Journal of Theoretical and Applied Information Technology
15th August 2021. Vol.99. No 15

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

A MATHEMATICAL MODEL TO EVALUATE DELAY AND POWER CONSUMPTION OF S-ALOHA PROTOCOL IN AN IOT ENVIRONMENT

[1,2]ABDELLAH ZAALOUL, [2]MOHAMED BEN EL AATTAR

[1]Ibn Zohr University of Agadir, Faculty of Sciences, Engineering, Mathematics and Computer Science Laboratory (IMI). Agadir. Morocco

[2]Hassan First University of Settat, Faculty of Sciences and Techniques, Computer, Networks, Mobility and Modeling laboratory: IR2M, 26000 - Settat, Morocco

E-mail: [1]a.zaaloul@uiz.ac.ma, [2]benelaattar@gmail.com

ABSTRACT

During the last decade the Internet of Things (IoT) has taken on great importance in human life flooded by the increased use of new technologies. IoT aims to make users' lives more comfortable. To achieve this objective, the researchers were interested in the communication protocols used which play an important role in the guarantee of quality for the services offered. MAC protocols are in this sense those that have received the most importance. In this context, we are interested in this paper to evaluate the performance in latency and in energy consumption of one of the most used Mac protocols which is the Slotted-Aloha protocol. For this, we propose a mathematical model based on Markov chains which allows to take into account the different aspects of the protocol studied in the IoT environment. The theoretical evaluation of the delay and of the energy consumption are made and a numerical analysis is given for the validation of our model.

Keywords: *IOT, Delay, Power Consumption, Slotted-Aloha, Markov Chain.*

1. INTRODUCTION

The paradigm of Internet-of-Things (IoT) is a new paradigm in information technology area that revolutionizing the world [1]. IoT is a term used to designate the connection of billions of various devices with each other or used to collect data from their surrounding [2][3] to ensure smart services (Fig.1). By 2025, the number of IoT online devices is expected to rise to 75 billion devices, and the IoT market revenue will grow to around 1.6 trillion U.S dollars (from 212 billion in 2020) [4].

In everyday life, the IoT technology has a wide range of applications such as smart house [5], smart cities [6], smart environment, smart health care [7], industrial control [8], smart agriculture [9,10], and other applications.

With the potential value that IoT has in applications, it has received considerable interest from industry and academic researchers. Indeed, this new technology continues to pose several challenges mainly due to the heterogeneity of the devices used in IoT [11]. This concerns specially:

- Interoperability [12]; [13]; [14]; [15]; [16];
- Communication protocols [17];
- Energy efficiency [2]; [18]; [19]; [20]; [21]; [11]; [22]; [23];
- Quality of service [24]; [25]; [26]; [27];
- Security and privacy [28]; [29]; [30]; [31].

The problems of energy and communication protocols, in all communication layers, are by far the challenges that have received the most importance in the concerns of companies and researchers in the field of IoT.This is due to the diversity and heterogeneity of the nodes connected in the IoT, both at the level of the access providers, used technologies and the networking environment.

The allocation of communication channels in IoT is a key performance that can affect severely the quality of the communication and its overhead cost. This is defined mainly by the design of the utilized multiple access protocols [32], [33].

Given the difficulty of communication and coordination between the different entities connected in an IoT network, and due of the complexity of deterministic communication protocols, Random access protocols are therefore the most efficient techniques for implementing applications based on the IoT [34]. ALOHA and its variants are the most used protocols in communications in IoT networks [35][36]. S-Aloha is one of the most used random-access protocol in IoT because of its simplicity of deployment [2]; [37]; [38]. For this, in this paper, we focus on modeling Slotted Aloha protocol in an IoT environment, in order to assess and evaluate its delay and its energy needs.

It should be noted that this paper extends the work in [38]. In this extension we were interested in the energy and delay parameters which are essential for communications in an IoT context.

In contrast to the works already published in the interest field of this paper, our purpose in this work can be summarized as follows:

- To propose a mathematical model using stochastic approach to study the properties of S-Aloha mechanism in an IoT environment;
- To determine analytically the communication performances using S-Aloha, mainly delay and energy consumption;
- To numerically validate theoretical results under different scenarios.

The remaining parts of this article are organized as follows. Section 2 gives an overview of MAC protocols in IoT. Section 3 studies the constraints of real time data in IoT. Section 4describes the Markov chain model used in this paper. Section 5 gives the analytical evaluation of the studied parameters. Section 6 presents the numerical results. Finally, the work is concluded in section 7.

2. MAC PROTOCOLS IN IOT ENVIRONMENT

Medium access control (MAC) is an element that plays a central role in any communication system [39]. The performances in IoT networks, both in terms of quality of service provided and in terms of communication costs, are highly dependent on the multiple access protocols deployed on top of the physical layer to coordinate access to the wireless channel among end-devices [2].

Centered In general, MAC protocols can be classified into two broad categories [32]:

- Deterministic access protocols which adopt a predetermined approach that requires coordination among devices. Time division multiple access (TDMA) is a such protocol.
- Random access protocols, where devices share the medium in a distributed way. Aloha is a most common protocol.

Most of MAC protocols using a deterministic approach suffer from a high cost since the communication coordination nodes need to process a large amount of information. Moreover, these protocols are not adapted to situations of dense networks such as those of IoT technology which limits their scalability and reliability [40]. Therefore, random access protocols appear to be solutions adapted to IoT networks.

The most representative of the random-access protocols and the one that opened the door to several improvements widely used in communication networks is the pure ALOHA [41]. However, Aloha suffers from a limitation in the level of throughput it achieves. This flaw was overcome by using the improved version Slotted Aloha [42].

For IoT applications, Slotted Aloha appears as a good opportunity [43], [44] of MAC protocols. In this context, Slotted Aloha has been exploited with several proposals for MAC protocols in the IoT, as it is the case for NOMA in [32], LoRaWAN in [44], [45] and [46], and P-persistent protocol in [47]. Multi-Packet Reception Dynamic Frame-Slotted ALOHA for IoT in [48].

3. MAC PROTOCOLS CONSTRAINTS FOR REAL TIME DATA

By adopting IoT paradigm, the IT world aims to make users' life more comfortable. This can be achieved by ensuring a level of quality of service for each type of data according to its requirements. The real time data, such as video streaming, tele-diagnostic in medical areas, website clickstreams, application logs, and IoT telemetry data for machine learning …, are the most sensitive to transmission delay and are also very tolerant to losses that can occur when nodes die due to power failure. Thereby, it will be very interesting to evaluate the transmission delays inherent in the routing protocol used in the IoT.

Otherwise, the concern of energy consumption is a big challenge in IoT technology. This is due to the exponential increasing of energy consumed if we count the total energy consumed by all the devices in IoT.

For these reasons, we are interested in evaluating delay of packet transmitted and energy consumption involved in Slotted-Aloha protocol. This evaluation is done through a mathematical modeling approach which is described in the following section.

4. MARKOV MODELING FOR SLOTTED-ALOHA IN IOT

The principle of a random MAC protocol is to coordinate the node's access to the communication resources and resolves the contention among their accessing the shared medium [49]. In a Slotted Aloha protocol, at each time unit only a user can transmit its data on the channel. The transmission decision only depends on the state of the user. Users can cooperate between each other by choosing the same probability to transmit their data in a given time slot.

In this section, we present a Markov Model for S-Aloha protocol, to evaluate delay and energy consumed in an IoT environment.

The Markovian assumption can be justified by the fact that, the transmission decision only depends on the state of the user which can be either a new user in the system or a backlogged user.

Notations used in the proposed model are presented in Table 1.

The states of the Markov model used can be described as follows:

- first state: the medium is busy,
- second state: the system is idle,
- third state: the system is backlogged and there is a collision.

Fig.2 represents the transition diagram of this Markov chain, where the transition probabilities between states can be defined by the transition matrix:

$$P=(p_{ij});\ (i,j)\in\{1,2,3\}^2 \qquad (1)$$

Assuming that there is a cooperation between nodes in the system, we can set that the transmitting probabilities at free stateare the same for all nodes: $PT_i = PT$, the same assumption holds at collision state: $PR_i = PR$.

Table1: Parameters used in the model

Parameters	Descriptions
M	Number of users in the system
N	Number of backlogged packets in the system
PTi	Transmitting probability at free state for node i
PRi	Transmitting probability at collision state for node i
D	The average delay of a node
EI	Energy consumed by a node in the idle state
EB	Energy consumed by a node in the busy state
EC	Energy consumed by a node in the collision state
Et	Total energy consumed by a node

The transition probabilities satisfy the following system equations:

$$\begin{cases} p_{11}=1-p_C-p_I \\ p_{12}=p_I \\ p_{13}=p_C \end{cases} ; \begin{cases} p_{21}=p_B \\ p_{22}=1-p_B-p_C \\ p_{23}=p_C \end{cases} \qquad (2)$$

and $\begin{cases} p_{31}=p_B \\ p_{32}=p_I \\ p_{33}=1-p_I-p_B \end{cases}$

where p_I, p_B *and* p_C are defined as follows:

$$p_I=(1-PR)^N(1-PT)^{M-N}$$

is the probability of the case where there is neither transmission nor retransmission;

$$p_C = (PT)^2\left(\frac{1-(1-PT)^{M-N-1}}{1-PT}\right) + (PR)^2\left(\frac{1-(1-PR)^{N-1}}{1-PR}\right) + (PT)\left(\frac{1-(1-PT)^{M-N-1}}{1-PT}\right)(PR)\left(\frac{1-(1-PR)^{N-1}}{1-PR}\right)$$

is the probability of the state where at least two users request access channel at the same time and a collision occurs;

$$p_B = (M-N)PT(1-PT)^{M-N-1} + NPR(1-PR)^{N-1}(1-PT)^{M-N}$$

is the probability that a user gets access to the channel successfully.

As the studied Markov chain is irreducible and has a finite set of states, we can compute its steady state probability which is the solution of the following system:

$$\begin{cases} \pi = \pi P \\ \sum_{i=1}^{3} \pi_i = 1 \end{cases} \qquad (3)$$

Where: $\pi = (\pi_i);\ i \in \{1,\ 2,\ 3\}$.

By combining equations (1) and (2) with the system (3), we have:

$$\pi_1 = \frac{p_B}{p_B + p_C + p_I};\ \pi_2 = \frac{p_I}{p_B + p_C + p_I} \quad \text{and } \pi_3 = \frac{p_C}{p_B + p_C + p_I} \qquad (4)$$

5. ALOHA DELAY AND ENERGY EVALUATION

As discussed in section 3, the parameters of delay and energy considered as performance requirement for real time data in IoT environment will be evaluated in this section.

5.1 Delay evaluation

In general, after one user successfully transmits a packet, it obtains the channel. This user will continue to occupy the channel for a random amount of time T. We assume that T is an exponential random variable with parameter:

$$\lambda = (p_I + p_C)$$

Let $E[T]$ the mean for the random variable T. If we put $E[T] = U$, we know that $E[T] = \frac{1}{\lambda}$ then:

$$U = \frac{1}{p_C + p_I}.$$

A relevant quantity which must be taken into consideration is the expected delay of packets which is defined as the average time, in slots that a packet takes to go from its source to its destination.

We note by Q the number of users in the system.

$$Q = \pi_1 + \pi_3 \times n_3 \qquad (5)$$

Where: $n_3 = \frac{(M+1)\times(M-1)}{2}$ represents the number of users in the cases where the system can be in a backlogged state. We find that:

$$Q = \pi_1 + \pi_3 \times \frac{(M-1)\times(M+1)}{2} \qquad (6)$$

Therefore, by the Little's law formula [50], the delay is:

$$D = \frac{Q}{\pi_1} = 1 + \frac{\pi_3}{\pi_1} \times \frac{(M-1)\times(M+1)}{2} \qquad (7)$$

5.2 Power consumption evaluation

The power consumed by a user during transmission in the S-Aloha protocol depends on the probability that the sending node is in one of its three states: idle, busy and collision.

If we set EI equal to the power consumption for the node in the idle state, EB the power consumption for the node in the busy state and EC the power consumption for the node in the collision state, then the total power consumed by the node can be calculated by the following formula:

$$E_t = \pi_1.E_B + \pi_2.E_I + \pi_3.E_C \qquad (8)$$

6. NUMERICAL RESULTS

In this section we present the numerical results for the performance parameters obtained using the proposed Markov model. The results are given and interpreted in different scenarios.

Figure.3 shows the variation of delay relative to the probability of retransmission. The delay of backlogged packets is an increasing function of the probability of retransmission. Moreover, for low values of PR the delay is not affected by the number N of backlogged packets in the system and when N increases these packets take more delay in the system.

In Figure.4, the effect of parameters PT and N on the backlogged packet delay is shown. The main idea that can be drawn from this figure is the large effect of the number N on the delay when PT varies. Indeed, the difference between the curves becomes quite important with the increase of N.

The Figure.5 shows the evolution of the power consumption by the nodes of the system when PR varies under different scenarios of values of M. The obtained results show that the energy consumption increases when the backlogged packets have a greater chance of accessing the transmission channel (PR increases). On the other hand, if M increases, the energy consumption increases. For example, the consumption growth is over 50% when M goes from 200 to 400.

In Fig.6 we plot the power consumption of the system when M and PR are varying. The obtained results show that the power consumed increases with the number of users in the system and confirm the increasing relationship between the power and the values of the retransmission probability.

From the results obtained through this numerical analysis of the proposed model, we can say that our model can be used as:

- a performance evaluation tool, to evaluate delay and energy consumption, which extends the results of literature studies such as [36], [38] and [49];
- a decision-making tool on network control parameters. In particular, for predefined delay in a service level agreement (SLA), it is possible to control the probability of transmission (Pt) and retransmission (Pr) and also the number of users to be admitted into the system. To our knowledge, this has not been covered in previous researchs.

7. CONCLUSION

In this paper we were interested in the performance evaluation of the Slotted Aloha protocol in an IoT environment, in particular packet delay and the power consumption. For this, we adopted a three-state Markov chain model describing the states where a node can be, namely: Idle, Busy and Collision. The mathematical study of this model made it possible to deduce the analytical formulas of the parameters studied according to the various parameters of the system which describe its density, its transmission policy and the nature of the nodes in the network. The numerical evaluation of the results obtained was made under different scenarios and showed the validity of the used approach. Moreover, our proposition can be used not only as a performane evaluation tool but also as a decision-making tool that can help the provider to control the network parameters in order to ensure a level of quality of services or to respect a threshold of consumed energy in the network. In future works, it will be more interstig if we extend this model to the case with heterogenous packets and where the arrivals are not exponential. We can also think of applying this model to evaluate the performance in a real-time data situation sensitive to the delay and energy parameters, such as the health sector.

REFRENCES:

[1] J. Chase, ''The evolution of the Internet of Things,'' Texas Instrum., Dallas, TX, USA, White Paper, Feb. 2013, p. 7
[2] Vázquez-Gallego, F.; Tuset-Peiró, P.; Alonso, L.; Alonso-Zarate, J. Delay and Energy Consumption Analysis of Frame Slotted ALOHA variants for Massive Data Collection in Internet-of-Things Scenarios. Appl. Sci. 2020, 10, 327.
[3] Al-Fuqaha, A.; Guizani, M.; Mohammadi, M.; Aledhari, M.; Ayyash, M. Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications. IEEE Commun. Surv. Tutor. 2015, 17, 2347–2376.
[4] IoT end-user spending worldwide 2017-2025 Published by Statista Research Department, Jan 22, 2021
[5] [4 Ref(1)] Kelly, S.D.T.; Suryadevara, N.K.; Mukhopadhyay, S.C. Towards the Implementation of IoT for Environmental Condition Monitoring in Homes. IEEE Sensors J. 2013, 13, 3846–3853.
[6] Zanella, A.; Bui, N.; Castellani, A.; Vangelista, L.; Zorzi, M. Internet of Things for Smart Cities. IEEE Internet Things J. 2014, 1, 22–32.
[7] Islam, S.M.R.; Kwak, D.; Kabir, M.H.; Hossain, M.; Kwak, K. The Internet of Things for Health Care: A Comprehensive Survey. IEEE Access 2015, 3, 678–708.
[8] Xu, L.D.; He, W.; Li, S. Internet of Things in Industries: A Survey. IEEE Trans. Ind. Inform. 2014, 10, 2233–2243.

[9] Chen, X. Y., & Jin, Z. G. (2012). Research on key technology and applications for internet of things. International Conference on Medical Physics and Biomedical Engineering (ICMPBE), 33, 561–566.

[10] Dusan Markovic, Ranko Koprivica, Uroš Pešović , “ Application of IoT in monitoring and controlling agricultural production”; 2015; Acta agriculturae Serbica 20 (40):145-153

[11] Sobin, C. C. "A Survey on Architecture, Protocols and Challenges in IoT." Wireless Personal Communications 112.3 (2020): 1383-1429.

[12] Noura, M., Atiquzzaman, M. & Gaedke, M. Interoperability in Internet of Things: Taxonomies and Open Challenges. Mobile Netw Appl 24, 796–809 (2019).

[13] Bansal, S., Kumar, D. IoT Ecosystem: A Survey on Devices, Gateways, Operating Systems, Middleware and Communication. Int J Wireless Inf Networks 27, 340–364 (2020).

[14] Hussain, M.I. Internet of Things: challenges and research opportunities. CSIT 5, 87–95 (2017).

[15] Duan. R; Chen. X; Xing. T, "A QoS Architecture for IOT," in Internet of Things (iThings/CPSCom), 2011 International Conference on and 4th International Conference on Cyber, Physical and Social Computing , vol., no., pp.717-720, 19-22 Oct. 2011

[16] Baranwal, G., Singh, M. & Vidyarthi, D.P. A framework for IoT service selection. J Supercomput 76, 2777–2814 (2020).

[17] Sobin, C.C. A Survey on Architecture, Protocols and Challenges in IoT. Wireless Pers Commun 112, 1383–1429 (2020).

[18] K. Georgiou, S. Xavier-de-Souza and K. Eder, "The IoT Energy Challenge: A Software Perspective," in IEEE Embedded Systems Letters, vol. 10, no. 3, pp. 53-56, Sept. 2018.

[19] R. Arshad, S. Zahoor, M. A. Shah, A. Wahid and H. Yu, "Green IoT: An Investigation on Energy Saving Practices for 2020 and Beyond," in IEEE Access, vol. 5, pp. 15667-15681, 2017.

[20] B. Martinez, M. Montón, I. Vilajosana and J. D. Prades, "The Power of Models: Modeling Power Consumption for IoT Devices," in IEEE Sensors Journal, vol. 15, no. 10, pp. 5777-5789, Oct. 2015.

[21] A. Kumar, M. Zhao, K. Wong, Y. L. Guan and P. H. J. Chong, "A Comprehensive Study of IoT and WSN MAC Protocols: Research Issues, Challenges and Opportunities," in IEEE Access, vol. 6, pp. 76228-76262, 2018.

[22] Antar Shaddad H. Abdul-Qawy, Nasr Musaed S. Almurisi, Srinivasulu Tadisetty, Classification of Energy Saving Techniques for IoT-based Heterogeneous Wireless Nodes, Procedia Computer Science, Volume 171, 2020, Pages 2590-2599,

[23] Shabana Anjum, Shaik, Md Noor, Rafidah; Ahmedy, Ismail; Hossein Anisi, Mohammad; "Energy optimization of sustainable Internet of Things (IoT) systems using an energy harvesting medium access protocol"; IOP Conference Series: Earth and Environmental Science; IOP Publishing; 2019

[24] Singh, M., Baranwal, G. & Tripathi, A.K. QoS-Aware Selection of IoT-Based Service. Arab J Sci Eng 45, 10033–10050 (2020).

[25] Rani, S., Saravanakumar, N., Rajeyyagari, S. et al. QoS aware cross layer paradigm for urban development applications in IoT. Wireless Netw 26, 6203–6214 (2020).

[26] Badawy, M.M., Ali, Z.H. & Ali, H.A. QoS provisioning framework for service-oriented internet of things (IoT). Cluster Comput 23, 575–591 (2020).

[27] Awan I., Younas M. (2013) Towards QoS in Internet of Things for Delay Sensitive Information. In: Matera M., Rossi G. (eds) Trends in Mobile Web Information Systems. MobiWIS 2013. Communications in Computer and Information Science, vol 183. Springer, Cham

[28] Das M.L. (2015) Privacy and Security Challenges in Internet of Things. In: Natarajan R., Barua G., Patra M.R. (eds) Distributed Computing and Internet Technology. ICDCIT 2015. Lecture Notes in Computer Science, vol 8956. Springer, Cham.

[29] Varadharajan V., Bansal S. (2016) Data Security and Privacy in the Internet of Things (IoT) Environment. In: Mahmood Z. (eds) Connectivity Frameworks for Smart Devices. Computer Communications and Networks. Springer, Cham.

[30] Alfandi, O., Khanji, S., Ahmad, L. et al. A survey on boosting IoT security and privacy through blockchain. Cluster Comput (2020).

[31] Jurcut, A., Niculcea, T., Ranaweera, P. et al. Security Considerations for Internet of Things: A Survey. SN COMPUT. SCI. 1, 193 (2020).

[32] S. A. Tegos, P. D. Diamantoulakis, A. S. Lioumpas, P. G. Sarigiannidis and G. K. Karagiannidis, "Slotted ALOHA With NOMA for the Next Generation IoT," in IEEE Transactions on Communications, vol. 68, no. 10, pp. 6289-6301, Oct. 2020.

[33] Oliveira L, Rodrigues JJPC, Kozlov SA, Rabêlo RAL, Albuquerque VHCd. MAC Layer Protocols for Internet of Things: A Survey. Future Internet. 2019; 11(1):16

[34] E. Balevi and R. D. Gitlin, "A Random Access Scheme for Large Scale 5G/IoT Applications," 2018 IEEE 5G World Forum (5GWF), 2018, pp. 452-456.

[35] Badgotya, S., & Rai, D., Prof. (2018). A survey on aloha protocol for iot based applications. International journal of engineering sciences & research technology, 7(5), 289-297.

[36] Amirmahdi Khodaian, Babak H. Khalaj, Mohammad S. Talebi ; "Utility Constrained Energy Minimization In Aloha Networks" Proceedings of the 2007 4th IEEE Consumer Communications and Networking Conference January 2007

[37] S. Ihirri, E. Sabir, A. Errami and M. Khaldoun, "A Scalable Slotted Aloha for Massive IoT: A Throughput Analysis," 2019 15thInternationalWireless Communications & Mobile Computing Conference (IWCMC), 2019, pp. 508-513.

[38] Abdellah Zaaloul, Mohamed Ben El Aattar, Mohamed Hanini, Abdelkrim Haqiq and Mohammed Boulmalf, "A Markov model to evaluate system performances under slotted Aloha protocol", The Fifth International Conference on Next Generation Networks & Services, IEEE, pp. 54 - 59 , Casablanca, Morocco, May 28 - 30, 2014.

[39] Dutta D. (2019) IEEE 802.15.4 as the MAC Protocol for Internet of Things (IoT) Applications for Achieving QoS and Energy Efficiency. In: Sarma H., Borah S., Dutta N. (eds) Advances in Communication, Cloud, and Big Data. Lecture Notes in Networks and Systems, vol 31. Springer, Singapore.

[40] P. Z. Sotenga, K. Djouani and A. M. Kurien, "Media Access Control in Large-Scale Internet of Things: A Review," in IEEE Access, vol. 8, pp. 55834-55859, 2020.

[41] N. Abramson, "The ALOHA system-another alternative for computer Communications", Proceedings of the fall joint computer conference, pp. 281-285, November 17-19, 1970.

[42] Roberts L. G. Aloha packet system with and without slots and capture.Tech. Rep. Ass Note 8, Stanford Research Institute, AdvanceResearchProjects Agency, Network Information Center, 1972.

[43] S. Mehta, K.S. Kwak, H-MAC: A Hybrid MAC Protocol for Wireless Sensor Networks, International Journal of Computer Networks & Communications 2.2 (2010) 108-117

[44] Dimitrios Zorbas, Khaled Abdelfadeel, Panayiotis Kotzanikolaou, Dirk Pesch, "TS-LoRa: Time-slotted LoRaWAN for the Industrial Internet of Things" Computer Communications, Volume 153, 2020, Pages 1-10

[45] G. Yapar, T. Tugcu and O. Ermis, "Time-Slotted ALOHA-based LoRaWAN Scheduling with Aggregated Acknowledgement Approach," 2019 25th Conference of Open Innovations Association (FRUCT), 2019, pp. 383-390.

[46] Dimitrios Zorbas, Khaled Abdelfadeel, Panayiotis Kotzanikolaou, Dirk Pesch, TS-LoRa: Time-slotted LoRaWAN for the Industrial Internet of Things, Computer Communications, Volume 153, 2020, Pages 1-10,

[47] A. Ramli and H. Basarudin; Performance Analysis of P-persistent Slotted ALOHA Protocol for Low Power IoT Applications; International Journal of Innovative Technology and Exploring Engineering (IJITEE), Volume-8 Issue-7, 2019

[48] Arun George, T.G. Venkatesh, Multi-Packet Reception Dynamic Frame-Slotted ALOHA for IoT: Design and Analysis, Internet of Things (2020),

[49] Huanhuan Huang and Tong Ye and T. Lee; Throughput and Delay Analysis of Slotted Aloha with Batch Service; ArXiv 1910.07312v1; 2019.

[50] R. Nelson, Probability, stochastic process, and queueing theory, Springer-Verlag, third printing, 2000.

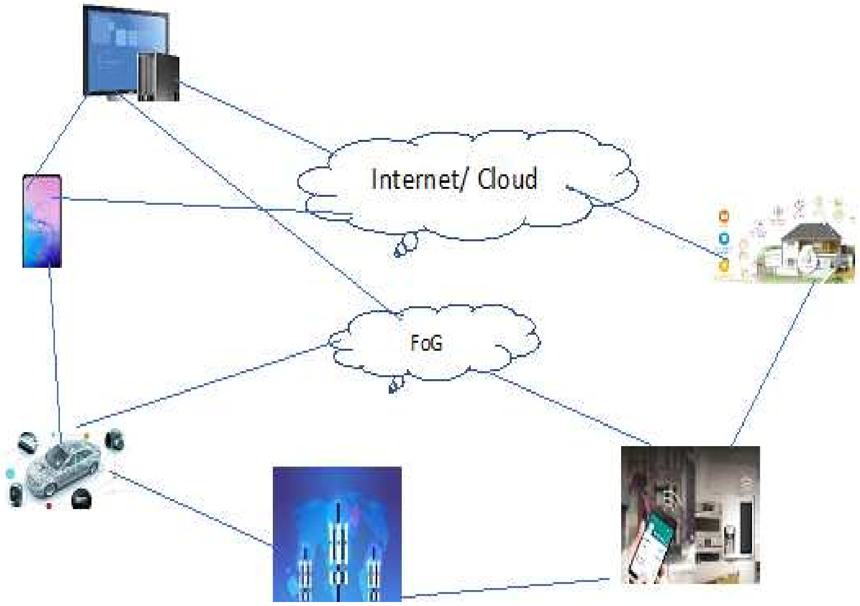

Figure 1. Internet of Things paradigm

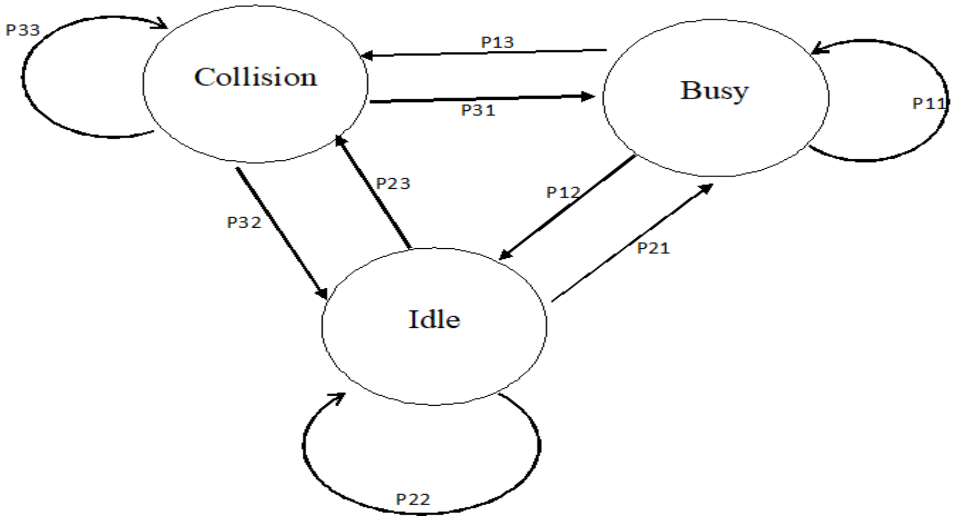

Figure 2. Transition Diagram of the Markov chain

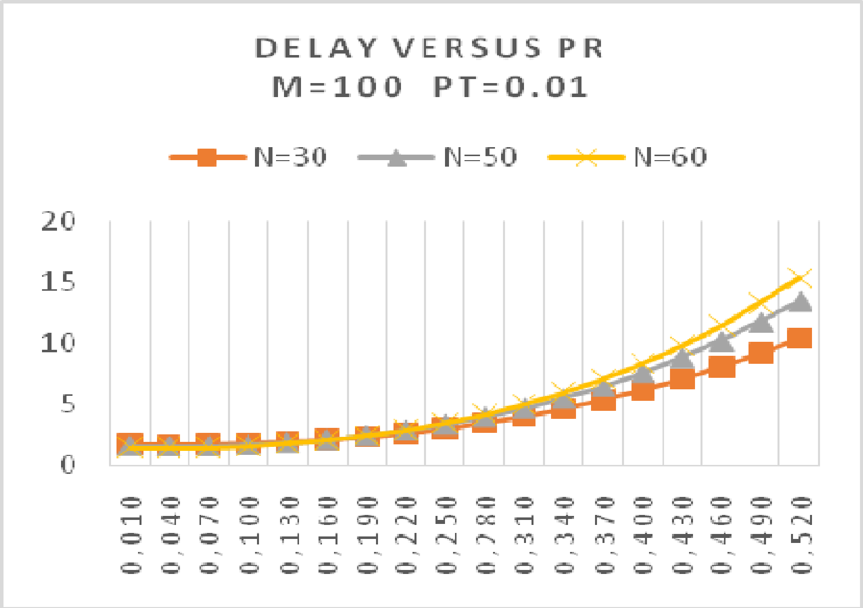

Figure 3. Backlogged Delay Versus PR Under Different Values Of N.

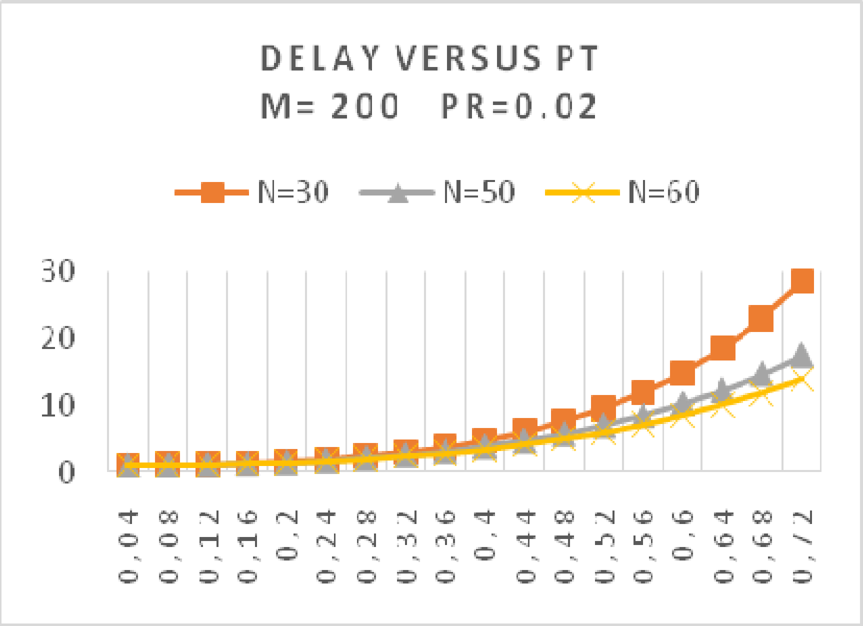

Figure 4. Backlogged Delay Versus PT Under Different Values Of N.

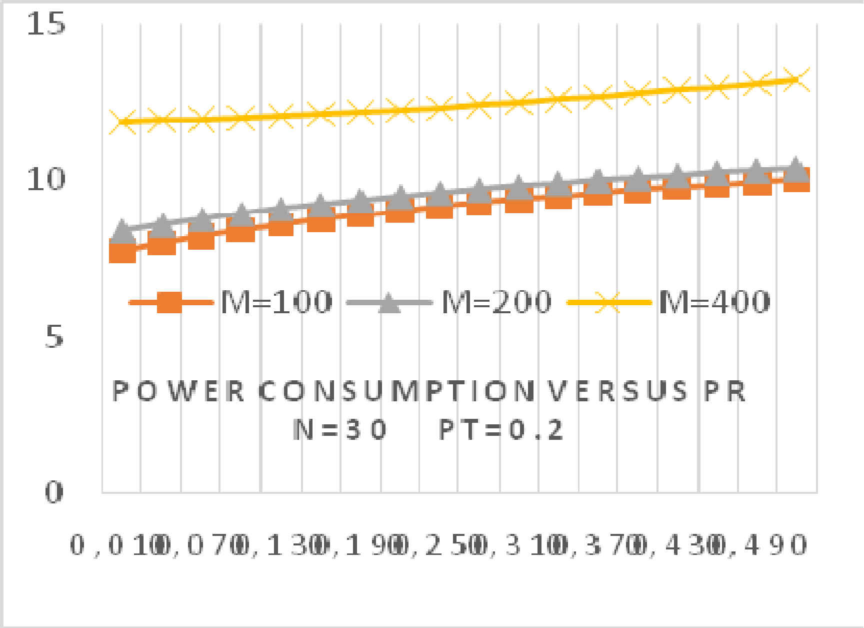

Figure 5. Power Consumed Versus PR Under Different Values Of M.

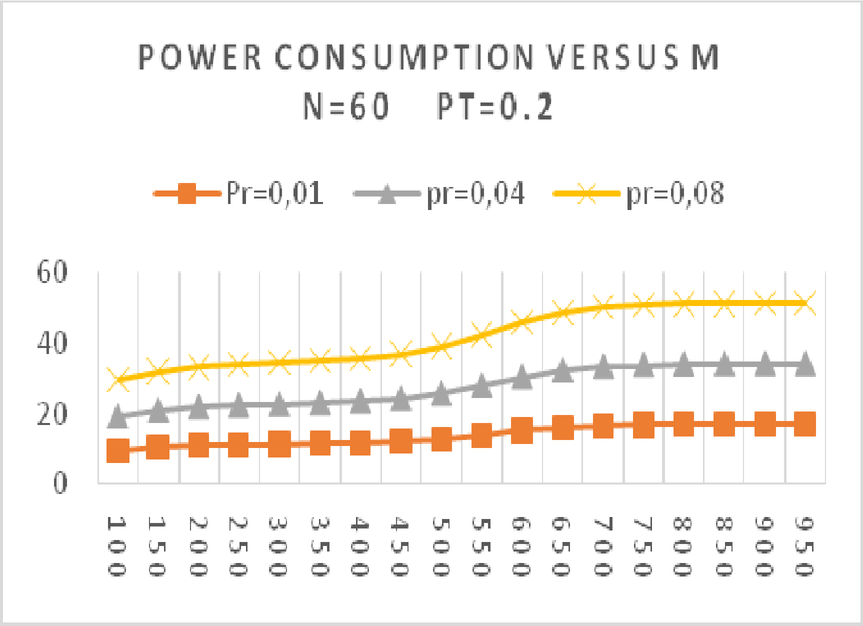

Figure 6. Power Consumed Versus M Under Different Values Of PR