Received May 6, 2019, accepted June 12, 2019, date of publication June 14, 2019, date of current version July 2, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2923203

SAHCI: Scheduling Approach for Heterogeneous Content-Centric IoT Applications

FADI AL-TURJMAN[1], (Member, IEEE), ENVER EVER[2], (Member, IEEE), YOUSAF BIN ZIKRIA[3], (Senior Member, IEEE), SUNG WON KIM[3], AND ABDULMALEK ELMAHGOUBI[2]

[1]Department of Computer Engineering, Antalya Bilim University, 05190 Antalya, Turkey
[2]Department of Computer Engineering, Middle East Technical University, Northern Cyprus Campus, 99738 Mersin, Turkey
[3]Department of Information and Communication Engineering, Yeungnam University, Gyeongsan-si 38541, South Korea

Corresponding author: Yousaf Bin Zikria (yousafbinzikria@ynu.ac.kr)

This research was supported in part by the Brain Korea 21 Plus Program (No. 22A20130012814) funded by the National Research Foundation of Korea (NRF), in part by the MSIT (Ministry of Science and ICT), Korea, under the ITRC (Information Technology Research Center) support program (IITP-2019-2016-0-00313) supervised by the IITP (Institute for Information and Communications Technology Planning and Evaluation), and in part by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (2018R1D1A1A09082266).

ABSTRACT The Internet of Things (IoT) is one of the dominating paradigms of the new era with its abilities to provide ubiquitous intelligence and pervasive interconnections to diverse physical objects. With the advancements, such as new generation 5G communication and cloud/edge computing-based paradigms, the degree of domination is expected to further increase. Therefore, improvements for quality of service have become a critical issue. Traditional packets scheduling algorithms cannot meet the requirements of the large-scale IoT systems. In this paper, a novel scheduling approach is proposed for different data classes (types) to be exchanged between heterogeneous nodes of a generic IoT infrastructure. The possible ways of organizing these classes depending on different metrics, such as time latency, reliability, and data loss, are investigated. The proposed approach has the advantage of being able to tune the priorities and network characteristics to reach a specifically desired performance state. Since each type of packets is considered separately, it is possible to prioritize them, by tuning the related parameters, which changes the priorities between packets. The numerical results presented show that the new approach performs better than the existing typical scheduling approaches. The developed approach can be used in the various IoT applications with the support of 5G communication and edge computing, such as agriculture, wearables, connected cars, smart retail, and smart cities.

INDEX TERMS Networks, scheduling, simulation quality of service, IoT, buffering.

I. INTRODUCTION

Quality of Service (QoS) can be specified as the network performance as per specific use or application or can be further defined as the underlying principle used in networks to define the priority of each data stream or service in using network resources. With the introduction of the new paradigm Internet of Things (IoT), it was inevitable for scientists to show efforts in formalizing requirements and parameters to define QoS for numerous services. Such parameters and requirements can be used to define priorities for different traffic and services with potential to use IoT based technologies. Furthermore, it is expected to have a significant increase in number of devices in near future parallel to the increasing popularity of IoT phenomena. Fifth Generation (5G) of the emerging cellular networks is the advanced communication technology, which has been designed to provide competitive data transfer speeds, decreased delays, vitality sparing, cost decrement, and enormous gadget availability. In [14], authors have expressed that when 5G is completely grasped, there will be tens or several billions of gadgets that require the utilization of the 5G innovation, due to individual use, because of the numerous emerging heterogeneous information-centric and IoT applications. Furthermore, this rapid increase in IoT related applications and connected devices together with the success of rich cloud services have introduced a potentially more efficient computing paradigm known as edge computing. This efficiency is mainly obtained

The associate editor coordinating the review of this manuscript and approving it for publication was Chi Zhang.

through implementing the processing of the data at the edge of the network. As mentioned in [15] edge computing is one of the main technologies to address the near future requirements in terms of response time requirement, battery life constraint, and bandwidth cost saving. Typical services over networks include voice packets, ordinary video and data packets [13]. In today's services, Machine-to-Machine Communications (M2M) and HD video services are typical examples of resources' demanding services based on content [13]. M2M protocols are well-defined architecture consisting of communication parameters and paradigm to exchange the data or information over the network. Unlike human-type communications M2M communications refer to automated data communications among devices and the underlying data transport infrastructure instead requiring approval, validation, and authorization from humans. IoT compromises the M2M concept for structured communications with system tools and processing devices at the various level of communication.

Scheduling is a concept extensively used in the design of various Quality of Service (QoS) mechanisms and protocols. It is used to prioritize the service of data packets according to their service requirements as well as to minimize latency, data corruption and data loss, and is a topic that has been extensively studied in the past few decades for various types of connected systems. In this study, we propose a new Scheduling Approach for Heterogeneous Content-centric IoT (SAHCI) in multi-class data traffic systems. Please note that the priority of M2M communications is carefully considered in the new protocol for IoT applications. The remainder of this paper is organized as follows: related studies in the literature are discussed in the next section. Section III provides the detailed explanations for the considered SAHCI approach. Section IV evaluates the performance of SAHCI. Finally, Section V summarizes the contributions of this paper.

II. RELATED WORKS

There are various types of studies in the literature, which discuss the issue of traffic management in communication systems and introduce scheduling methods in various levels in order to satisfy the required QoS. Some of the existing approaches discuss the scheduling directly by abstracting the communication system as a simple queue system with nodes and buffers, while others like [9] discuss how it is related to different sorts of packets specifically M2M packets and how they impact the Human to Human (H2H) communication.

Intermittent disconnections in wireless networks due to mobility of terminals between the information-centric nodes (ICNs) represent a challenging networking environment and add to the delay in mobile networks. Frequent connection loss can also be caused by the operational environment of the network. To over-come connection loss, networks use protocols of store-carry-forward to achieve continuity of the traffic stream and ensure data delivery. Store-Carry-Forward stands for queue methodology of representation in which data packets are received stored in a node's buffer and prioritized. Hence, it is delayed until the right forwarding chance for this packet arise [2]. Using Store-Carry-Forward introduces the challenge of management for the limited buffers inside the intermediate nodes. Some variations of this approach such as those in [3] and [4] proposed the idea of replicating packets inside the same buffer to ensure or increase the delivering probability. These approaches in turn introduced new challenges for managing the resulting storage overhead. Furthermore, the challenge of specifying the priority of incoming packets depending on the network status and the types of packets remains as an unresolved issue.

In [2] a study is presented for optimal buffer management policies. The "drop tail policy" in buffer management, that is to drop all new incoming packets to the queue until there is room in the queue to accommodate incoming packets, and similarly "drop front" are defined as semi optimal. It is necessary to note here that drop front policy is tested in [5] against drop tail and it is concluded that drop front outperforms drop-tail policy when it comes to managing the capacity limit of buffers in nodes. However, in [2] the algorithms and policies proposed are dynamic in the sense that they are tunable to either minimize the delivery rate or maximize it which is an important improvement over the study in [5]. In order to propose the tunable protocols, statistical learning which is relative to global knowledge about the network is employed. Simulation results are presented for the problem with different probabilistic models to generate data in a similar fashion to that of the real-world traffic. Results show that the buffer management policies introduced approximates the performance of the optimal policy in all considered scenarios and outperforms existing policies in the literature in terms of average delivery rate and delivery delay. SAHCI approach presented in this study is different than that the work presented in [2] in the way that while statistical learning is employed, we only make use of current information about the system, rather than globally known information. The latter facilitates a wider range of results since it will adapt to that network specifically.

A well-known buffer management approach is the Random Early Detection (RED) [1], which was proposed mainly due to the bias of the traditional policies such as drop tail and drop front. RED is favorable compared to the traditional methods since it provides a fairer queuing management scheme. RED was also recommended to be used as the default mechanism for many applications. However, studies such as [1] show that RED alone is not the best solution and further active queue management schemes should be employed to manage queue lengths and structure dynamically, in order to reduce end to end latency which can help with reducing the data dropping rate.

In [17] an improvement in queue management policies in presence of two different types of packets (data and voice) is considered. The process introduced is simple and effective and uses the concept of pre-emption. Since the voice packets are time sensitive they are provided with higher priority over data packets and hence queued in a higher position or rank in the buffer. In case there is a voice packet arrival the active node trying to send the packet is preempted directly forwarding the new-coming voice packet if there is space in the queue. In case the buffer of packets is full the incoming voice packet is dropped. Using different probabilistic and mathematical models as well as simulations to the process, it is shown that the approach presented is more effective in handling voice packets. The details of the proposed flow are also presented explicitly for the decisions to be made depending on different situations. In contrast to the proposed approach in [17], our algorithm tries to handle the flow of four types of packets to the buffer with different generators, those being human and machine, hence a more dynamic and active queue-management scheme is proposed to manage the four packet types.

In [9], a similar approach to ours was used, where the effect of new M2M communications is considered on previous H2H communication (human to human) such as data, VoIP and video streaming. Similar to our approach current and previous knowledge of the system is employed in order to satisfy the QoS requirements. The problem of fairness is considered in resource allocation the congestion caused by the M2M devices is analyzed. The types of data and devices are classified as M2M and H2H.The approach is divided into two phases, where the first phase decides on which devices will receive resources based on the analytical model, and the second phase addresses which device of the selected ones, will receive which resource blocks (RB) based on a greedy approach.

In this study, a new scheduling approach is proposed with various types of traffics. Generic models are employed in order to compare the performance of the proposed approach with the approaches presented in [3], and [9], which consider the FIFO and priority based scheduling algorithms respectively.

III. SAHCI APPROACH

Queuing theory based modeling and simulation studies can be used for all the systems where waiting lines are observed [16]. The queues considered can be unbounded or bounded. Unbounded queues can grow as large as necessary for holding all waiting customers and the bounded queues are for holding a fixed number of waiting customers. The considered waiting lists (i.e., queues) can be bounded and/or unbounded. Unbounded lists can increase in size as vital for holding every coming and waiting user request. However, the bounded lists can evolve up to a specific size (or threshold) and starts dropping the incoming requests afterward.

The arriving requests pass by these queues (lists) in our proposed framework. After that, they are sent to accessible servers. Inter-arrival and service times can be categorized by utilizing different probabilistic patterns. Likewise, it is conceivable to categorize queuing systems into open versus closed systems. In open systems, there is at least one source of arriving requests and one sink that anticipate the request departure. However, in a closed system, requests do not arrive and do not depart from the system.

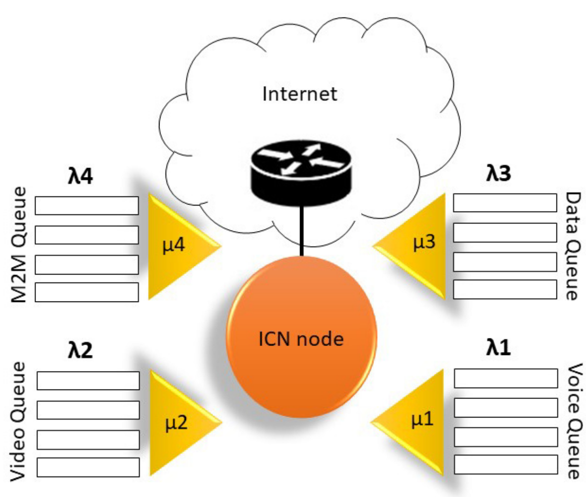

FIGURE 1. The modeled system architecture of an information centric node (ICN) in the IoT era.

A commonly used model for random, mutually independent packet arrivals is the Poisson process [2], [3], [16]. In this study as well, it is possible to use Poisson distribution for the arrivals with the following assumptions.

- The probability that an arrival occurs between time t and $t + \Delta t$ is $\lambda t + o(t)$, where λ is a constant, independent of the time t as well as the arrivals in earlier intervals. In this study similar to many, λ is used to denote the arrival rate of incoming packets to the queues considered.
- The number of arrivals in non-overlapping intervals is statistically independent.
- The probability that two or more arrivals occur at the same time t is negligibly small compared to the probability of zero or one arrival.

For service time as well similar to the arrival processes, it is possible to use exponential distribution assuming that the minimum service time is very small compared to the mean value [16], [17].

In this study, we consider open queuing systems with bounded queues, Poisson arrivals and exponentially distributed service times. The system architecture is depicted in Fig. 1. In this system, machine to machine (M2M), data packets (DP), video packets (VP), and voice over IP (VoIP) packets are considered to generate heterogeneous data traffic for the associated four Queues (one for each data type).

The system entities are as follows: Packets, Queues, Node (Server). The activities of the system considered can be one of the following: 1) Store a packet in Queue (Enqueue), 2) Push a packet out of Queue (Dequeue), 3) Process a packet in the Node, 4) Drop a packet form the Queue (due to mobility reasons), and 5) Choose which packet in the Queue to process. The system state variable is the current Queue size for each type.

As for the observed events in this Queue model, we consider the following: 1) *Packet arrival* (λ), which can be any of the four aforementioned types, and 2) *Packet departure* ($\boldsymbol{\mu}$) after the completion of its service. The proposed queuing and

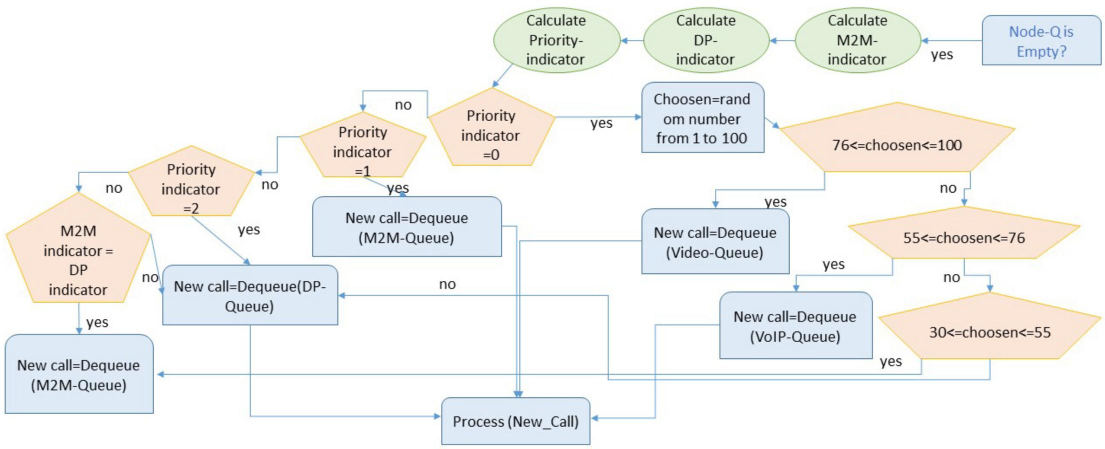

FIGURE 2. The operational workflow of the Proposed SAHCI approach.

Algorithm 1 Dynamic Priority Indicator

1. *Begin*
2. Priority_Indicator = 0;
3. T_{served} = Total served packets;
4. C_{M2M} = Count of served M2M packets
5. C_{DP} = Count of served data packets.
6. ***If*** $(T_{served}\ \%4 = 0)\&(T_{served} = 0)$ $\&(T_{served}\ /4 >= C_{M2M})\ \&(T_{served}\ /4 >= C_{DP})$:
   Then skipped_M2M = $(T_{served}/4) - C_{M2M}$
   skipped_dp = $(T_{served}/4) - C_{DP}$
7. Remainder_M2M = $\max Q_{length} -$ $Queue_{Size}(M2M_{wait})$
8. Remainder_dp = $\max Q_{length} - Queue_{Size}(DP_{wait})$
9. ***If*** Remainder_M2M/skkiped_M2M <= 1:
   Then Priority_Indicator = 1;
10. ***If*** Remainder_dp*0.5/skipped_dp <= 1:
   Then Priority_Indicator = *2;*
11. ***If*** Remainder_dp*0.5/skipped_dp <= 1 &Remainder_M2M <= 1:
   Then Priority_Indicator = 3; *12.*
12. ***End***

Algorithm 2 Dynamic Decision

1. *Begin*
2. *Generate* a random number between 0 and 1
3. ***If*** the priority indicator = 0 (system is stable):
   then there is a 25 percent chance to dequeue the first Video Packet, 20 percent chance to dequeue the first voice packet, 25 percent chance to dequeue the first M2M packet and, 30 percent chance to dequeue the first data packet based on the random number.
4. ***If*** priority_indicator = 1:
   Then *dequeue* first M2M packet,
5. ***Else if*** priority_indicator = 2:
   Then *dequeue* first Data packet
6. ***Else if*** priority_indicator = 3:
   Then If Remainder_M2M/skipped_m2m <= 1:
   Dequeue first M2M;
   If Remainder_dp*0.5/skipped_dp <= 1:
   Dequeue first DP;

End

processing model is represented by two phases. These two phases are described as follows. In the first phase, we try to monitor the pattern of how each packet arrives into the system. In the second phase, we try to determine and predict which packet to serve and depart based on the arrival pattern. Based on this prediction, our approach then decides which packet to Dequeue next.

The operational workflow of this approach is shown in Fig. 2. In case all the queues are full, the incoming packets are discarded. Please note that the workflow presented is heavily dependent on algorithms 1 and 2 explained below. For the cases where allocation is possible, at first the priority indicators are calculated using the algorithm 1. In case the priority indicator is zero, the system provides services in a balanced way for each type of packet. Some probabilities are assigned for this state to handle incoming packets, however various probabilities can be assigned specific to the user requirements. In case the priority indicators can be one, two or three, this specifies whether to serve the data packets or M2M packets. After the completion of the service, the routine is repeated. Typically, any priority-based approach (e.g., the potential priority-based benchmark we are considering in our results section) will try to serve the 4 types of requests in this study according to the following order: First, the machine-to-machine (M2M), Second, the video packets (VP), Third, the voice packets (VoIP), and last one would be the data packets (DP). However, this can lead to a significant problem, which is the deadlock in real-time applications. Accordingly, we introduced a new factor in our approach that takes in to consideration the balance ratio in order to avoid this deadlock problem that can be experienced with any request type. This factor is measured by the ratio of remaining to the served requests so far for each type. Since the data packets (DP) type can tolerate further delays, we assigned a lower weight factor (=0.5) to it in comparison to the most important type which is the M2M. This weight value can varies according to the experienced scenarios at the four different system queues.

The following two algorithms summarize SAHCI approach, which has been employed in this study. Algorithm one is used to set the priority indicators which is essential in decision of which type of packet to serve. Initially the indicator is zero, which means the system is well balanced. In case the number of skipped packets become higher than number of packets in the queue for M2M or greater than half of the data packets, the indicator is set to one and two respectively. In Algorithm two, the M2M packets are prioritized if indicator is one and data packets are prioritized if the indicator is two. Otherwise the indicator is set to be three and in algorithm two both M2M and data packets in front are served. Unlike many of the existing scheduling approaches in the literature such as the ones employed in [2], [5] and the one introduced in [17], our approach provides a more dynamic priority scheme which can be used to further improve QoS by fine tuning. In other words, in studies such as [17], data packets do not receive any service in case there are voice packets waiting. Instead, our approach allows data packets to receive service depending on the stochastic processes involved.

We remark that probabilities in line 3 of Algorithm 2 should not be based on analytical results but rather on experimental one for more effective solutions.

IV. DISCUSSIONS AND RESULTS

The following section discusses the first set of results obtained from various test case scenarios. Mathematical explanations are also provided for the test cases. All of the following results are not based on one run, but rather the average of 1000 runs for statistically stable results with varying seed values for the random number generator to ensure more practical performance and results. A simulation tool is developed for discrete event simulation of the queuing systems considered similar to [4], [7], [8], [17]. The simulated system environment is described by population and packet size. In the following, we list our tuned simulation parameters:

- Queue capacity: The maximum number of packets the queue considered can accommodate.
- Number of Queues: There are four queues in the system modeled where one queue is provided for each type of packet.
- Service time: Exponentially distributed service times are employed
- Inter-arrival time: The time between packet arrivals are also specified following exponential distribution.

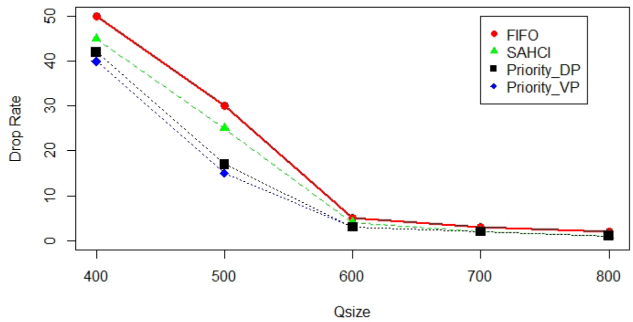

FIGURE 3. M2M Drop Rate vs. Queue size.

As for the main performance metrics used in order to show the effectiveness of the recommended SAHCI approach, the following are employed:

- Latency: It is defined as the total waiting time in queue for each data type.
- Drop factor: It is defined as the number of packets dropped from the waiting queue before receiving service for each type.

To measure how SAHCI approach performs in comparison to other approaches, we implemented two other simulators for two different relevant approaches. These two approaches are described as follows:

- FIFO: this approach implements a First in First Out (served) queue with RED as the dropping mechanism.
- Priority Drop-Tail: this approach implements a priority queue with the following order of priorities (M2M > VP > VoIP > DP) with the first being of the highest priority, and RED as dropping mechanism.

For the case where we change the Queue size, we ran the simulation 1000 times and then we take the mean, which is represented by a dot in results figures. Simulation results are presented comparatively with the well-known analytical models for M/M/1 queuing which means the queuing discipline is FIFO the service rate is taken as $\mu = 80$/msec, $\lambda = 40$/msec; i.e. $\lambda_{M2M}+\lambda_{DP}+\lambda_{VP}+\lambda_{VoIP} = 40$. The parameters chosen are similar to the ones in studies such as [8], where traffic intensity is 0.5 like our work, [9], which specifies the wide range of possible delays from a few milliseconds to several minutes depending on the application, and [17], which also takes the service and inter-arrival times in units of milliseconds.

A. DROP RATE VS. QUEUE SIZE FOR THE FOUR PACKET TYPES

In this section we have compared the drop rate of the SAHCI approach against three other baselines, which are FIFO, Priority_VP (priorities set as M2M > VP > VoIP > DP), and Priority_DP (priorities set as M2M > DP > VP > VOIP). Figures 3 shows that priority based approaches perform better in terms of M2M traffic as expected since they do not serve any other type while there are M2M packets in the system. This has a slight effect on DP dropping probability as shown

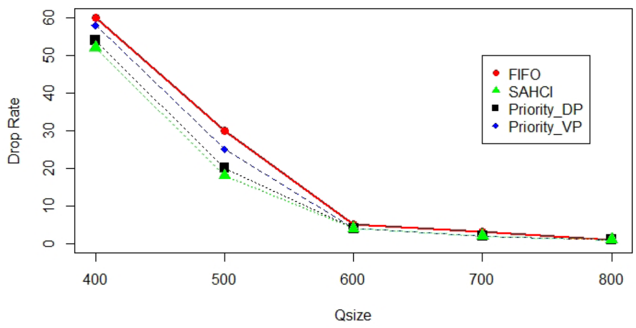

FIGURE 4. DP Drop Rate vs Queue size.

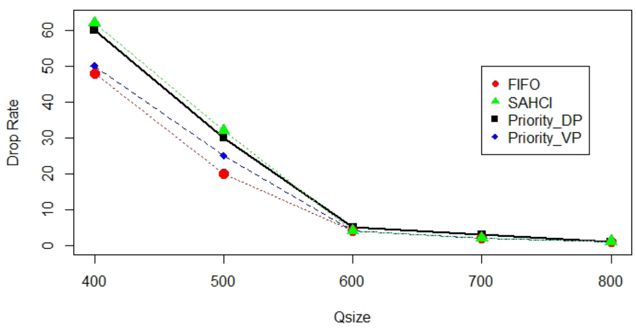

FIGURE 5. VoIP Drop Rate vs Queue size.

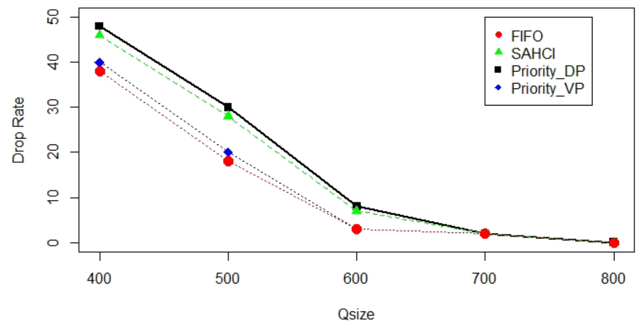

FIGURE 6. VP Drop Rate vs. Queue size.

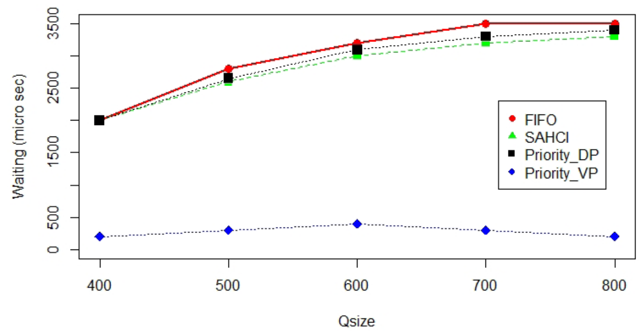

FIGURE 7. M2M waiting vs. QSize.

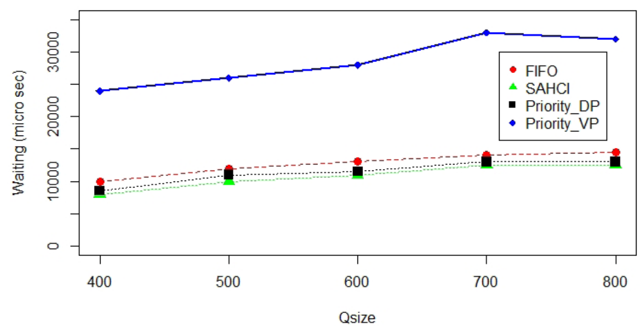

FIGURE 8. DP waiting vs. QSize.

in figure 4, making SAHCI performance slightly superior to Priority_DP. In the SAHCI approach, we are targeting a low drop rate in M2M and DP packets, while the waiting time for the VoIP and VP packets are still in acceptable levels. Please note that the dynamic nature of the SACHI algorithm allows us to have manageable response times for VoIP and VP packets. In case of some static scheduling algorithms, which prioritize M2M and DP packets disregarding the involved, stochastic processes are employed; the response times can reach to levels, which are not suitable for real time applications.

Since the algorithm presented checks the conditions of queues for M2M and DP and sets the priority indicators accordingly, it has the capability to reduce the Drop Rate.

Unlike M2M and DP packets, as illustrated in Figure 5, the VoIP drop rate of SAHCI, is higher than the drop rate of the other approaches across all Queue sizes. This is an expected result for our model, since we traded off this with a better drop rate for M2M and DP, and a better waiting time for VoIP and VP. Moreover, Priority_VP and FIFO have close drop rates for VoIP, because of the fact that both follow a RED dropping manner, but Priority gives VoIP a higher priority over DP while FIFO is fair, and that has a very slight effect on the figure. A similar scenario is observed for Figure 6, since video is prioritized over M2M and DP packets.

B. WAITING TIME VS QSIZE

In this section, the comparison is based on measuring the average waiting time for each packet type using our SAHCI approach versus the other three approaches. The following figures show detailed results.

Figure 7 illustrates the average waiting time of each approach for the M2M packets. Even though the expected results were to have our approach with higher waiting times than Priority_DP, the results show that the waiting time of the SAHCI approach is very close to Priority_DP and better than that of FIFO. We can say that the dynamic allocation of service facilities, which consider the state of queues, adopt better than the commonly used FIFO approach.

Figure 8 illustrates the average waiting time of each approach for the DP packets. This figure shows that our approach has the lowest waiting time for DP, while the Priority_VP approach has the highest waiting time since DP is of the lowest priority. FIFO and Priority_DP, on the other hand, are on average close to our approach relative to how high the priority approach is. Since the Priority_VP approach does not consider serving the DP packets in presence of video and voice, our approach once again presents a more balanced implementation in terms of QoS.

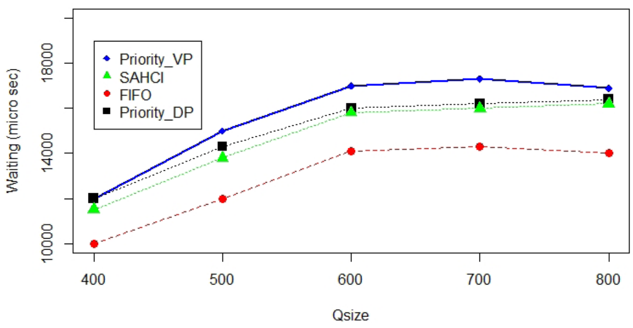

FIGURE 9. VoIP waiting vs. QSize.

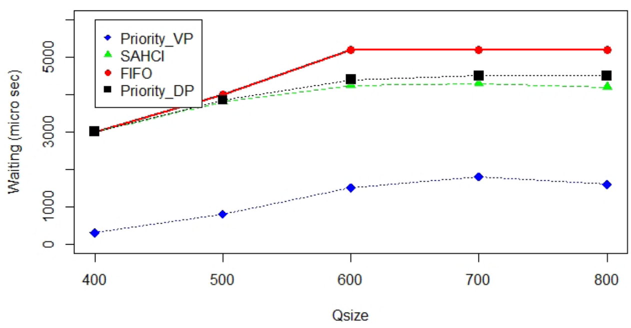

FIGURE 10. VP waiting vs. QSize.

Figure 9 illustrates the average waiting time of each approach for VoIP packets. The figure shows that our approach performs in between priority based approaches and FIFO, giving it a good performance but not the best results we anticipated for the VoIP, while the priority_VP approach has the highest waiting time but still not as high as DP for the same approach, since VoIP is higher in priority than DP (i.e. VoIP is processed before DP in the queue). Furthermore, FIFO shows the lowest waiting time for VoIP, which is close to that of M2M and DP for the same approach.

Figure 10 illustrates the average waiting time for each approach of VP packets. For SAHCI, we can see from this figure that the reversed role between DP and VP takes place where the waiting time of VP is higher than anticipated. However, when FIFO, Priority_DP, and SAHCI are compared, unlike the previous figure, waiting times are not that high and still acceptable for VP communications. Priority_VP approach, however, has the lowest waiting time since VP has the second highest priority in the queue so it is right after M2M.

Figures 9 and 10 also show that although for specific types of packets, our approach is not always giving the best outcome in terms of QoS, it is always better than the other methods in case the best method implements a strict priority policy. Instead, when Figure 8 is considered, together with Priority_DP, SAHCI approach has the lowest waiting times. Please note that the dynamic nature of SAHCI, which is employed to reduce the drop rate of M2M and DP traffic is the main reason for this behavior.

In general, for SAHCI, when Figure 3 is considered, the dropping of M2M is relatively close to that of the FIFO and with similar trend, since they both follow the same dropping mechanism RED. For the FIFO approach, the similar dropping and waiting pattern for all packet types (refer to Figures 5, 6, 7 and 8) also indicate fairness that is expected since no priority is given based on data type. Finally, there is close pattern between both FIFO and Priority_VP approaches in the dropping rate since they both follow the same dropping mechanism.

V. CONCLUSION

In this study, a SAHCI approach for packet content-based scheduling is presented for various types of packets from machine and human sources. Results of the new approach (SAHCI) are compared against two well-known approaches, which are FIFO and priority-based Drop-Tail, using extensive simulations. These results show that the SAHCI approach is able to reduce the dropping rate of M2M and VP packets, while similar but slightly higher dropping rates are observed for VoIP and DP packets. The results obtained for the waiting time shows that the SAHCI approach is superior for DP packets and better than FIFO scheduling for M2M. When VoIP type of packets are considered, the SAHCI approach is still comparable to the other mechanisms while for VP traffic it performs better than FIFO. In other words, the SAHCI approach presents itself as a more balanced approach to reduce the drop rate for non real-time communications, which is very important for congestion control while keeping the waiting times in manageable levels for the real time communications.

Furthermore, the SAHCI approach has the potential to control its behavior by modifying the control variables in the algorithm in order to get better results for specific traffic characteristics. The latter for us represents the forte of the approach. Hence using this approach for a better optimized buffer allocation to meet the QoS requirements, or even other requirements for a specific service that uses the same or a similar setup to the one represented in the system model figure earlier is possible by changing the control variables in the algorithm.

REFERENCES

[1] F. Al-Turjman, E. Ever, and H. Zahmatkesh, "Small cells in the forthcoming 5G/IoT: Traffic modelling and deployment overview," *IEEE Commun. Surveys Tuts.*, vol. 21, no. 1, pp. 28–65, 1st Quart. 2019. doi: 10.1109/COMST.2018.2864779.

[2] S. Alabady, F. Al-Turjman, and S. Din, "A novel security model for cooperative virtual networks in the IoT era," *Int. J. Parallel Program.*, vol. 30, pp. 1–16, Jul. 2018. doi: 10.1007/s10766-018-0580-z.

[3] F. Al-Turjman, E. Ever, and H. Zahmatkesh, "Green femtocells in the IoT era: Traffic modeling and challenges—An overview," *IEEE Netw.*, vol. 31, no. 6, pp. 48–55, Dec. 2017.

[4] K. Gomez, L. Goratti, F. Granelli, and T. Rasheed, "A comparative study of scheduling disciplines in 5G systems for emergency communications," in *Proc. 1st Int. Conf. 5G Ubiquitous Connectivity*, Nov. 2014, pp. 40–45.

[5] M. Z. Hasan, F. Al-Turjman, and H. Al-Rizzo, "Analysis of cross-layer design of quality-of-service forward geographic wireless sensor network routing strategies in green Internet of Things," *IEEE Access*, vol. 6, pp. 20371–20389, 2018.

[6] L. Zhang, L. Zhang, and D. Xu, "Characteristics of network delay and delay jitter and its effect on voice over IP (VoIP)," in *Proc. IEEE Int. Conf. Commun., Conf. Rec.*, Jun. 2001, pp. 122–126.

[7] F. Al-Turjman, ‘‘Information-centric framework for the Internet of Things (IoT): Traffic modeling & optimization,’’ *Future Gener. Comput. Syst.*, vol. 80, pp. 63–75, Mar. 2018.

[8] F. Al-Turjman, ‘‘QoS—Aware data delivery framework for safety-inspired multimedia in integrated vehicular-IoT,’’ *Comput. Commun.*, vol. 121, pp. 33–43, May 2018.

[9] A. M. Maia, D. Vieira, M. F. de Castro, and Y. Ghamri-Doudane, ‘‘A mechanism for uplink packet scheduler in LTE network in the context of machine-to-machine communication,’’ in *Proc. IEEE Global Commun. Conf.*, Dec. 2014, pp. 2776–2782.

[10] J. Cho and D. Hong, ‘‘Tradeoff analysis of throughput and fairness on CDMA packet downlinks with location-dependent QoS,’’ *IEEE Trans. Veh. Technol.*, vol. 54, no. 1, pp. 259–271, Jan. 2005.

[11] V. Abdrashitov, W. Nam, and D. Bai, ‘‘Rate and UE selection algorithms for interference-aware receivers,’’ in *Proc. VTC Spring*, May 2014, pp. 1–5.

[12] A. Kumar, A. Sharma, A. Singh, and B. Ambedkar, ‘‘Comparison and analysis of drop tail and RED queuing methodology in PIM-DM multicasting network,’’ *Int. J. Comput. Sci. Inf. Technol.*, vol. 3, no. 2, pp. 3816–3820, 2012.

[13] S. A. Alabady and F. Al-Turjman, ‘‘Low complexity parity check code for futuristic wireless networks applications,’’ *IEEE Access*, vol. 6, pp. 18398–18407, 2018.

[14] A. Gupta and E. R. K. Jha, ‘‘A survey of 5G network: Architecture and emerging technologies,’’ *IEEE Access*, vol. 3, pp. 1206–1232, 2015.

[15] W. Shi, J. Cao, Q. Zhang, Y. Li, and L. Xu, ‘‘Edge computing: Vision and challenges,’’ *IEEE Internet Things J.*, vol. 3, no. 5, pp. 637–646, Oct. 2016.

[16] J. F. Shortle, J. M. Thompson, D. Grossand, and C. M. Harris, *Fundamentals of Queueing Theory*. Hoboken, NJ, USA: Wiley, 2008.

[17] E. Gemikonakli, E. Ever, G. Mapp, and O. Gemikonakli, ‘‘Admission control and buffer management of wireless communication systems with mobile stations and integrated voice and data services,’’ *Telecommun. Syst.*, vol. 65, no. 4, pp. 663–675, 2017.

FADI AL-TURJMAN received the Ph.D. degree in computer science from Queen’s University, Canada, in 2011. He is currently a Professor with Antalya Bilim University, Turkey. He is also a leading authority in the areas of smart, wireless and mobile networks’ architectures, protocols, deployments, and performance evaluation. His record spans over 200 publications in journals, conferences, patents, books, and book chapters, in addition to numerous keynotes and plenary talks at flagship venues. He has authored or edited more than 12 published books about cognition, security, and wireless sensor networks’ deployments in smart environments with Taylor & Francis, and the Springer (Top tier publishers in the area). He was a recipient of several recognitions and best papers’ awards at top international conferences. He also received the prestigious *Best Research Paper Award* from *Computer Communications Journal* (Elsevier) for the last three years prior to 2018, in addition to the Top Researcher Award for 2018 at Antalya Bilim University, Turkey. He led a number of international symposia and workshops in flagship the IEEE ComSoc conferences. He is serving as the Lead Guest Editor in several journals, including the *IET Wireless Sensor Systems*, *EURASIP* (Springer), *Sensors* (MDPI), *Wiley WCM*, and the *Computer Communications* (Elsevier).

ENVER EVER received the B.Sc. degree from the Department of Computer Engineering, Eastern Mediterranean University, Cyprus, in 2002, and the M.Sc. degree in computer networks and the Ph.D. degree in performance evaluation of computer networks and communication systems from Middlesex University, in 2004 and 2008, respectively. He was with Bradford University as a Postdoctoral Research Associate for a year. He was a Senior Lecturer with the Computer and Communications Engineering Department, Middlesex University. He is currently an Associate Professor with Middle East Technical University, Northern Cyprus Campus. His current research interests include computer networks, wireless communication systems, parallel computing paradigms, wireless sensor networks, integrated circuits, and performance/reliability modeling. He serves on various Programme Committees and received the Exemplary Reviewer Award for his contributions as a Reviewer.

YOUSAF BIN ZIKRIA (SM’17) received the Ph.D. degree from the Department of Information and Communication Engineering, Yeungnam University, South Korea, in 2016. He has more than 10 years of experience in research, academia and industry in the field of information and communication engineering and computer science. He is currently as an Assistant Professor with the Department of Information and Communication Engineering, College of Engineering, Yeungnam University, Gyeongsan-Si, South Korea. His research interests include the IoT, 5G, wireless communications and networks, opportunistic communications, wireless sensor networks, routing protocols, cognitive radio ad hoc networks, cognitive radio ad hoc sensor networks, transport protocols, VANETS, embedded systems, and information security. He is also an Associate/Guest Editor of FT/SI for FT/SI on Unlocking 5G Spectrum Potential for the Intelligent IoT: Opportunities, Challenges, and Solutions for the *IEEE Communications Magazine*, Tactile Internet: Technologies, Test Platforms, Trials, and Applications and the Internet of Things (IoT): Operating System, Applications and Protocols Design, and Validation Techniques for *Future Generation Computer Systems* (FGCS) (Elsevier), Data Driven Intelligence in Wireless Networks: Issues, Challenges, and Solution for *Transactions for Emerging Telecommunications Technologies* (ETT), the Internet of Things (IoT) Operating Systems Management: Opportunities, Challenges, and Solution for MDPI Sensors, and 5G Mobile Services and Scenarios: Challenges and Solutions for MDPI Sustainability. He is also serving as a Reviewer of the IEEE Communications Surveys and Tutorials, the *IEEE Communications Magazine*, the IEEE Communications Letters, the IEEE Sensors, IEEE Access, the IEEE IT Professional, *Elsevier Future Generation Computer Systems*, *Computer Standards and Interfaces* (Elsevier), *The Journal of Supercomputing* (Springer), *Journal of Distributed Sensor Networks* (Sage International), and *KSII Transactions on Internet and Information Systems*. He was a recipient of the Excellent Paper Award of the ICIDB 2016 Conference and fully funded scholarship for master’s and Ph.D. degrees. He held the prestigious CISA, JNCIS-SEC, JNCIS-ER, JNCIA-ER, JNCIA-EX, and Advance Routing Switching and WAN Technologies certifications.

SUNG WON KIM received the B.S. and M.S. degrees from the Department of Control and Instrumentation Engineering, Seoul National University, South Korea, in 1990 and 1992, respectively, and the Ph.D. degree from the School of Electrical Engineering and Computer Sciences, Seoul National University, South Korea, in 2002. From 1992 to 2001, he was a Researcher with the Research and Development Center of LG Electronics, South Korea. From 2001 to 2003, he was a Researcher with the Research and Development Center of AL Tech, South Korea. From 2003 to 2005, he was a Postdoctoral Researcher with the Department of Electrical and Computer Engineering, University of Florida, Gainesville, FL, USA. In 2005, he joined the Department of Information and Communication Engineering, Yeungnam University, Gyeongsangbuk-do, South Korea, where he is currently a Professor. His research interests include resource management, wireless networks, mobile computing, performance evaluation, and machine learning.

ABDULMALEK ELMAHGOUBI received the B.Sc. degree in computer engineering from the Middle East Technical University, Northern Cyprus Campus, Mersin, Turkey. He is with Middle East Technical University and involved in several smart projects via which he expands his practical skills. His research interests include 5G communications, wireless sensor networks, sustainable and renewable energy integration, distributed power generation, and smart grid applications.

• • •