2012). Ada-MAC: An adaptive MAC protocol for real-time and reliable health monitoring. In 2012 IEEE International Conference on Cyber Technology in Automation, Control, and Intelligent Systems (CYBER) (pp. 203-208). IEEE

[15] El Fissaoui, M., Beni-hssane, A., Ouhmad, S., & El Makkaoui, K. (2020). A Survey on Mobile Agent Itinerary Planning for Information Fusion in Wireless Sensor Networks. Archives of Computational Methods in Engineering, 1-12.

[16] Viloria, A., Senior Naveda, A., Hernández Palma, H., Niebles Núẽz, W., & Niebles Núẽz, L. (2020). Electrical Consumption Patterns through Machine Learning. In Journal of Physics: Conference Series (Vol. 1432). Institute of Physics Publishing. https://doi.org/10.1088/1742-6596/1432/1/012093.

[17] Viloria, A., Hernández Palma, H., Gamboa Suarez, R., Niebles Núẽz, W., & Solórzano Movilla, J. (2020). Intelligent Model for Electric Power Management: Patterns. In Journal of Physics: Conference Series (Vol. 1432). Institute of Physics Publishing. https://doi.org/10.1088/1742-6596/1432/1/012032