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RESEARCH ARTICLE

Performance Analysis of a Dynamically Power Managed and Event-Based Wireless Sensor Node Enabled by Queue Discipline

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Abstract – In recent years, Wireless Sensor Networks (WSNs) have attracted the attention of researchers in view of providing a system with high performance and low power consumption. The consistent challenge is to address the trade-off between performance and power consumption. Hence, many key performance metrics need to be analysed for the design of an efficient Wireless Sensor Network. Existing power management techniques, when surveyed, have addressed the issue of power and performance of the node but with the limitation on the selection of queue discipline; this motivates our study to analyse the importance on the selection of queue discipline as it majorly plays a vital role in power and performance management. Thus, we developed a Dynamically Power Managed WSN node in MATLAB Simulink depicting the stochastic behaviour of event arrival and performed the analysis on a single server. This article focuses on the study of queue discipline based on M/M/1 queuing theory with a detailed analysis of First In First Out Queue on the performance of an individual WSN node. The innovation of our work is in the detailed analysis of the behaviour of events in the queue. The parameters analysed are waiting time, average length of the event in the queue and the number of events missed the service by the server. The simulation results make it evident that the events when served based on the First Come First Serve basis performs 10% better in terms of missing events in the queue as compared to Last in First Out Discipline. It is also observed that the arrival rate of the events has an impact on the number of missed events and the utilization of the processor; hence we analysed the need to reduce the number of missed events, especially when the arrival of events is fast.

Index Terms – Wireless Sensor Network, Dynamic Power Management, First In First Out Queue, Waiting Time, Utilization.

1. INTRODUCTION

Wireless Sensor Network (WSN) has a wide spectrum of applications that encompasses the medical field, the healthcare industry, process industries, defence applications, agricultural sector, power systems and smart grid application, etc. Many applications demand continuous monitoring and therefore, the need of the hour is to meet the requirements of an efficient, power-optimized WSN. Such a WSN consists of numerous nodes, which are self-organized and monitored, and are deployed at remote locations. Recently, longer life and high performance have assumed importance for both, the industry and academic researchers in the interpretation of providing a power-managed WSN with high performance, and which is operated with longer life in any of the WSN applications. This in turn requires continuous monitoring; however, human intervention is difficult at all times. Various researchers have designed sensor nodes in varied applications. Authors in [1] designed a sensor node using the Whispering gallery mode resonance method to measure thermal deformation in MEMS. The researchers [2] designed a humidity monitoring sensor using the thermal lens detection technique. A team of researchers [3] investigated and proposed a displacement sensor for structural health monitoring and detected the early corrosion based on Fiber Bragg Sensor. WSN in the industrial environment is an important application and authors in [4] formulated an optimization problem considering the deployment problem, the researchers continued the work in [5] for Wireless Data Center Network and formulated optimization problem considering the coverage as objective. There is a massive

RESEARCH ARTICLE

research opportunity in designing a sensor node considering the application and different performance parameters in recent days. Therefore, there is a demand to design energy-efficient nodes which have either power or performance as the constraint. This has in turn resulted in extensive research being conducted on the power and the performance of WSN sensor node design.

The WSN nodes are either trigger driven or event-driven, depending on the application. Mostly, the sensor node is event-driven as it processes and communicates the collected information on an event sensed by the sensing unit. The events that occur are random by nature, and these independent events appear at discrete time intervals. These events are then required to be serviced by the sensor node. Further, the random and independent events need to be pre-processed, analysed and served by the processor [6]. The served events are further communicated to the next node in case of a multi-hop scenario; else, these events are communicated to the main coordinator. These nodes are then optimized for power consumption under the constraint of performance or power consumption. The factors which are known to largely affect the performance are event arrival rate, length of the waiting time for the events to be serviced, the number of missing events, the opportunity to be serviced by the processor, the power consumption of the node, etc. Since the nodes are usually resource-constrained and need to be managed for better performance efficiently, the selection of the appropriate management policy assumes importance. Researchers have proposed many techniques and protocols in the state of art to enhance the lifetime of such resource-constrained nodes. The most promising technique is the implementation of Dynamic Power Management (DPM) which is observed to need the art of selecting the appropriate queue discipline which affects the system performance. Then based on the queue discipline, the number of events to be serviced can be improvised and simultaneously the number of missed events can be reduced.

1.1. Research Objective

In our previous work [7], we have analysed the impact of arrival rate and the probability of change detection on the lifetime and consumption of power in a WSN node; however, without considering the queue discipline, the number of arrived and served events by the processor, average time of a waiting event, and the other factors which affect the performance of a WSN node. Further, following [8], we have also modelled a semi Markov based event-driven node using a queue theoretic approach. The work conducted by us demonstrates the stochastic behaviour of an input event arrival and discusses its effect on the performance of the node. However, this analysis was limited to investigating the effect of queue parameters on the performance of the node. Thus, it motivates us to investigate and find the dependency of queue parameters on node performance.

In the current work, we aim to extend our previous work by considering the queue discipline and the DPM technique for an event-based WSN sensor node. The model developed in the current article details the behaviour of the queue in terms of the number of events departing, waiting events, missed events and the effect of variation in arrival rate in terms of waiting time, and the events to be serviced by the processor in terms of utilization factor. The model aids in the analysis of queue discipline in terms of the average waiting time of the event, and an average number of events in the queue over time. We perform the analysis of the queue discipline considering the First In First Out (FIFO) with a single server by developing a Simulink model on the MATLAB software. We also focus on the analysis of the queue parameters which affect the performance of the WSN sensor node.

The rest of the work is structured as follows: Section 2 describes the related work; Section 3 presents the developed model of the sensor node with the FIFO Queue using the MATLAB Simulink software. Section 4 discusses the obtained simulation results. Finally, Section 5 concludes the study.

2. RELATED WORK

Much research exists in the literature on the analysis of the performance metrics of WSN under power constraint. Authors in [9] have proposed an admission control model based on probability to obtain improved throughput using the Markov Decision Process and analysed the decision policy on the utilization of energy by switching the status of the node. The proposed model applies to all the events that arrive at the sensor input. The limitation of the model is that it does not consider that an event that arrived might be undesired, and if such an event is serviced without the analysis, it would lead to an increase in power consumption. The authors in [10] have analysed the waiting time distribution of a finite capacity multi-server queue using a Markov chain. They have analysed the optimal performance strategies of the S-staggered setup policy, and have determined the mean response time of task with servers to remain inactive for a random amount of time with the limitation of analysis only on multi-server systems. In another work, the clustering approach is used for the analysis of performance, and the stochastic approach is applied for the energy evaluation by the authors in [11]. The authors provide an analytical model considering the failure of node and channel and the queue capacity with sleep/active operating conditions. The results are obtained using the spectral expansion solution method, simultaneous linear equations, and discrete event simulation. The results demonstrate approximately 70% of the utilization of energy and savings in the idle state. The authors also mention that the study can be extended for other sleep scheduling techniques. Researchers focused on modelling the queue system in [12], the authors present their study on the performance of fog

RESEARCH ARTICLE

computing system using a mathematical and analytical model. They have derived formulas for key performance metrics and have validated the results using the JMT simulator. The authors have mentioned the research gap in the field of IoT and focused the study of analysis on fog nodes. The other work by the authors in [13] models a stochastic system with two queues; representing the battery and the senor data buffer. The results of the experiments reveal that the data arrival correlation has a limited impact on the performance measures, and the time visit of the mobile sink has an impact on the mean data delay. The limitation of the work is the discipline of the queue modelled and encourages our analysis. To perform the theoretical analysis and to find the relation, authors in [14] have performed the analysis on an M/G/I queuing model, and have proposed a novel three-way handshaking mechanism. The simulation results prove that the in-band full-duplex access point outperforms the half-duplex access point. Researchers in [15] have also worked on the Quality of Service (QoS) and have developed the QoS model of WSNs communication in a smart distribution grid based on IEEE 802.15.4 protocol. They have focused on multi-priority data, and have developed the model using a Markov chain model. In their work, delay time, rate of collision and throughput are analysed for the proposed method with IEEE 802.15.4e and a hybrid model. The authors have also presented the sending rates for multi-priority data for the smart distribution grid. As an extension, the authors in [15] will be working on the evaluation of the performance of an improved QoS model by NS-3 simulator or QualNet Simulator.

Researchers have also contributed in the domain of multi sink wireless sensor networks. The work by authors in [16] has discussed the need of increasing the network lifetime and energy balance. They have studied the load distribution of nodes and cascading of nodes and the relevant effect on the network lifetime. The Authors mention that increasing the node capacity can reduce the failure caused by cascading. In continuation of the work, the authors in [17] have proposed the Mematic Algorithm to assist the Wireless Sensor Network through topology optimization to reduce the chances of cascading failures. In the study, the authors learnt the onion-grid topology structure to be more efficient relatively. And authors are extending their work towards improving the effectiveness of the algorithm using Signal to Interference Noise Ratio (SINR) to communication links. Authors in [4] constructed a radio propagation model considering the Line of Sight and interference issues. In the article, they have formulated topology optimization with coverage as objective and intensity and interference as constraints. Authors in [5]extended the study and Analysed multipath routing and discussed the different issues when the sensors are deployed in an industrial environment considering Industrial Wireless Sensor Network(IWSN) and formulated the deployment problem as an optimization problem with mentioning the limitation of time consumed with respect to proposed algorithm and existing algorithm. A group of researchers surveyed multi-sensor fusion in [18]. Authors have mentioned the motivation of obstacle detection using a single type of sensor along with the limitation, and have presented the concept of multi-sensor configuration with comparisons. Experimental research was carried out by authors in [19] using Fiber Bragg (FBG) displacement sensor to monitor the health of a structure using the central wavelength concept. Results prove that the sensor has good sensitivity and the sensor is suitable for high precision application. The authors in [19] used the FBG sensor to detect the early monitoring of Rebar Corrosion and shown the wavelength variation of the sensor and mass-loss rate of Rebar.

3. SIMULATION MODEL

As shown in Figure 1, the system under consideration is modelled with a service requestor (sensing unit), a service queue (memory), and a service provider (Processor). The sensing unit detects the occurrence of a stochastic event at a discrete interval of time. These events are further to be processed by the processing unit. The processing unit filters the arrived events and has an analyser unit to analyse the arrived events to be a desired event. It must be noted that the current work assumes that the events generated by the service requestor are the desired events. These desired events are to be serviced by the processor in a disciplined logical manner such that, all the events are effectively processed. Thus, in the proposed model, the events are passed through a service queue to a single service provider.

The proposed model is developed on the M/M/1 Queuing system on MATLAB software using the SimEvents Library package in SIMULINK [20]. The events generated by the service requestor are arranged in the FIFO discipline hence creating a real-time scenario. In FIFO, the events are serviced based on arrival, and the FIFO queue discipline implies that the events to be scheduled are based on the order/ sequence of the arrival to be serviced. The real-time scheduling of WSN is exhibited by the TinyOS, i.e., the FIFO queue base for all event-based applications [21].

The events are randomly generated by the service requestor subsystem. This subsystem abstracts the stochastic behaviour of the events which can occur. As shown in Figure 2, the proposed model has an event-based random number block [20] which follows a Poisson distribution since, merging and splitting needs to be considered in the event-based WSN [22, 23, 6]. Further, the time-based entity generator follows an exponential distribution such that, the inter-arrival time is exponentially distributed among the events, and follows the memory less property [24].

The following assumptions are made in the system design

1. Poisson distribution for generation of event arrival ‘ λ ’.
2. Exponential distribution for the inter arrival time distribution.
3. The simulation parameters as shown in Table 1 from our previous work [7].
4. The model under analysis is power managed by a power manager unit designed in our previous work [7] by employing DPM technique based on Semi Markov Model.
5. The Event based random number generator is used to generate entities with Poisson distribution.
6. The Time-based entity generator is used with exponential distribution.
7. Generated events are stored in the queue with a 1000 queue capacity.

The current analysis follows a stochastic process, and hence, it is modelled as $\{x_t, t \in T\}$, where x_t are the numbers of events arriving in a time interval t. We consider $N(t)$, be the number of events arrived within the period $[0,t]$. The ‘set attribute block’ sets the service time for the server with the scheduled time out in addition to the setting of the attribute for the events to be generated. Further, the FIFO departs the number of events in the output port ‘*d*’ and ‘*n*’ port departs the waiting events in the queue, ‘*w*’ describes the average waiting time, ‘*len*’ describes the average number of events in the queue, and the missed events from the queue are out through ‘t_o’ port of the queue.

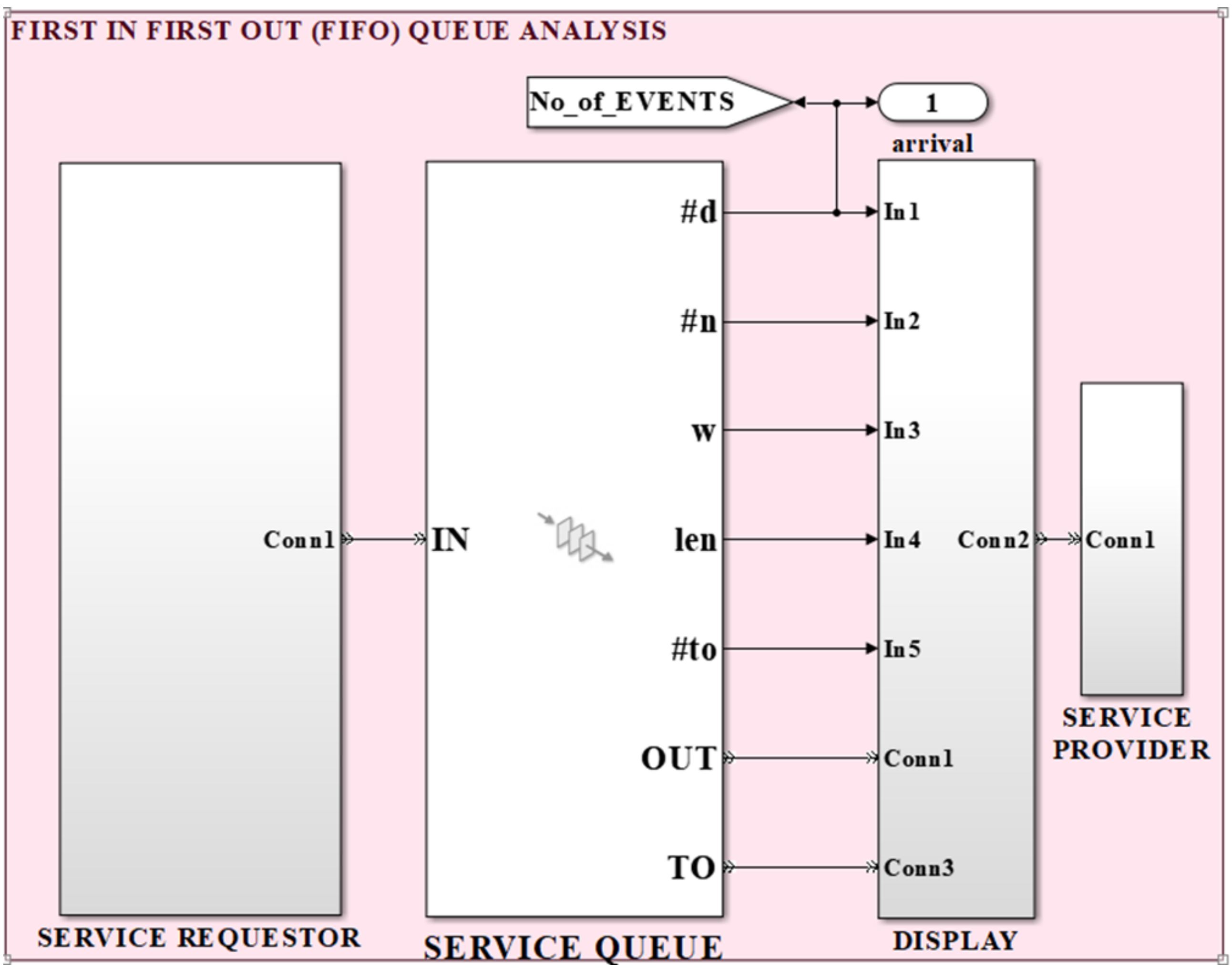

Figure 1 Sensor Node Model [20]

RESEARCH ARTICLE

Parameters	Value	Parameters	value
Power State at sensing unit	2.3mW	Processing time	2s
Power State at analyser unit	2.3 mW	Transmission time	0.175s
Power State at Processing unit	237.5mW	Analyzing time	0.05s
Power state at communication unit	307.9mW	Battery Energy	1863J

Table 1 Simulation Parameters [7]

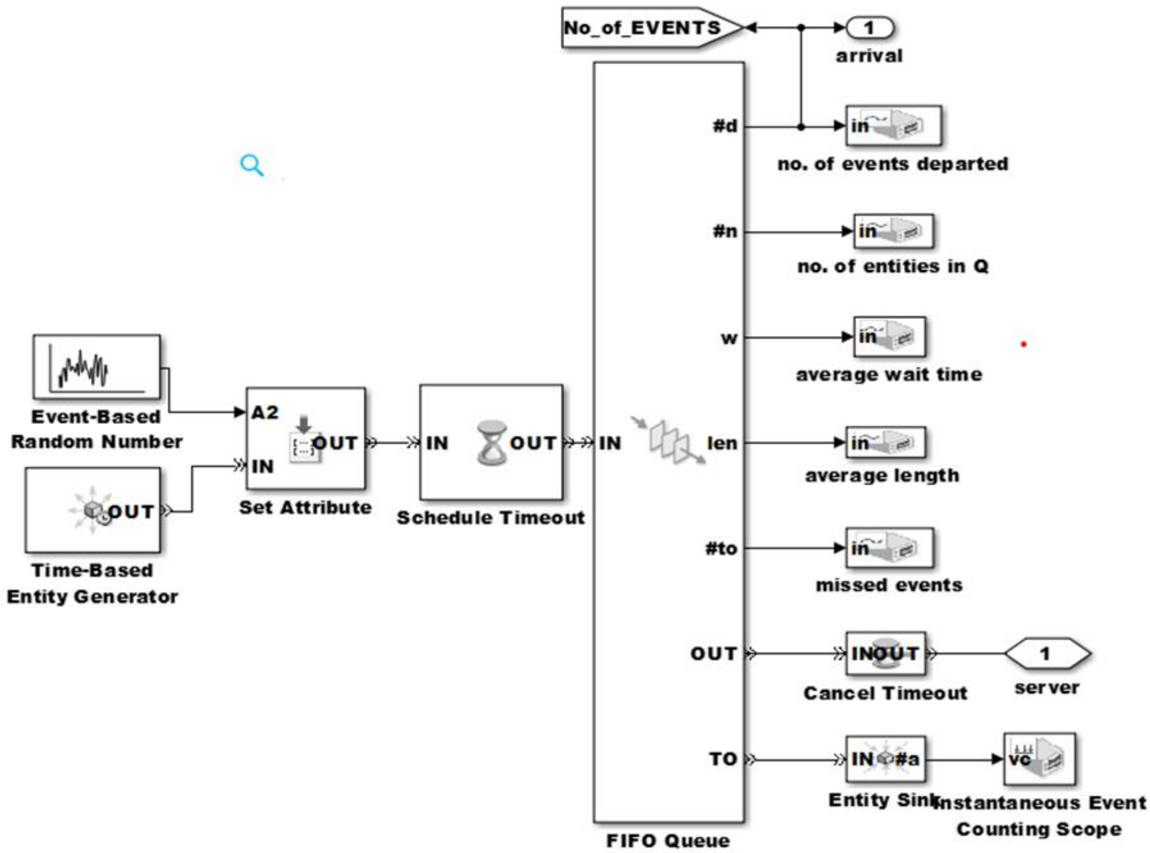

Figure 2 The Generated Model [20]

Arrived Event (IN)	Departed Event (d)	Events In Queue (n)	Missed Event (to)	Waiting Time (w)	Avg. No. Of Events In Queue (len)
32	28	4	0	0.70862	0.773622633
32	28	3	1	0.68419	0.773622633
34	31	1	2	0.93955	0.977764117
50	44	3	3	0.91961	0.896433119
55	47	4	4	1.01233	1.100566345
58	49	4	5	1.1582	1.231425701
65	54	5	6	1.39812	1.534912686
66	54	5	7	1.44077	1.563129956

67	55	4	8	1.45929	1.609867553
67	56	2	9	1.52956	1.625545648
83	72	1	10	1.67638	1.716979292

Table2 FIFO Block Parameters [20]

3.1. Algorithm

The aim of the work is on simulation analysis on the behaviour of events; 1) the impact of the logical arrangement of these events; 2) the waiting time of these events; 3) the average length of these events to stay in the queue; 4) the events that miss the service of the server in the queue using M/M/1queuing theory thus we have attempted to use queuing theory and the simulation analysis to measure system performance based on the function of input parameters. The input parameters considered are the arrival rate of the events, service rate. However, any mathematical model in the current work is beyond the scope of this paper instead we are focusing on establishing an analysed relationship between the system performance parameters by varying the input parameters by using the established queuing theory.Motivation of our study is the negligence on the arrangement of the events in the queue and the behaviour of the events in the queue by the previous work and we extend our analysis in comprehending the effect of the waiting time on the utilization of the server thus we developed the detailed algorithm as follows:

- Generate the events randomly using event-based random number block with event arrival having Poisson distribution.
- The inter-arrival time between the randomly generated events is exponentially distributed by the time-based entity generator.
- The Service time of the server is set using the set attribute block
- From the SimEvents Library select the Queue Discipline, to arrange the events in a logical order and a single server.
- Analyse the block parameters of the Queue by varying arrival rate.

4. SIMULATION RESULTS

The developed model demonstrates the stochastic behaviour of an input event arrival with FIFO Queue and a single server. The model is analysed for the (i) arrived events which are to be serviced, and are arranged in a logical and structured manner, and (ii) impact on the consumption of power and node lifetime. The model integrates the DPM technique to manage the power and queuing discipline for the analysis of improving the performance of the node. The obtained simulation results are presented and discussed in what follows.

The developed model is simulated to establish a relationship between the dependent variables and independent variables. The input variables are independent and we extended our study by varying the arrival rate and establishing its effect on the power and performance of the node. We initiated the study considering the arrangement of events to be serviced as the events arrive i.e. FIFO discipline. The FIFO block parameters are tabulated in Table 2. The table details the behaviour of the events before getting serviced by the processor. It can be observed that the summation of the departed events, waiting events, and the missed events are equal to the number of arrived events into the storage memory.

Further, the waiting time is seen to affect the missing events. Also, the waiting time and the average number of waiting events increase with the variation of time, in turn, replicating the real-time applications of WSNs. It is also observed that the events waiting in the queue are departed from the block to be serviced else, they contribute as the missed event. It must be noted that a detailed analysis of the missed events is beyond the scope of the current article. However, in the current work, we have analysed the departed events and the service of these events in terms of utilization of the processor.

Figure 3 depicts the events that are out from the FIFO block are to be serviced by the processor. As mentioned earlier, the generated events enter the FIFO, and are departed out from the output port 'd'. Figure 4 shows the number of events that are missed from the queue. It is to be noted that the events which are missed are collected through the port 'to'. Also, in our analysis, of the 95 generated events, 85 are departed, and 10 are missed events. This can be considered as the limitation of the FIFO queue as the missed events could be critical and misses out on the provisioning of the server. Further, this limitation makes the FIFO Queue less effective in the event-based sensor application.

As shown in Figure 5, the 'len' label in the queue describes the average number of events in the queue over time. Considering the number of missed events in the queue, in the FIFO analysis, the maximum average number of events over a period is found to be 35.71 % more efficient than the LIFO analysis. The average waiting time of the events is shown in Figure 6. It can be observed from the figure that the average waiting time increases with the variation of time. This also depicts the waiting time in processing the events and describes the mean of waiting times in the block for all the events which have departed from the queue. The maximum waiting time for the given queue is noted as 1.68472 seconds.

Figure 4 shows the variation of the arrived events concerning the missed events, departed events and events in the queue. In our study, 95 arrived events are generated and are arranged in FIFO which block-outs the events on a First come first serve basis to the Processor via 'd' port. As shown in Figure 7, 10 events are missed with no events waiting in the queue at the end of the simulation (see Figure 9); hence, the departed events from the queue to be serviced are 85 as shown in Figure 8.

Table 3 shows the effect of arrival rate on the performance parameters of a WSN node. The parameters considered for our analysis are the (i) number of events entering the queue, (ii) the number of departed events departed from the queue, (iii) number of missed events from the queue, (iv) average waiting time of the events in the queue, (v) power consumption of the node in mW, (vi) Lifetime of a WSN node in days, and (vii) utilization of a single processor of the node. The theoretical value of utilization of server is calculated using the Little formula equation for M/M/1 Queuing system as shown in equation (1) [25].

$$\rho = \frac{\lambda}{\mu} \quad (1)$$

Where, λ is the events arrived in the server and μ is the service time of the server to find the utilization ρ.

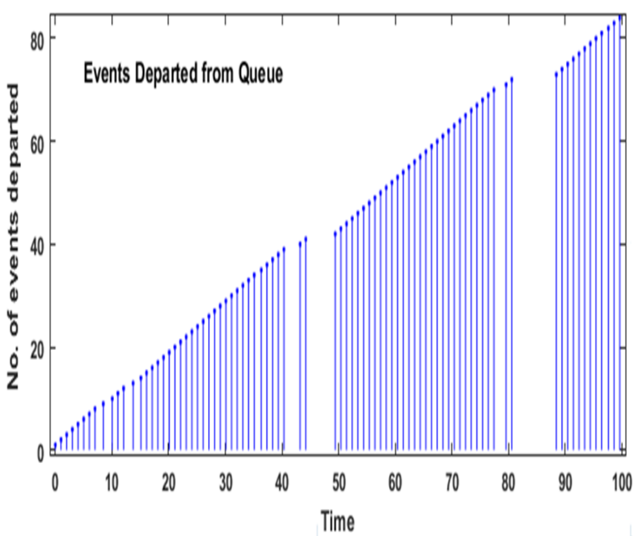

Figure 3 Output Ports of FIFO Queue: The Number of Events Departed vs Time[20]

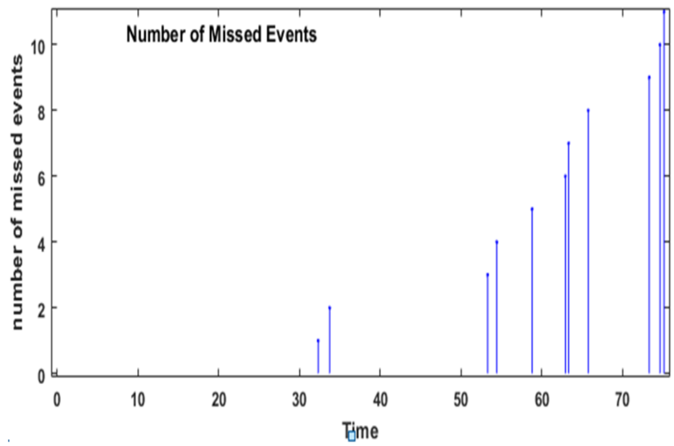

Figure 4 Output Ports of FIFO Queue: The Number of Missed Events vs Time[20]

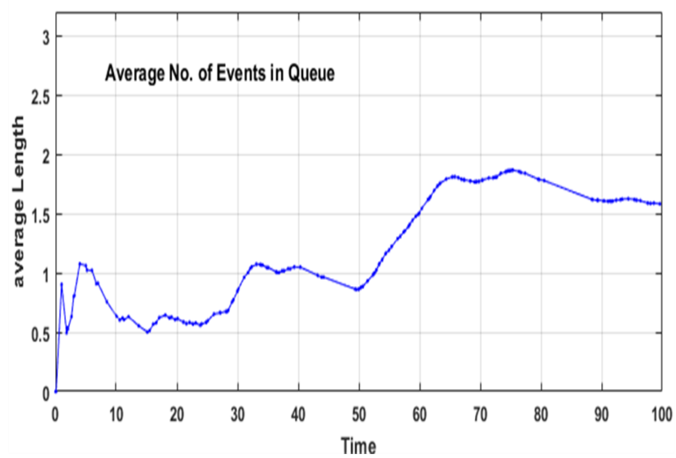

Figure 5 Output Ports of FIFO Queue: Average Number of Events in Queue Over Time [20]

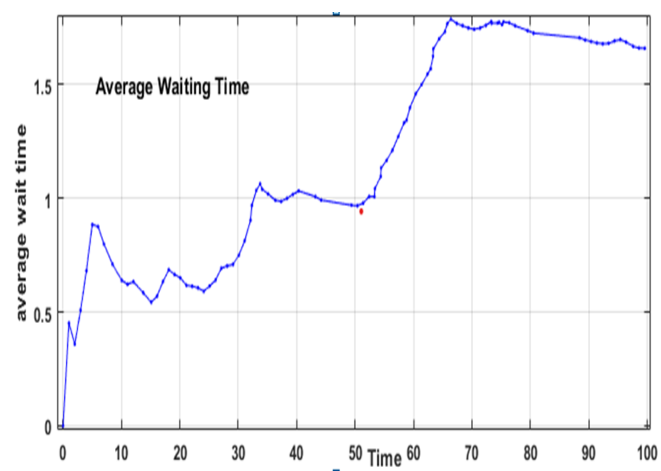

Figure 6 Output Ports of FIFO Queue: Average Waiting Time of Events in a Queue [20]

RESEARCH ARTICLE

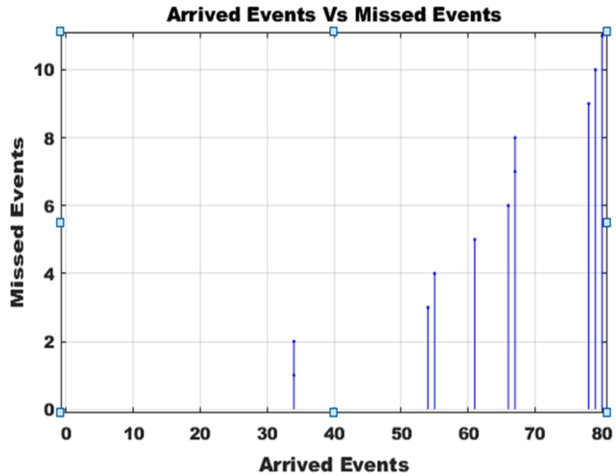

Figure 7 Variation of Arrived Events vs Missed Events [20]

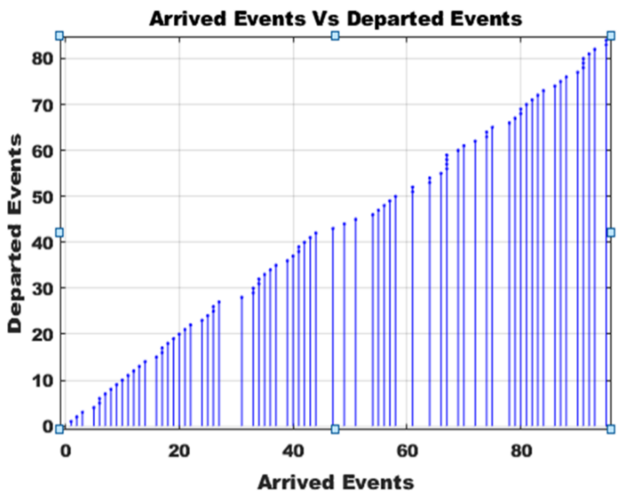

Figure 8 Variation of Arrived Events vs Departed Events [20]

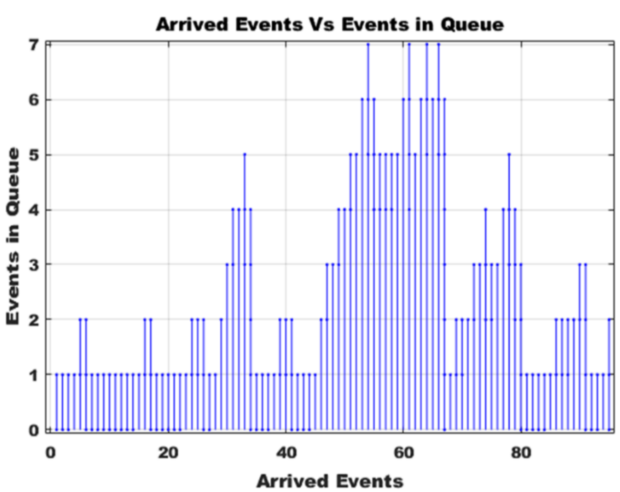

Figure 9 Variation of Arrived Events vs Events in the Queue [20]

It is observed from Table 3 that the arrival rate and the scheduled time out decide the number of events to be served within a specified time. However, it can also be observed that the decrease in the arrival rate, affects the time of the events waiting in the queue, and also on the missed events. Further, the consumption of power in the node is reduced by reducing the event arrival rate which in turn also improves the lifetime of the node. The average time of waiting events in the queue is observed to affect the overall performance of the WSN node.

Table 3 also shows the relation of the departed events from the queue, and the service time in terms of utilization of the processor. The utilization is found to be affected by the change in the arrival rate. It can be observed clearly that the slower the arrival of the events, the lesser is the utilization of the processor. Even with more missed events, utilization is better if the arrival rate is fast. Thus, it can be concluded that the arrival rate has a major impact on the time of the waiting events in the queue, and also on processor utilization. Overall, the system is found to be performing better with more number of missed events for a faster arrival rate.

Figure 10 demonstrates the behaviour of the server utilization and the events waiting time with the variation in time. It can be seen from the figure that the waiting time of the events affects the utilization of the server. This in turn indicates that the long delays in waiting for the events to be serviced affect the node performance. It can also be seen that that initially, the utilization is 100% until the number of waiting events in the queue increases. The variation in the utilization is due to the change in the average time of the events in the queue.

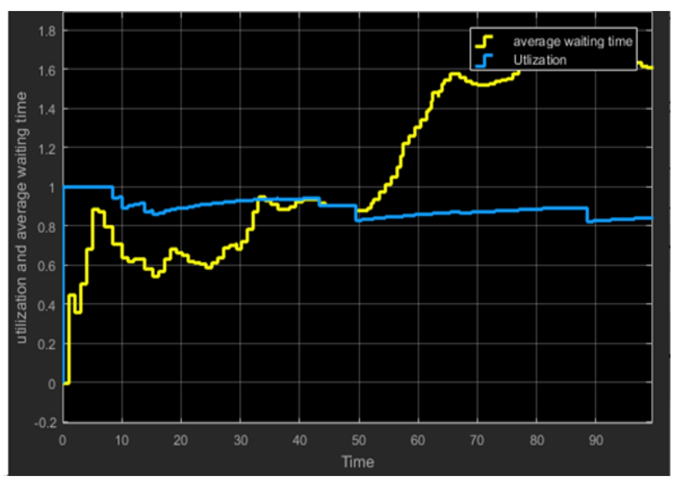

Figure 10 Average Waiting Time and Utilization [20]

Further, it can also be observed that once the system attains the state of equilibrium, there is no major change in the utilization of the processor which implies that with an increase in the waiting time of the waiting events, the missed events increase thereby, affecting the performance of the

RESEARCH ARTICLE

node. This extensive analysis in the selection of Queue discipline and better utilization of the server in terms of waiting time and the average length of events in the queue motivates the researchers to find an optimal way to reduce the missing events and enhance the performance of the node as the nodes are to be dynamically managed with respect to power and extend the performance in terms of lifetime for all the event-based applications.

Arrival Rate	Arrived Events	Departure Events	Missed Events	Average Waiting Time	Power Consumption (mW)	Lifetime (days)	Simulated Utilization	Theoretical Utilization
1	95	85	10	1.610438	237.4253	78.46	84.3%	85%
3	34	33	1	0.233688	235.31	79.17	34.3%	33.0%
5	19	19	0	0.067049	232.7056	80.05	19.1%	19%
7	13	13	0	0.024765	229.7996	81.07	13.4%	13%
10	9	9	0	0.003484	225.5755	82.58	10.5%	9%

Table 3 Effect on Performance Parameters with Variation in the Arrival Rate [20]

5. CONCLUSION

In the DPM model, the missed events are required to be minimized and hence, WSN nodes require the reduction in the missing rate of the events. The current work details the delay in terms of the waiting time which affects the server performance, and the events departing the queue. Extensive simulations are conducted to analyze the queue parameters affecting the overall performance of the node in a WSN. The obtained results make it evident that the pattern of the event arrival, arrangement of the events, and the behaviour of the events has a major impact on the performance of the node. It is also inferred that, in view of obtaining better utilization of the processor, it is required to reduce the number of missed events for a higher arrival rate based application where the arrival of events is fast. Further, for the same arrival rate, if the events are prioritized as high and low priority, then the performance of the entire system can be improved. Lastly, our study motivates the necessity of prioritizing the events such that, the missing events can be minimized, and eventually the performance of the node in a WSN system can be improved.

As the scope for future work, we will focus on implementing the priority queue discipline on the wireless sensor nodes.

REFERENCES

[1] A. Rahman: Novel Optical Sensor Based on Morphology-Dependent Resonances for Measuring Thermal Deformation in Microelectromechanical Systems Devices, Journal of Micro/Nanolithography, MEMS, and MOEMS, Vol. 8, No. 3, 2009, pp. 033-071.

[2] Y. Atsushi, T. Nakanishi: Optical Fiber Sensor for Humidity Monitoring Based on Thermal Lens Detection Technique, IEICE Electronics Express, Vol. 2, No. 14, 2005, 417–422.

[3] C. Li, et al.: Experimental Investigation and Error Analysis of High Precision FBG Displacement Sensor for Structural Health Monitoring, International Journal of Structural Stability and Dynamics, Vol. 20, No. 6, 2020.

[4] C. Bin, J. Zhao, P. Yang, et al.: Multiobjective 3-D Topology Optimization of Next-Generation Wireless Data Center Network, IEEE Transactions on Industrial Informatics, Vol. 16, No. 5, 2020, pp. 3597–3605.

[5] C. Bin, J. Zhao, Y. Gu, et al.: Security-Aware Industrial Wireless Sensor Network Deployment Optimization, IEEE Transactions on Industrial Informatics, Vol. 16, No. 8, 2020, pp. 5309–5316.

[6] A. Pughat, V. Sharma: Queue Discipline Analysis for Dynamic Power Management in Wireless Sensor Node, 12th IEEE International Conference Electronics, Energy, Environment, Communication, Computer, Control: (E3-C3), INDICON 2015.

[7] R Kallimani, K Pai, ,K Rasane: Stochastic Model of a Sensor Node. In Next Generation Information Processing System, Vol. 1162,Springer, Singapore, 2021, pp. 242-250.

[8] O. Mokrenko, S. Lesecq, W. Lombardi, D. Puschini, C. Albea, and O. Debicki.: Dynamic power management in a wireless sensor network using predictive control. In IECON 2014-40th Annual Conference of the IEEE Industrial Electronics Society, IEEE, 2014, pp. 4756-4761.

[9] X. Zhang, L. Demin, Z. Yihong: Maximum Throughput under Admission Control with Unknown Queue-Length in Wireless Sensor Networks, IEEE Sensors Journal, Vol. 20, No. 19, 2020, pp. 11387–11399.

[10] T. Phung-Duc, K. Kenichi: Delay Performance of Data-Center Queue with Setup Policy and Abandonment, Annals of Operations Research, Vol. 293, No. 1, 2020, pp. 269–93.

[11] E. Ever, et al.: On the Performance, Availability and Energy Consumption Modelling of Clustered IoT Systems, Computing, Vol. 101, No. 12, 2019.

[12] S. El Kafhali, S. Khaled: Efficient and Dynamic Scaling of Fog Nodes for IoT Devices, Journal of Supercomputing, Vol. 73, No. 12, 2017, pp. 5261–5284.

[13] E. De Cuypere, K. De Turck, D. Fiems: A Queueing Model of an Energy Harvesting Sensor Node with Data Buffering, Telecommunication Systems, Vol. 67, No. 2, 2018, pp. 281–295.

[14] Y. Sun, Z. Haiwei, C. Yan, W. Bin: Queueing and Channel Access Delay Analysis in In-Band Full-Duplex Wireless Networks,

RESEARCH ARTICLE

International Journal of Distributed Sensor Networks, Vol. 15, No. 4, 2019.

[15] R. Fang, W. Jianping, S. Wei, L. Qiyue: QoS Model of WSNs Communication in Smart Distribution Grid, International Journal of Distributed Sensor Networks, Vol. 12, No. 1, 2016.

[16] X. Fu, Y. Yongsheng: Modeling and Analysis of Cascading Node-Link Failures in Multi-Sink Wireless Sensor Networks, Reliability Engineering and System Safety, Vol. 197, 2020.

[17] X. Fu, et al.: Topology Optimization against Cascading Failures on Wireless Sensor Networks Using a Memetic Algorithm, Computer Networks, Vol. 177, 2020.

[18] J. Hu, et al.: A Survey on Multi-Sensor Fusion Based Obstacle Detection for Intelligent Ground Vehicles in off-Road Environments, Frontiers of Information Technology and Electronic Engineering, Vol. 21, No. 5, 2020, pp. 675–692.

[19] L. Sun, et al.: Early Monitoring of Rebar Corrosion Evolution Based on FBG Sensor, International Journal of Structural Stability and Dynamics, Vol. 18, No. 8, 2018, pp. 1–11.

[20] MathWorks. 2020: SimEvents - MATLAB & Simulink,https://uk.mathworks.com/products/simevents.html.<January 16, 2021>.

[21] P Levis, S Madden, J Polastre, R Szewczyk, K Whitehouse, A Woo, D Gay et al. :TinyOS: An operating system for sensor networks. In Ambient intelligence, Springer, Berlin, Heidelberg, 2005, pp. 115-148.

[22] H. Gillert, G. F. Newell: Applications of Queuing Theory, Monographs on Applied Probability and Statistics. New Fetter. Lane. Chapman and Hall Ltd. Vol. 53, No. 3, 1973, pp. 209–209.

[23] A. Ivo, J. Resing: AR01 Queueing Systems: Queuing Systems, Department of Mathematics and Computing Science Eindhoven University of Technology, Course Hero.https://www.coursehero.com/file/22722521/AR01-Queueing-Systems<January 16, 2021>.

[24] M. Zukerman: Introduction to Queueing Theory and Stochastic Teletraffic Models, 2013. http://arxiv.org/abs/1307.2968,<January 13, 2021>.

[25] M/M/1 Queuing System: MATLAB & Simulink – MathWorks, India.https://in.mathworks.com/help/simevents/ug/m-m-1-queuing-system.html, < January 16, 2021>.

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