ADAPTIVE PRIORITY ALGORITHM FOR PMME PROTOCOL IN MULTI-EVENT WIRELESS SENSOR NETWORK

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ABSTRACT

Nowadays, multi-event Wireless Sensor Networks (WSNs) have a wide range of applications in healthcare, industry, agriculture monitoring, and automation. In these WSNs, there are various events or multi-priority data which can concurrently occur with different quality of service (QoS) requirements based on priority levels. In the previous research, we proposed and implemented PMME protocol for significantly reducing the chances of collision and the delay of all packet types in multi-event WSNs against QAEE and MPQ priority MAC protocols. However, our PMME protocol always fixed the value of data priority levels without considering the network density. Thus, in this paper, we analyze and evaluate the effects of network density on multi-event WSNs performance when using the PMME protocol. After that, we propose an Adaptive Priority Algorithm for PMME, namely APAP. The simulation of APAP shows that it is more efficient than PMME in terms of packet latency, energy and packet loss rate.

THUẬT TOÁN THÍCH NGHI ĐỘ ƯU TIÊN CHO GIAO THỨC PMME TRONG MẠNG CẢM BIẾN KHÔNG DÂY ĐA SỰ KIỆN

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TỪ KHÓA

Giao thức MAC ưu tiên
Mạng cảm biến không dây đa sự kiện
Giao thức MAC
Thuật toán thích nghi độ ưu tiên
Ưu tiên dữ liệu

TÓM TẮT

Ngày nay, mạng cảm biến không dây đa sự kiện được ứng dụng rất rộng rãi trong nhiều lĩnh vực như giám sát trong y tế, nông nghiệp, công nghiệp và các hệ thống tự động hoá. Trong mạng cảm biến không dây đa sự kiện này, chúng giám sát đồng thời nhiều sự kiện hoặc dữ liệu đa mức ưu tiên với những yêu cầu về chất lượng dịch vụ (QoS – Quality of Service) khác nhau được dựa trên mức độ ưu tiên. Trong nghiên cứu trước, chúng tôi đã đề xuất và xây dựng giao thức PMME để giảm đáng kể nguy cơ xung đột và độ trễ của tất cả gói tin so với giao thức MAC ưu tiên QAEE và MPQ trong mạng cảm biến không dây đa sự kiện. Tuy nhiên, giao thức PMME của chúng tôi luôn cố định giá trị mức độ ưu tiên mà không xem xét đến yếu tố số lượng nút mạng. Do đó, trong bài báo này, chúng tôi thực hiện việc đánh giá yếu tố này cho giao thức PMME trong mạng cảm biến không dây đa sự kiện. Sau đó, chúng tôi đề xuất thuật toán thích nghi độ ưu tiên cho giao thức PMME, có tên là APAP. Kết quả mô phỏng cho thấy giao thức APAP hiệu quả hơn so với giao thức PMME về năng lượng, độ trễ và tỷ lệ mất gói tin.

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1. Introduction

With the development in sensor technology and wireless communication, there has emerged new generations of wireless sensor networks for expanding to different applications in multi-event environments as early warning systems (fire, flood and volcano) or smart alert systems and smart grid systems [1]-[4]. In these new scenarios, sensor nodes measure and collect concurrently different types of data in the environment surrounding them, such as relative humidity, temperature, smoke, lack of oxygen, electrical conductivity (EC) - all these factors are required for determining early warning or emergency events. After that, these sensors communicate either among each other or directly to an external base station for transmitting their data by using different QoS policies such as minimized energy, communication time or highest priority to real-time tasks [5]-[8]. However, with conventional MAC in WSNs, communication data are always stored in a buffer/queue of nodes that has non-preemptive priority and use assignments based on First Come First Serve (FCFS) rule [9]. This rule is not suitable for data priority systems based on multi-event WSNs, especially in systems that have types of event data as abnormal or early warning data and control data may need to transfer to a sink node in the quickest way [1], [4], [10], [11]. Thus, there is increasing research about the priority of packets in multi-event WSNs in recent years, including designing a suitable MAC protocol that supports priority data transmission.

In [12], authors introduce PQMAC based on the priority queue idea. PQMAC protocol divides data into four priority levels to differentiate among data transmissions. This protocol has reduced communication time of high priority data while maintaining energy efficiency. But PQMAC protocol requires synchronization between nodes and packet transmission latency is still higher than the emergency applications.

QAEE protocol is proposed by authors in [13] with a mechanism that relies on the receiver to initiate communication. It means that the receiver node will wake up periodically to receive packets sent from the sender. QAEE considers two data priority levels and allows high-priority data to have the opportunity to be sent before lower priority one during any listen time. However, QAEE protocol has some disadvantages such as the receiver node has to wait for the entire Tx-Beacons from the sender nodes, and later it broadcasts the Rx-Beacon to all sender nodes. It leads to increased packet transmission latency of high priority data, as well as average packet delay of all packet types.

In research [14], authors present MPQ protocol. It has been improved over QAEE by using four types of priority levels (from 1 to 4), corresponding to the normal data, important data, most important data and urgent data. In MPQ protocol, the highest priority data will be firstly accepted and then sends an Rx-Beacon to the selected sender node without waiting until T_w runs out. Besides the advantages, this protocol also has a main disadvantage that the lower priority sender nodes have to spend time waiting until T_w expires. With the drawbacks of QAEE and MPQ protocol, we have proposed a new priority MAC protocol for multi-event WSN which is Priority MAC protocol for Multi-Event industrial wireless sensor networks protocol (PMME) is presented in [15], [16].

The rest of this paper is structured as follows. The methodology in section 2 is given a brief overview of the PMME protocol and introduction of the APAP algorithm. Section 3 presents analysis and evaluation simulation results of APAP. Finally, section 4 is the conclusions and future work.

2. Methodology

2.1. Overview of PMME protocol

PMME protocol is a priority MAC for multi-even WSNs that has developed based on Castalia 3.3 simulation [17] and OMNeT ++ 4.6 [18] with using the CC2420 transceiver standard [19].

The protocol overcomes the drawbacks of MPQ and QAEE protocol by using two mechanisms which are the earliest possible Tx-Beacon acceptance and the CSMA p-persistent value proportional to the priority level of data. Figure 1 shows a brief illustration of two PMME protocol' mechanisms.

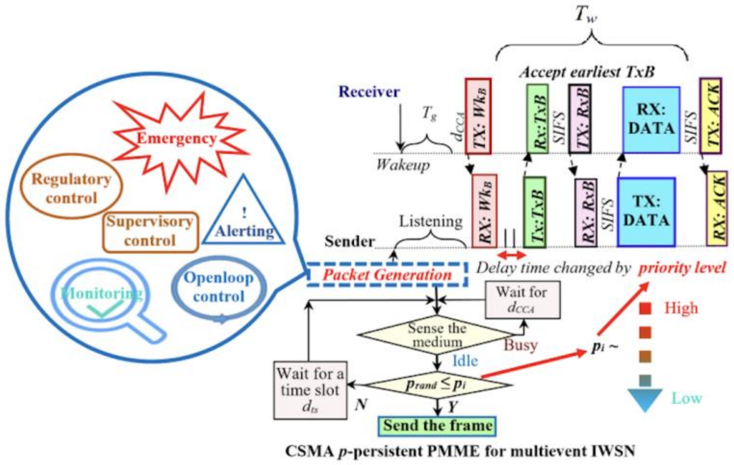


Figure 1. *Description of the PMME operations in multi-event WSNs*

As shown in Figure 1, after waking up, the receiver listens to the medium in Tg time (guarantee time) and then it broadcasts WkB beacon to all sender nodes and waits for receiving all TxB sender nodes's beacon. When the senders receive the WkB then they transmit the TxB beacon to the receiver node. Thus, the sink node will receive all TxB. Based on the value of the priority field in these TxB beacons, the receiver selects the sender node which has the highest priority level. This is the earliest possible Tx-Beacon acceptance mechanism of PMME. The mechanism helps other sender nodes (lower priority) in saving energy by sleeping during NAV (Network Allocation Vector) time and preventing collision of their data.

Meanwhile, before its data transmission, the selected sender will listen to the channel. If the medium is idle, it checks the priority value on the condition $p_i \geq p_{rand}$. If the condition is true, it decides to send the data frame. Therefore, the second mechanism of PMME will support a better chance of early channel access for higher priority data. Thus, highest priority data always have the opportunity to be sent before lower priority data.

The topology of PMME protocol is illustrated in Figure 2. Accordingly, at each sender node, data packets are classified into four different priority levels that are p_1, p_2, p_3 and p_4, in which p_4 is the highest priority level. These priority levels are referenced in [20]. Based on the priority level of data, PMME allows the sender nodes to transmit a TxB beacon with the sending frequency proportional to the priority level of data. The sink node listens the beacon from any sender node, and it sends the RxB beacon to the selected node and also notified other nodes to sleep during this time. It means that data with highest priority level will have more chance to be sent than lower priority one, as well as saving energy for the network.

PMME has been proven to have energy efficiency, high packet success rate and significantly reducing the average packet delay for all packet types, delay of different packets by priority levels in comparison with QAEE and MPQ [15].

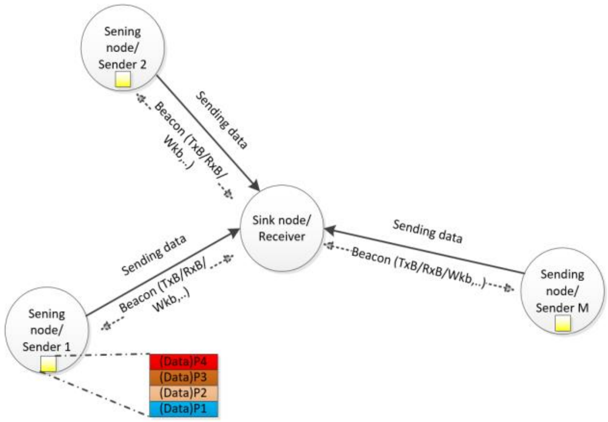


Figure 2. *Topology of PMME in multi-event WSNs*

2.2. Analysis and evaluation of the effects of network density to performance by using PMME protocol in multi-event WSNs

In PMME protocol, all value of data priority levels, p_1, p_2, p_3 *and* p_4 which does not change according to the network density. It means that PMME has not yet considered the effect of network density on its performance. However, to the best of our knowledge, in the same condition, traffic of WSN increases when the number of nodes increases, where traffic (e.g. data, beacon) increases to its aggregated capacity of the channel [21], [22].

Thus, in case the number of sensor nodes changes, using constant p- persistent values for each data priority level of the PMME protocol may be not appropriate and requires analysis and evaluation.

Table 1. *The priority parameters set for PMME*

Name	Priority			
	p_4	p_3	p_2	p_1
S^1	0.1	0.075	0.05	0.025
S^2	0.2	0.15	0.1	0.05
S^3	0.3	0.225	0.15	0.075
S^4	0.4	0.3	0.2	0.1
S^5	0.5	0.375	0.25	0.125
S^6	0.6	0.45	0.3	0.15
S^7	0.7	0.525	0.35	0.175
S^8	0.8	0.6	0.4	0.2

Because the average data delay of linear priority levels is better than nonlinear priority levels with a=2 and a=3 [16]. Thus, in this research, we study on the factors of node number and priority value that effect on network performance by using the simulation parameters as the same scenario in [16] and using linear priority levels parameters are defined as in the table 1.

With analyzing the results in Figure 3, we have some main evaluations as follows:

- The data delay is directly proportional to the number of nodes. It means that the number of nodes increases, the data latency increases and vice versa.
- The value of data priority is also proportional to the data delay when the number of nodes is increased. But for the number of nodes is small, i.e. less than 5 in some scenarios, the data priority does not affect data delay.
- The lower the value of data priority, the bigger the data delay.
- The $S^4(p_4 = 0.4, p_3 = 0.3, p_2 = 0.2, p_1 = 0.1)$ has the smallest data delay in case number of nodes is more than five.

- The $S^6(p_4 = 0.6, p_3 = 0.45, p_2 = 0.3, p_1 = 0.15)$ has the smallest delay in case number of nodes is less than or equal 5.

Besides, we also jointly consider energy and packet loss rate factors in these scenarios. We see that the energy has no significant change but the packet loss rate is higher as the data priority value increases. It shows that the value of data priority is not the bigger the better, especially in case the number of nodes is bigger than 5.

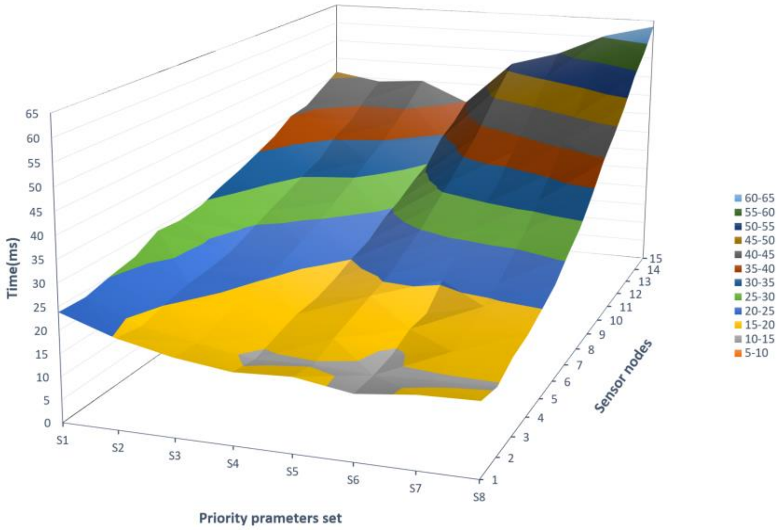


Figure 3. *Average data delay of each priority parameters set for PMME protocol*

With the evaluations above, we affirm that using constant priority values of the PMME protocol is not appropriate in case number of sensor node changes. Therefore, we need to improve the PMME protocol for solving this problem.

2.3. Adaptive Priority Algorithm for PMME (APAP)

In our survey, we have analyzed a lot of the simulation results of PMME by varying the p_i according to the network density. Hence, we have evaluated as follows:

- In case of network density is more than 01, if the p_i value is larger, the network performance (e.g. delay, energy and packet loss rate) does not increase. Because, with a large p_i value, there are many sender nodes that have a chance to communicate by sending its data to the sink node. It means that the probability of collision is bigger. Thus, the network will be more conflicted, and sender nodes cannot transmit immediately its data and have to sleep/wait until it has the chance to send the data.
- The p_i values do not affect linearly to network performance. It means that each p_i value is a function with different parameters.
- As the number of sender nodes increases, the p_i values need to be set to a suitable smaller value.
- With the p_i value is relatively small, the network performance has not improved because the probability of $p_i > p_{rand}$ is low. It means that there are a few sender nodes that have a chance to transmit their data to the sink node. It leads to increased packet transmission latency of all data types, as well as reduced network performance.
- The $p_1 \leq 0.1$ is not the best value.

The idea of APAP is not only adapted to the priority level of data, but also adapted to the network density. It means that as network density varies, each p_i value needs to be changed appropriately. In [8], authors also proposed the TMPQ protocol with a similar idea. In this protocol, the $p_i = \frac{p_i}{M}$ in which M is total concurrent sensor nodes of the network. With this formula, we see that the higher the number of sending nodes, the smaller the p_i values are. It leads to emergency data/events not sent immediately. Thus, we need to give new formulas for each p_i priority level as a function with n parameter, namely $p_i(n)$, in which n is the total number of sensor nodes.

Based on our research and evaluations above, we found formulas for $p_i(n)$ that can be expressed as follows.

$$p_4(n) = \begin{cases} a_4\alpha^{n-1} & , \quad if\ n = 1 \\ (a_4 - \beta)\alpha^{n-1}, & if\ 2 \le n < 10 \\ (a_4 - (\beta + \theta))\alpha^{n-1}, & if\ n \ge 10 \end{cases} \quad (1)$$

$$p_3(n) = \begin{cases} a_3\alpha^{n-1} & , \quad if\ n = 1 \\ (a_3 - \beta)\alpha^{n-1}, & if\ 2 \le n < 10 \\ (a_3 - (\beta + \theta))\alpha^{n-1}, & if\ n \ge 10 \end{cases} \quad (2)$$

$$p_2(n) = \begin{cases} a_2\alpha^{n-1} & , \quad if\ n = 1 \\ (a_2 - \beta)\alpha^{n-1}, & if\ 2 \le n < 10 \\ (a_2 - (\beta + \theta))\alpha^{n-1}, & if\ n \ge 10 \end{cases} \quad (3)$$

$$p_1(n) = a_{01}\alpha^{n-1} \quad (4)$$

Where $a_4 = 0.56$, $a_3 = 0.4$, $a_2 = 0.35$, $a_1 = 0.12$ are initialization values; $\alpha = 0.99$ is coefficient of change; $\beta = 0.1228\ and\ \theta = 0.0248$ are called attenuation coefficient.

The APAP will run on each sender node for receiving its RxB beacon from the receiver node/sink node, as well as sending its beacon or data frame as the channel is clear or idle. In case of collision, the sender node will check the txRetries field to decide whether to transmit its data or not. Based on total number of nodes, APAP will calculate $p_i(n)$ for all sending nodes based on the formulas (1), (2), (3), (4). This process is repeated during active sender node state.

3. Evaluation of APAP protocol

3.1. Topology and simulation parameters

The APAP algorithm is developed based on PMME protocol. To evaluate the APAP against PMME, we use the same topology and simulation scenarios as in section II with the main parameters in table 2. The performance of APAP and PMME protocol is considered by three performance parameters that are energy consumption, packet/data delay and packet loss rate of four priority levels.

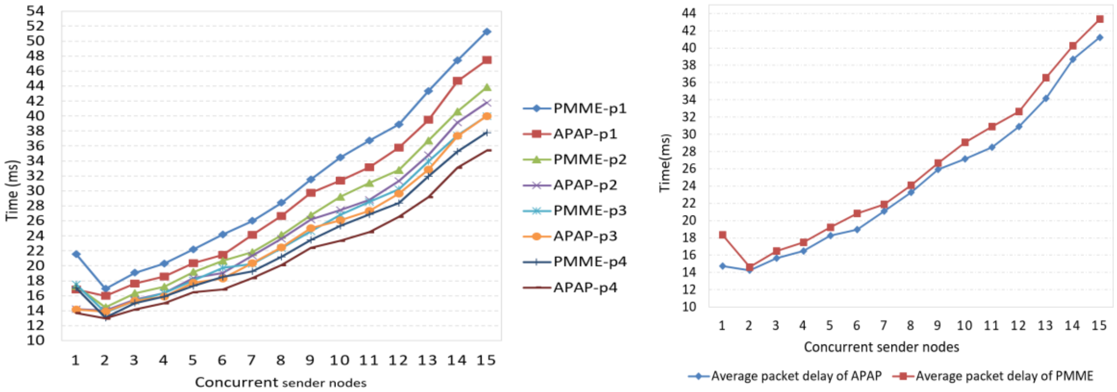
Table 2. *Main simulation parameters*

No	Parameter Description	Value
1	Network size	$10mx10m$
2	Number of concurrent sender nodes	1-15
3	Senders' positions	Random
4	Bandwidth	250kb/s
5	Retry limit maxTxRetries	10
6	Random start time of sensors	0-5ms
7	DATA packet size	28bytes
8	Event rate or Packet rate	1 event/s or 1 packet/s
9	Number of packets/ sensor	1000
10	The ratio of traffic of each packet	25%

3.2. Packet delay

Packet delay is end to end delay of priority packets. It means that the time of different priority packets start generating to the time it reaches the receiving/sink node. In this section, we compare average delay of different priority packets and average delay packets between APAP and PMME protocols.

In Figure 4a, it represents the average delay of different priority packets between APAP and PMME protocols. In this figure, we can see that the delay of the priority packets p_4 , p_3 , p_2, p_1 of APAP is 5.03%, 2.35%, 3.12%, 8.45% lower than the delay of those four appropriate priority packets of PMME on average. Its means that APAP has a better effected on the priority packets p_4 and $p_1$than the priority packets p_3 and p_2. And we also see that the average packet delay of APAP is better than average packet delay of PMME as in Figure 4b. Therefore, with these results, it shows that the packet delay of APAP is better than the packet delay of PMME protocol.



(a) *(b)*

Figure 4. *Average delay of each priority packets between APAP and PMME protocol a) and average packet delay of APAP and PMME protocol (b)*

3.3. Average energy consumption

In this section, we evaluate average energy consumption in mJ per bit for the successful transmission between APAP and PMME protocols. Figure 5 presents that the average energy consumption of APAP is a little smaller than the PMME protocol.

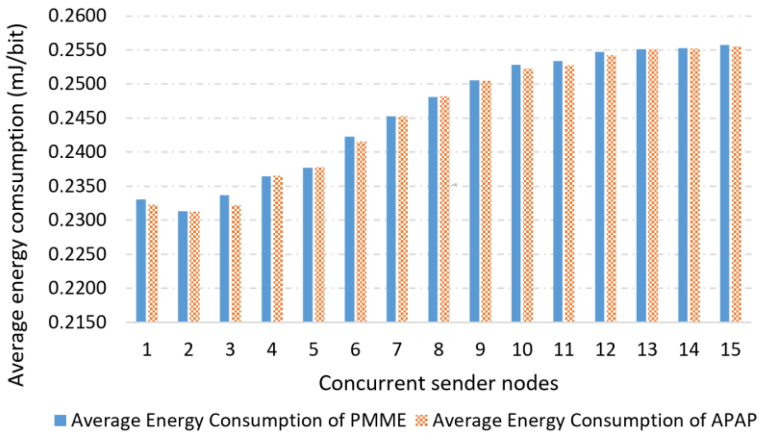


Figure 5. *Average consumption between APAP and PMME*

3.4. Packet loss rate

Figure 6 shows the comparison of the average packet loss rate of APAP and PMME protocols. It can be seen that the number of nodes has not only affected the packet delay and average energy consumption but also the packet loss rate. The average packet loss rate of APAP is less than that of the PMME. In particular, we see that in the case of the number of nodes are 14 and 15, the packet loss rate of APAP is much smaller than the packet loss rate of PMME. It shows that APAP is more efficient than PMME protocol with higher the number of the sending nodes.

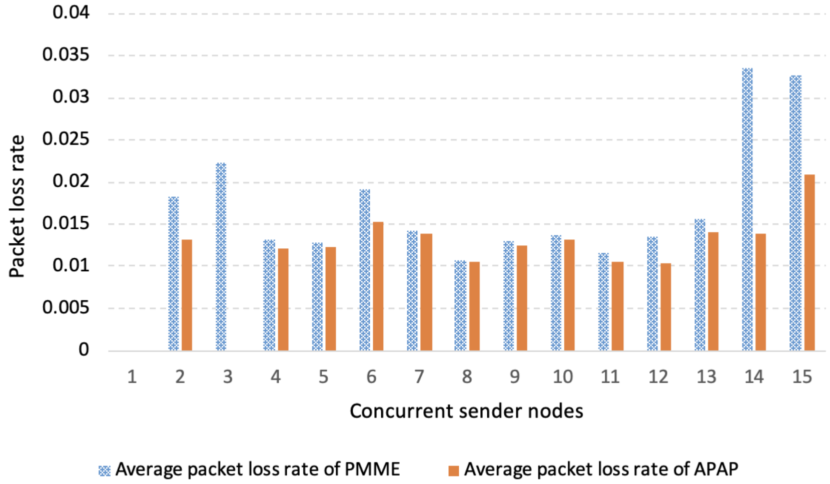


Figure 6. *Average packet loss rate of APAP and PMME*

3. Conclusions

In this paper, we have proposed and implemented the APAP protocol to improve multi-event wireless sensor network performance, in terms of packet delay, average energy consumption and packet loss rate. With simulation results, we affirm that using constant priority values of PMME protocol is not appropriate in case number of sending node changes, so the higher the number of sending nodes, the smaller the p_i value should be. However, when the p_i values are so small, it also causes a decrease in network performance. Therefore, in our future work, we will continue to focus on improving the MAC protocol of multi-event wireless sensor networks in industry environments.

REFERENCES

[1] A. K. Sharma, B. S. Sohi, and S. Chandra, “SN based forest fire detection and early warning system,” *International Journal of Innovative Technology and Exploring Engineering*, vol. 8, no. 9, pp. 209-214, 2019.

[2] H. A. B. Salameh, M. F. Dhainat, and E. Benkhelifa, “An End-to-End Early Warning System Based on Wireless Sensor Network for Gas Leakage Detection in Industrial Facilities,” *IEEE Systems Journal*, vol. 15, no. 4, pp. 5135-5143, 2021.

[3] M. Li, X. -B. Chi, X. -C. Jia and J. -L. Zhang, "WSN-based efficient monitoring for overhead transmission line in smart grid," *In Proc 35th Chinese Control Conference (CCC)*, 2016, pp. 8485-8489, doi: 10.1109/ChiCC.2016.7554711.

[4] L. Banjanovic-Mehmedovic, M. Zukic, and Mehmedovic, “Alarm detection and monitoring in industrial environment using hybrid wireless sensor network,” *SN Applied Sciences*, vol. 1, no. 3, pp. 1-11, 2019.

[5] R. Fang, J. Wang, W. Sun, and Q. Li, “QoS Model of WSNs Communication in Smart Distribution Grid,” *International Journal of Distributed Sensor Networks*, vol. 2016, pp. 1-23, 2016.

[6] S. Sarang, M. Drieberg and A. Awang, "Multi-priority based QoS MAC protocol for wireless sensor networks," *7th IEEE International Conference on System Engineering and Technology (ICSET)*, 2017, pp. 54-58, doi: 10.1109/ICSEngT.2017.8123420.

[7] B. A. Muzakkari, M. A. Mohamed, M. F. A. Kadir, and M. Mamat, “Queue and Priority-Aware Adaptive Duty Cycle Scheme for Energy Efficient Wireless Sensor Networks,” *IEEE Access*, vol. 8, pp. 17231-17242, 2020.

[8] A. N. Sakib, M. Drieberg, A. Aziz, "Energy-Efficient Synchronous MAC Protocol based on QoS and Multi-priority for Wireless Sensor Networks," *IEEE 11th IEEE Symposium on Computer Applications & Industrial Electronics (ISCAIE)*, 2021, pp. 347-352, doi: 10.1109/ISCAIE51753.2021.9431806.
[9] T. Mirzoev, "Standard speciation for Low-Rate Wireless Personal Area Networks (LR-WPANs)," *IEEE 802.15.4*, 2003.
[10] L. Karim, N. Nasser, T. Taleb and A. Alqallaf, "An efficient priority packet scheduling algorithm for Wireless Sensor Network," *IEEE International Conference on Communications (ICC)*, 2012, pp. 334-338, doi: 10.1109/ICC.2012.6364150.
[11] S. Sarang, G. M. Stojanovi, S. Stankovski, and Ž. Trpovski, "Energy-Efficient Asynchronous QoS MAC Protocol for Wireless Sensor," *Wireless Communications and Mobile Computing*, vol. 2020, 2020, Art. no. 8860371, doi: https://doi.org/10.1155/2020/8860371.
[12] H. Kim and S.-G. Min, "Priority-based QoS MAC protocol for wireless sensor networks," *In Proc. IEEE Int. Symp. Parallel & Distributed Processing, Italy, May 23-29*, 2009, pp. 1-8.
[13] S. C. Kim, J. H. Jeon, H. J. Park, "QoS aware energy-efficient (QAEE) MAC protocol for energy harvesting wireless sensor networks," *In Processing of International Conference on Hybrid Information Technology, South Korea*, 2012, pp. 41-48.
[14] S. Sarang, M. Drieberg, and A. Awang, "Multi-priority based QoS MAC protocol for wireless sensor networks," *7th IEEE International Conference on System Engineering and Technology (ICSET)*, 2017, pp. 54-58, doi: 10.1109/ICSEngT.2017.8123420
[15] T. T. H. Nguyen, N. C. Trinh, N. T. Ban, M. Raza, and H. X. Nguyen, "Delay and Reliability Analysis of p-persistent Carrier Sense Multiple Access for Multi-event Industrial Wireless Sensor Networks," *IEEE Sensor Journal*, vol. 20, no. 20, pp. 12402-12414, 2020.
[16] T. T. H. Nguyen, C. T. Nguyen, and T. B. Nguyen, "PPME–Priority MAC protocol for MultiEvent Wireless Sensor Network," *Journal of Military Science and Technology*, vol. 59, pp. 12-25, 2019.
[17] A. Boulis, *Castalia: A simulator for wireless sensor networks and body area networks*, NICTA: National ICT Australia, 2011.
[18] A. Varga, "OMNeT++ user manual version 4.6," OpenSim Ltd, 2014. [Online]. Available: http://www.omnetpp.org/. [Accessed May 03, 2022].
[19] Texas Instruments. "CC2420 single-chip 2.4 GHz RF transceiver". [Online]. Available: http://www.ti.com/lit/ds/symlink/cc2420.pdf. [Accessed Apr. 12, 2022].
[20] S. Sarang, M. Drieberg, A. Awang, and R. Ahmad, "A QoS MAC Protocol for Prioritized Data in Energy Harvesting Wireless Sensor Networks," *Computer Networks, International Council for Computer Communication*, Elsevier, vol. 144, pp. 141-153, 2018.
[21] M. Doudou, D. Djenouri, J. M. Barcelo-Ordinas, and N. Badache, "Delay-efficient MAC protocol with traffic differentiation and run-time parameter adaptation for energy-constrained wireless sensor networks," *Wireless Networks*, vol. 22, no. 2, pp. 467-490, 2016.
[22] S. L. Yadav, R. L. Ujjwal, S. Kumar, O. Kaiwartya, M. Kumar, and P. K. Kashyap, "Traffic and Energy Aware Optimization for Congestion Control in Next Generation Wireless Sensor Networks," *Journal of Sensors*, vol. 2021, 2021, Art. no. 5575802, doi: 10.1155/2021/5575802.