Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol.44 No. 6 (2023)

Modeling Inter-Arrival Time for a Delay Efficient Packet Scheduler in Machine Type Communication Traffic

[1] Sunita T N, [2] Dr. Bharathi Malakreddy A.

Research Scholar Dept CSEBMS, Inst of Tech &Mgmt Bengaluru – 560064

Prof &HOD Dept AI & ML BMS,Inst of Tech &Mgmt Bengaluru – 560064

Abstract:-Machine-type-communication (MTC) applications are widely deployed across several industries. One example is the Automation Industry, where a delay in processing requests may result in misreading incoming data. This work mainly concentrates on the latency issues observed in the uplink channel of MTC, specifically in transmitting data from several sensors to the Programmable Logic Controller (PLC). The requests originating from sensors and directed toward the Programmable Logic Controller (PLC) exhibit a random nature, thereby necessitating the modeling of the unpredictability associated with the arrival of MTC requests. The incoming traffic to the MTC system is classified into Event-Driven (ED) and Periodic Update (PU). The PU traffic exhibits periodic behavior accompanied by specific latency deadlines. On the other hand, ED traffic exhibits a random nature and needs prompt processing following the criticality of the application. The total utility of the system will be determined by the multiplication of the average utility of ED delay and the average utility of PU. This study introduces a packet scheduling algorithm that prioritizes delay efficiency. The packet scheduler under consideration is being evaluated against scheduling policies such as preemptive priority, First Come, First Serve (FCFS), and Earliest Due Date (EDD). The findings indicate a significant enhancement of 90% in the performance of MTC.

Keywords: *M2M, Latency, Inter Arrival, Scheduling, Queueing Theory, MTC, LTE.*

1. Introduction

In recent times, significant progress has been made in the realm of the internet, particularly concerning the development of future networks such as the 5G platform. These networks are designed to prioritize low latency and high data connectivity as their primary objectives. Specific applications like live video sharing and health care are sensitive to delays. Assessing the efficiency of the MTC network has consistently posed a formidable task because of the diverse traffic patterns created by several Machine-To-Machine M2M applications. Furthermore, it is essential to note that each application may possess distinct Quality of Service (QoS) prerequisites. Considering the challenges mentioned above, it is recommended to opt for a comprehensive performance assessment encompassing various MTC traffic models. Cellular telecommunication offers two main types of services: Human-Type Communication (HTC) and Machine Type Communication (MTC). According to [1,2], HTC services entail human interaction, while MTC services either do not necessitate human intervention or involve minimal human engagement.

The M2M network has become increasingly important in meeting the growing global demand for wireless network traffic due to advancements in wireless network technology. The Internet of Things (IoT) is a rapidly evolving network technology. The IoT refers to a network infrastructure wherein various items and gadgets with communication capabilities are interconnected to carry out specific operations or accomplish predetermined objectives with minimal human interaction. The communication between machines, commonly called M2M communication, plays a pivotal role in facilitating the functionality of IoT technologies. The properties of MTC exhibit notable distinctions in comparison to H2H. Several characteristics of MTC include requests with tiny data payloads yet a significant number of access requests. The traffic of Machine Type Communication Devices (MTCD) is produced by events or regular updates, as discussed by [3,4]. The adoption of MTC is most effectively facilitated by Long-Term Evolution (LTE) technology due to its notable attributes of high availability, flexibility, and scalability. MTC services are commonly used to operate wireless sensors, monitoring devices, and similar technologies. Additionally, MTC's applications and services, including healthcare, vehicle transportation, and video streaming, are time-sensitive. Given that both HTC and MTC sources would utilize identical network infrastructure, there will inevitably be contention in acquiring network resources. In addition, it has been noted by [5,6] that delay-sensitive applications may experience certain levels of latency in terms of service delivery.

LTE technology poses challenges for MTC due to the inherent fluctuations in MTC traffic characteristics. One of the primary challenges encountered pertains to scheduling or radio resource management. Moreover, it can be observed that MTC exhibits a higher degree of uplink dominance than H2H, which is characterized by a greater emphasis on downlink communication. In certain instances, the traffic inside the MTC may be subject to time constraints, such as when there is a pressing need to disseminate emergency alerts. The presence of limited radio resources necessitates implementing effective radio resource management and scheduling mechanisms to prevent congestion. MTC demands are consistently of substantial magnitude. Therefore, it is imperative to incorporate a model that accurately represents the random receipt of MTC requests to improve resource scheduling efficiency for network resource access. According to [7,8].

2. Related Works

The proposed model can be employed to estimate the aggregate traffic of the base station, which will be represented as an endless server system. In their study, [9,10] proposed utilizing the Product Density (PD) technique to approximate the temporal variation of the combined traffic generated by HTC/MTC services over a 5G network. The probability density function (PD) is a specific correlation function employed in examining communication systems' performance, specifically in conjunction with the M/M/∞ queuing model. An unlimited server system is employed, hence eliminating any potential delays. In practical terms, achieving this objective is not feasible as there will inevitably be some delay. Therefore, it is necessary to analyze the finite server capacity to assess the resilience of the proposed approach [11,12].

When designing scheduling algorithms, it is essential to consider the criticality of data and prioritize the transmission of data traffic from many MTCDs. Typically, the data produced by the MTCDs exhibits a repetitious nature, indicating that the incoming data may not consistently possess significant relevance. In order to classify the incoming data as either of high relevance or high value, the data must exhibit substantial dissimilarity from the preceding data. In the context of MTC, it is imperative to give precedence to data containing high-value information rather than redundant data [13,14].

According to the study conducted by [15], An attempt was made to tackle the abovementioned problem by presenting a scheduling algorithm that aims to define the significance of data through statistical features. This quantified value is then utilized to optimize the scheduling of MTC data for radio resource access. There is the potential for inaccurately assessing the significance of the evidence and establishing the appropriate threshold. There is a potential for transmitting superfluous data or omitting critical data that should be designated with a high-priority designation.

There is a growing need in the telecommunication industry to manage server capacity and utilize network resources more effectively and optimally. There are various methodologies for modeling capacity, including but not limited to the quantification of active servers, utilization of exponential service rate to represent service time, and the implementation of time slice techniques. Capacity management involves the consideration of dynamic changes in capacity through various approaches. However, more research needs to be conducted on the management of capacity.

In their study, [16,17] examined regulating the number of servers in a queue while maintaining a consistent service duration. The buffer scheme for the queue was not taken into account. Consequently, the occurrence of service delay would lead to data loss. In their study, [18,19] introduced an analytical framework that utilizes a unique double queue model to examine the queuing behavior of MTCDs. The system will adjust its capacity accordingly if there is a substantial influx of access requests.

In their study, [20,21] examined regulating the number of servers in a queue while maintaining a consistent service duration. The buffer scheme for the queue was not taken into account. Consequently, the occurrence of service delay would lead to data loss. In their study, [22] introduced an analytical framework that utilizes a unique double queue model to examine the queuing behavior of MTCDs. The system will adjust its capacity accordingly if there is a substantial influx of access requests. The primary emphasis of this paper pertained to the uniform behavior exhibited by the devices.

3. System Model of the MTC Uplink Channel

Figure 1 illustrates the configuration of the MTC uplink channel, whereby many sensors interact with a programmable logic controller (PLC). The communication originating from a set of N sensors is handled by a Programmable Logic Controller (PLC). The traffic is classified into different categories, namely Event-Driven (ED) and periodic-update (PU), such as Fire Alarm and Smart Meters, based on factors such as delay required and arrival rate.

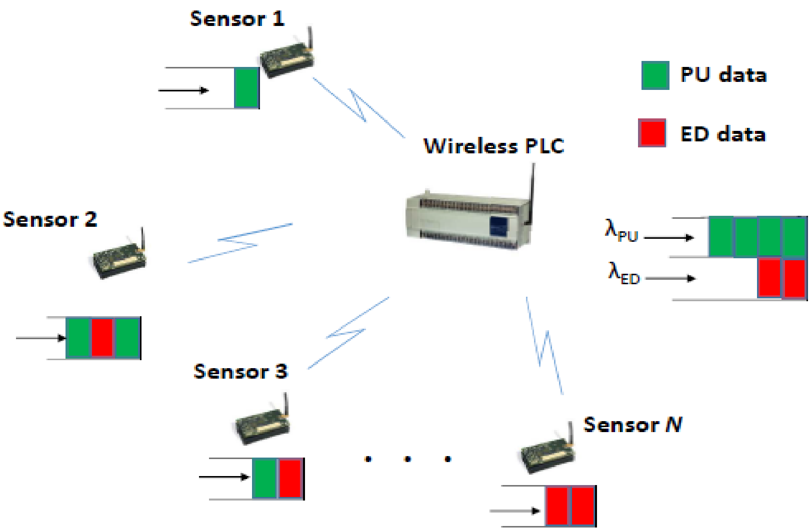

Figure 1: System model of the uplink channel

A deterministic process is used to model the inter-arrival time for the PU traffic coming from the sensor, whereas, for the ED traffic, the Poisson process is used to model the traffic arrivals with a rate. Hence, the arrival rate for the queuing process is and for the Periodic Update and Event-driven traffic, respectively [23].

The inter-arrival time T_{pu} for the PU traffic originating from the i^{th} sensor is modeled using a deterministic process. On the other hand, the traffic arrivals for the ED traffic are modeled using a Poisson process with a rate of λ_{ed}^{i} Therefore, the arrival rate for the queuing process is denoted as λ_{pu} for Periodic Update traffic and λ_{ed} for Event-driven traffic.

$$\lambda_{pu} = \sum_{i=1}^{N} 1/T_{pu}^{i}\ , \qquad \lambda_{ed} = \sum_{i=1}^{N} \lambda_{ed}^{i}$$

In MTC, traffic with small-sized data packets is generated continuously. In order to model such traffic, the exponential distribution is best suited. Hence μ_{pu}^{i} and μ_{ed}^{i} are the exponential service rates for PU and ED, respectively.

$\mu_{pu} = \mu/s_{pu}$ and $\mu_{ed} = \mu/s_{ed}$

s_{pu} : PU packet size

s_{ed} : ED packet size

μ : Service rate at PLC/Packet

T_{pu} : Inter Arrival time of PU packets

λ_{pu} : Arrival rate for PU packets

λ_{ed} : Arrival rate for ED packets

4. Problem Formulation

The literature mentioned above survey indicates a requirement for an enhanced scheduling method to utilize network resources efficiently. Therefore, it is imperative to develop an enhanced packet scheduler to facilitate resource access for Machine-to-Machine (M2M) communication. The M2M traffic will be categorized into Periodic Update (PU) traffic and event-driven (ED) traffic, with the latter being characterized by its random nature. Therefore, the delay requirements associated with event-driven traffic are represented mathematically as a sigmoidal function. The sigmoid function is a mathematical function that transforms an actual number into a probability value ranging between 0 and 1. The mathematical expression for the sigmoid function is given by 1 divided by the sum of 1, and the exponential function is raised to the power of negative x. This implies that as the value of x tends towards positive infinity, the probability tends towards 1, and as x tends towards negative infinity, the probability tends towards 0. The model establishes a threshold that determines the probability range associated with each binary variable. Periodic Update packets are subject to a stringent deadline, and once this limit is surpassed, processing the packets becomes futile. Therefore, the traffic of the Periodic Update is represented by a mathematical model known as the step function. Ultimately, amalgamate all the various utilities to establish a unified metric for system utility. The primary objective is to prioritize the optimization of the problem in order to get the highest possible system utility measure. A potential scenario exists wherein a packet may be in a state of waiting within the sensor queue, thereby resulting in a blockage of packets due to the complete occupation of the programmable logic controller (PLC). Therefore, in this study, it is necessary to construct a model for the inter-arrival time of event-driven traffic, as these events are highly sensitive to delays.

5. Inter-Arrival Request Modelling

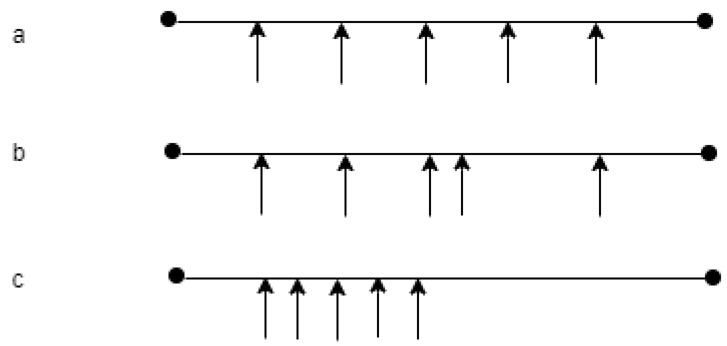

Figure 2: Request arrival probabilities in one unit of time

Let us examine a hypothetical situation where events exhibit an arrival rate of 5 requests (arrows indicating requests/packets) per unit of time, as depicted in Figure 2 (a,b,c). Figure 2(a,b,c) illustrates the incoming requests with varying inter-arrival times[24].

The expected average time between the events is given by:

$$E(x) = \int_{-\infty}^{\infty} t\, f_x(t)\,dt$$

$$= \int_{-\infty}^{\infty} t \lambda e^{-\lambda t} dt$$

$= {}^{1}/_{\lambda}$ (which is the reciprocal at which events occur) (1)

Variance is given by $V(x) = E(x^2) - E(x)^2 = \frac{2}{\lambda^2} - \frac{1}{\lambda^2} = \frac{1}{\lambda^2}$

6. Blocking Probability

The potential for denial of service may arise due to inadequate access to resources. Therefore, it is necessary to create a formula or equation by heuristic derivation to forecast the loss of data resulting from increased requests[25].

The proportion P_j Of time, j requests are busy, the formula:

$$P_j = \frac{(\lambda j)^j / j!}{\sum_{k=0}^{s} (\lambda j)^k / k!} \text{ where } (j = 1, 2, \ldots, s) \quad (2)$$

λ: Arrival rate

7. Proposed Scheduler

The traffic at the MTC is initially classified into two categories: PU traffic and ED traffic. Subsequently, the utility of the individual's PU and ED is computed. Once aggregated, the various utilities coalesce into a unified system utility metric. And finally, System utility is given by:

$$V(P) = U_{pu}^{\beta_{pu}}(P) * U_{ed}^{\beta_{ed}}(P)$$

8. Results and Discussion

- **Impact of PU deadline**

Figure 3 illustrates the influence of varying PU latency threshold (l_t) values and parameter 'b' on the system utility. Furthermore, an optimal value of the PU latency threshold (l_t) exists for a given value of b, which subsequently contributes to achieving the maximum System Utility. Additionally, it is worth noting that when the value of b increases, there is minimal fluctuation in the System Utility.

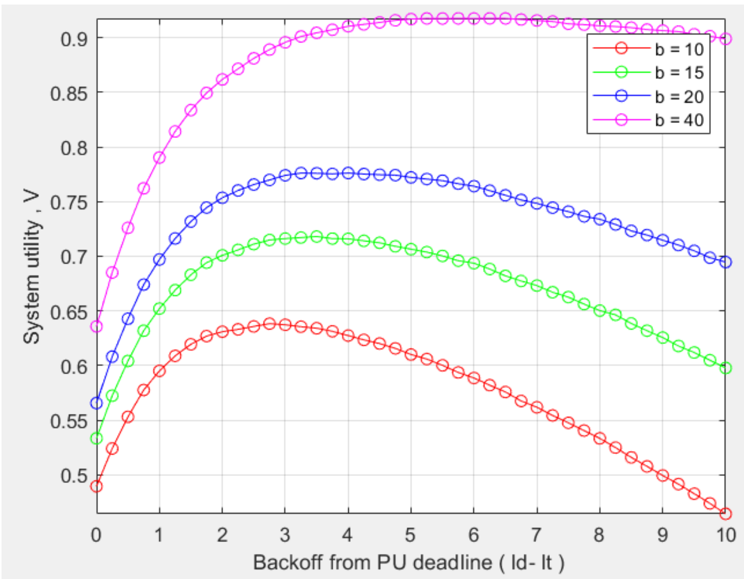

Figure 3: Impact of PU deadline

- **Impact of ED deadline**

Figure 4 illustrates the influence of the Event-Driven Utility parameter 'a' on the overall System Utility across different scheduling algorithms. It can be observed that when the value of variable 'a' decreases, the System Utility value exhibits an increase, reaching its maximum value.

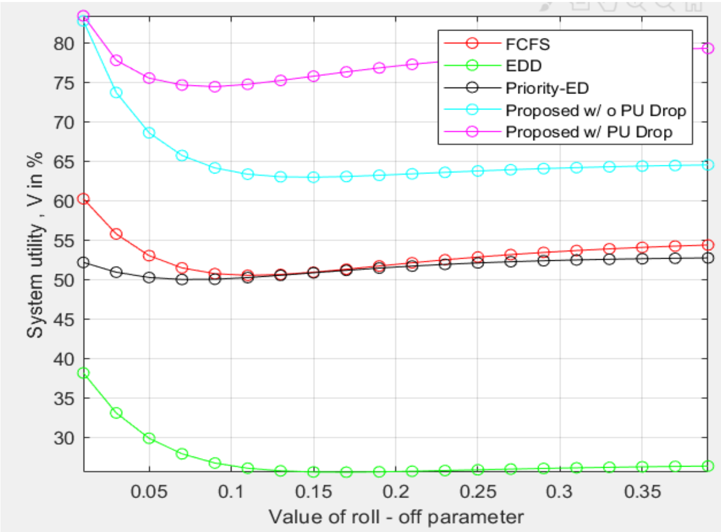

Figure 4: Impact of ED deadline

9. Conclusion

The simulation findings are juxtaposed with established scheduling policies such as Earliest Due Date (EDD), First-Come, First-Served (FCFS), and Preemptive Priority. As the rate of arrival to the emergency department (ED) grows, there is observed fluctuation in the utility of the system. However, the suggested scheduler demonstrates superior performance to traditional scheduling strategies, resulting in a notable 90% improvement in system performance. Subsequent research should consider situations in which sensor bottlenecks arise due to significant surges in emergency department (ED) admissions.

Refrences

[1] Thomsen, Henning, Carles Navarro Manchón, and Bernard Henri Fleury. "A traffic model for machine-type communications using spatial point processes." In *2017 IEEE 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, pp. 1-6. IEEE, 2017.

[2] Zhan, Wen, and Lin Dai. "Massive random access of machine-to-machine communications in LTE networks: Modeling and throughput optimization." *IEEE Transactions on Wireless Communications* 17, no. 4 (2018): 2771-2785.

[3] Mostafa, Ahmed Elhamy, and Yasser Gadallah. "A statistical priority-based scheduling metric for M2M communications in LTE networks." *IEEE Access* 5 (2017): 8106-8117.

[4] Chen, Xin, Zhuo Li, Ying Chen, and Xiangkun Wang. "Performance Analysis and Uplink Scheduling for QoS-Aware NB-IoT Networks in Mobile Computing." *IEEE Access* 7 (2019): 44404-44415.

[5] Teng, Yinglei, Wenyao Liang, Yong Zhang, and Ruizhe Yang. "Traffic-aware resource allocation scheme for mMTC in dynamic TDD systems." *IET Communications* 12, no. 15 (2018): 1910-1918.

[6] Gendy, Sylvia, and Yasser Gadallah. "LTE-Based Network Virtualization Schemes Adaptation for M2M Deployments." In *2019 IEEE International Black Sea Conference on Communications and Networking (BlackSeaCom)*, pp. 1-3. IEEE, 2019.

[7] Tello-Oquendo, Luis, José-Ramón Vidal, VicentPla, and Luis Guijarro. "Dynamic access class barring parameter tuning in LTE-A networks with massive M2M traffic." In *2018 17th Annual Mediterranean Ad Hoc Networking Workshop (Med-Hoc-Net)*, pp. 1-8. IEEE, 2018.

[8] Kumar, Akshay, Ahmed Abdelhadi, and T. Charles Clancy. *Design and Implementation of Practical Schedulers for M2M Uplink Networks: Using MATLAB*. Springer, 2018.

[9] Jiang, Nan, Yansha Deng, Xin Kang, and Arumugam Nallanathan. "Random access analysis for massive IoT networks under a new Spatio-temporal model: A stochastic geometry approach." *IEEE Transactions on Communications* 66, no. 11 (2018): 5788-5803.

[10] Tia, Too-Seng, Jane W-S. Liu, and Mallikarjun Shankar. "Algorithms and optimality of scheduling soft aperiodic requests in fixed-priority preemptive systems." *Real-Time Systems* 10, no. 1 (1996): 23-43.

[11] Shajaiah, Haya, Ahmed Abdelhadi, and Charles Clancy. "A price selective centralized algorithm for resource allocation with carrier aggregation in LTE cellular networks." In 2015 *IEEE Wireless Communications and Networking Conference (WCNC)*, pp. 813-818. IEEE, 2015.

[12] Hossain, Ekram, Zhu Han, and H. Vincent Poor, eds. Smart grid communications and networking. *Cambridge University Press*, 2012.

[13] Ghorbanzadeh, Mo, Ahmed Abdelhadi, and Charles Clancy. Cellular Communications Systems in Congested Environments. *Springer*, 2016.

[14] Abdel-Hadi, Ahmed, and Charles Clancy. "A utility proportional fairness approach for resource allocation in 4G-LTE." In 2014 *International Conference on Computing, Networking and Communications (ICNC)*, pp. 1034-1040. IEEE, 2014.

[15] Ghorbanzadeh, Mo, Ahmed Abdelhadi, and Charles Clancy. "Delay-based backhaul modeling." *In Cellular Communications Systems in Congested Environments*, pp. 179-240. Springer, Cham, 2017.

[16] Ghorbanzadeh, M., A. Abdelhadi, and C. Clancy. "A utility proportional fairness bandwidth allocation in radar-coexistent cellular networks." *In Military communications conference (MILCOM)*, vol. 10. 2014.

[17] Abdelhadi, Ahmed, and Charles Clancy. "An optimal resource allocation with joint carrier aggregation in 4G-LTE." *In 2015 international conference on computing, networking and communications (ICNC)*, pp. 138-142. IEEE, 2015.

[18] Abdelhadi, Ahmed, Mo Ghorbanzadeh, and Charles Clancy. "Optimal radio resource allocation for hybrid traffic in cellular networks: Centralized and distributed architecture." *arXiv preprint* arXiv:1411.4011 (2014).

[19] Mehmood, Yasir, Carmelita Görg, and Andreas Timm-Giel. "A radio resource sharing scheme for IoT/M2M communication in LTE-A downlink." In *2016 IEEE International Conference on Communications Workshops (ICC)*, pp. 296-301. IEEE, 2016.

[20] Song, Jaeseung, Andreas Kunz, Mischa Schmidt, and Piotr Szczytowski. "Connecting and managing m2m devices in the future internet." *Mobile Networks and Applications* 19, no. 1 (2014): 4-17.

[21] Hasan, Monowar, Ekram Hossain, and Dusit Niyato. "Random access for machine-to-machine communication in LTE-advanced networks: Issues and approaches." *IEEE Communications Magazine* 51, no. 6 (2013): 86-93.

[22] Ahmad, Farhan, Safdar Nawaz Khan Marwat, Yasir Zaki, and Carmelita Görg. "Tailoring LTE-advanced for M2M communication using wireless inband relay node." In *WTC 2014; World Telecommunications Congress 2014*, pp. 1-3. VDE, 2014.

[23] Ahmad, Farhan, Safdar Nawaz Khan Marwat, Yasir Zaki, Yasir Mehmood, and Carmelita Görg. "Machine-to-machine sensor data multiplexing using LTE-advanced relay node for logistics." In *Dynamics in Logistics*, pp. 247-257. Springer, Cham, 2016.

[24] Mehmood, Yasir, S. Nawaz Khan Marwat, Y. Zaki, C. Görg, and Andreas Timm-Giel. "Evaluation of M2M data traffic aggregation in LTE-A uplink." In *ITG/VDE Mobile Communication Conference*, pp. 24-29. 2015.

[25] Hosek, Jiri, Pavel Masek, Dominik Kovac, and Franz Kröpfl. "M2M gateway: The centerpiece of future home." In *2014 6th International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT)*, pp. 190-197. IEEE, 2014.