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Modeling and Performance Evaluation of Body Area Network in Mobile Edge Computing Paradigm

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Abstract—**Body Area Network (BAN) is composed of various sensors and some actuators which are attached on body or even implanted under skin. The data is gathered from sensors in different periods of time and transferred to the servers or doctors for interpretation. Sometimes after processing, control signals comeback to the origin for actuation activities. This application is delay-sensitive and its performance evaluation is critical concern. In this paper, we focus on performance evaluation of BAN technology in a typical hospital. We also employ the Mobile Edge Computing (MEC) paradigm. The idea of MEC is using small data centers in the proximity of mobile base stations. As a result, user requests will fulfill in shorter time. The motto of MEC is local problems should be solved locally. MEC is known as base and key technology of 5G and IoT. In this paper, we extract the servicing steps of BAN application in a hospital. Markov Reward Models (MRM) are presented for each steps. The models are solved by SHARPE software package. Mean response delay and request blocking probability are calculated under different situation. Moreover, the numerical results are verified by Discrete-Event Simulation.**

Keywords- Body Area Network; Mobile Edge Computing; Performance Evaluation; Markov Reward Model.

I. INTRODUCTION

Body Area Network (BAN) helps doctors to be aware of their patient's status. Usually, sensors are attached to the patient through cloths, wearable devices or even implant technique [1]. Sensors gather their related data from patient's body in different periods of time [2]. They transfer data to the servers via Personal Digital Assistant (PDA) or gateway [3]. In general, patients could continue their daily activity after sensors attachment [4]. However, in some cases, BAN or Wireless BAN (WBAN) is deployed for the patients whom hospitalized in the medical centers [5]. BAN applications are delay-sensitive and they could not tolerate long latency. Therefore, performance evaluation for BAN applications are a crucial issue.

On the other hand, cloud computing has opened a new window of information technology to academic researchers, industrial experts and end-users. Many companies instead of using their own data centers, choose the leasing resources from cloud providers [6]. The most advantage of this technology was the removing the process of buying, repairing, maintaining and upgrading servers. On the other hand, cloud computing concluded cost reduction pertaining to energy consumption and IT staffs. End users could provision storage, computing and network resources with their arbitrary amount in cloud computing. And, scale up or scale down these resources based on their requirements. The most attractive feature of cloud computing for end users is the pay-as-you-go manner [7]. Nowadays, many of the popular websites are deploying cloud computing platform. Therefore, they could be available at the peak time and their websites serve the visitors without paying cost of unused resources at other times. Indeed, this is the most important capability of cloud computing, which is called elasticity. Exponential growth of using smart phones and tablets have made the problem of deploying heavy games or computational software on these devices, because of their processing and energy constraints. Therefore, Mobile Cloud Computing (MCC) was formed. In MCC, tasks are offloaded to the cloud data center and after running on servers, the results come back to mobile devices. Many applications are deploying this technology. However, the problem is the produced latency due to data transfer which is not tolerable for deadline-based applications. To resolve this issue, researchers proposed a concept which is named cloudlet. In this manner, some public places such as airports or coffee shops which provide WiFi internet could gain from the small number of servers and they process the offloaded tasks if possible. Therefore, latency will be decreased. However, because the access of cloudlet only is possible through WiFi connection, another technology i.e. Mobile Edge Computing (MEC) was born in 2014. MEC is one of the fundamental technologies in 5G mobile systems to present Ultra Reliable and Low Latency Communication (URLLC) services [8]. Servers are moving to the edge of Radio Access Network (RAN). The motto of MEC is the local problems should be solved locally [9]. Therefore, latency will be decreased and reached in order of milliseconds. Furthermore, backbone traffic will be diminished significantly. European Telecommunications Standards Institute (ETSI) are working on the MEC and its relevant technologies.

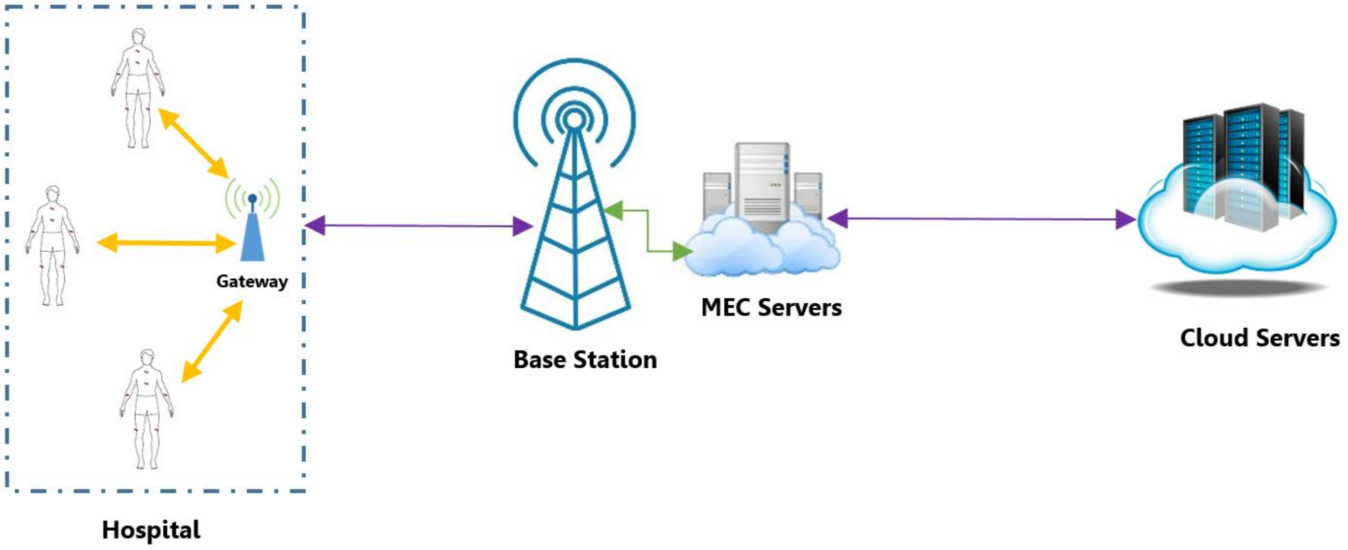

Figure 1. Body Area Network architecture using Mobile Edge Computing

As shown in fig. 1, data are collected by the sensors in various periods of time. We suppose that our patients are hospitalized and we gain from MEC technology. Therefore, data transferred from sink node of each patient to the gateway. Gateway is gathering data and it will send to the nearest base station. We suppose that the base station is equipped by MEC servers. The received data is processing by the MEC servers in certain virtual machine (VM). Sometimes the system is overloaded. It means that default VM cannot support all requests. After processing steps, control signals are coming back to the hospital for an appropriate actuation.

The main contributions of this paper are listed as follows:

- Various parameters such as workload, queue lengths, VM startup and number of servers are considered
- Our stochastic model captures the end-to-end performance metrics
- Markov Reward Model (MRM) are considered for each sub-model
- Models are solved by SHARPE [10] tools
- Discrete Event Simulation (DES) conducted by MATLAB [11] for verification of acquired numerical results

The rest of the paper is organized as follows. Section II brings the related works which pertaining to the performance analysis of BAN. In section III, we presented system description and main assumptions. Stochastic sub-models and overall model are proposed in section IV. Numerical results and simulation are provided in section V. Finally, in section VI, conclusion and future works are presented.

II. Related Works

Khan et al. [12] proposed a routing protocol which handle delay-sensitive packets in body area network. They simulated the proposed protocol by OMNeT++ [13] and illustrated its performance. D'Errico [14] presented a performance analysis of body area network in terms of packet error rate. They suppose a full-mesh topology for sensors and time-variant channel for communication. Martelli et al. [15] simulated the WBAN which using IEEE 802.15.6 protocol for communication. They evaluated some performance measures such as throughput, delay and packet loss rate. Khan et al. [16] worked on remote patient monitoring system and its performance evaluation. They considered ZigBee as WBAN communication protocol and examined its performance metrics. Li et al. [17] evaluated three different access schemes under IEEE 802.15.4 protocol. They illustrated the unslotted mode has better performance than the slotted one. However, its power consumption is much more. In contrast to these prominent works, our paper devoted to the performance evaluation of BAN under MEC paradigm which is a new and growing mobile computing technology.

III. System Description And Assumptions

As we illustrated in Fig. 1, sensors have the duty of gathering data from the patients. Although, sensing periods are different, however, we suppose that inter-arrival time of sending data from PDA to gateway follows the exponential distribution. Furthermore, we suppose that service rate of the requests has an exponential distribution.

Since we gain from MEC technology, the requests are transferred to the MEC servers for the appropriate processing. In MEC paradigm if MEC servers have insufficient capacity for processing or storage then the task will be offloaded to the cloud. However, we suppose that MEC servers have enough capacity. The control signals come back to the patient for an appropriate actuation after processing. Fig. 2 illustrates the servicing steps of BAN technology which is using MEC paradigm. Each of queues follows the First-In-First-Out (FIFO) manner. SDTE queue is the first queue which buffer the sensing data for transfer. PDE queue is for processing in the

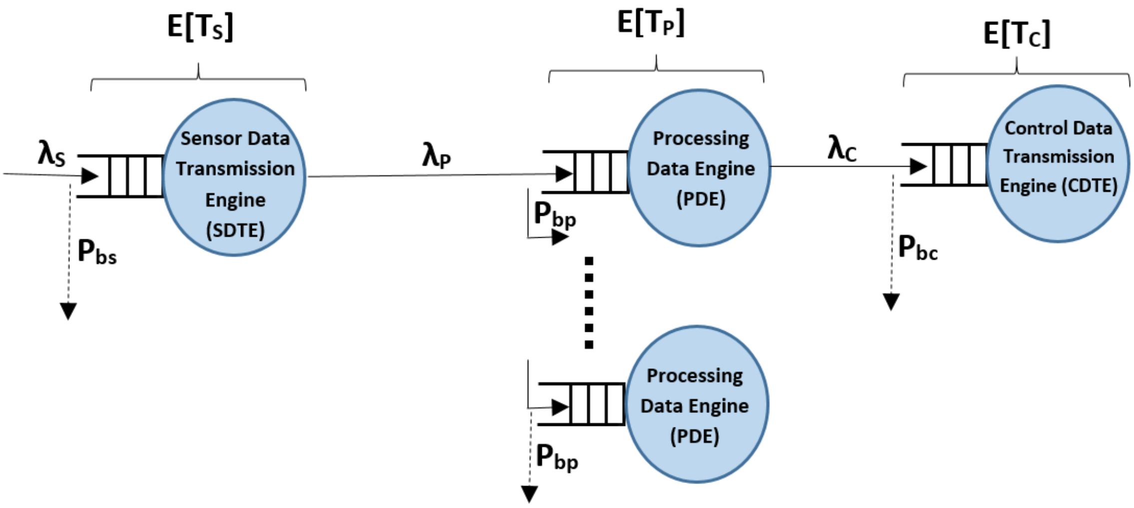

Figure 2. Servicing Steps of Body Area Network application in Mobile Edge Computing Platform

MEC server. If the request is blocked due to insufficient size of processing VM then another VM will be created. This process will be continued until there is an enough capacity in the MEC servers. Otherwise, the request will be blocked. CDTE queue is the last queue which buffers the sending control signals to the patients. The symbols which are using throughout the paper are listed in the Tab. I.

Table I
Notation description for the presented queueing models

Notation	Description
λ_S	Arrival rate of sensing data to base station
λ_P	Effective arrival rate for MEC servers
λ_C	Effective arrival rate of control signals transmission engine
μ_S	Service rate of SDTE queue
μ_P	Service rate of PDE queue
μ_C	Service rate of CDTE queue
P_{bs}	Request blocking probability in the SDTE queue
P_{bp}	Request blocking probability in the PDE queue
P_{bc}	Request blocking probability in the CDTE queue
$E[T_S]$	Mean delay time in SDTE queue
$E[T_p]$	Mean delay time in PDE queue
$E[T_C]$	Mean delay time in CDTE queue
$E[T]$	Mean Response Delay
L_S	Maximum size of SDTE queue
L_P	Maximum size of PDE queue
L_C	Maximum size of CDTE queue
L	Maximum size of VM expansion
β	VM startup rate

IV. Stochastic Sub-Models And Overall Model

In this section, we sketch the Markov Reward Models (MRMs) for each queueing engine which are introduced in previous section.

A. Sensor Data Transmission Engine (SDTE) sub-model

To show the nature of SDTE queue, an MRM depicted in fig. 3 which its states labeled as number of requests that is currently waiting in the queue. In fig. 3, λ_s is representative of request arrival rate, μ_s is the service rate and L_s is the maximum size of queue. In this sub-model, the SDTE queue will transit from state i to i+1 with λ_s where $0 \leq i \leq L_s$. Also, the requests served by the engine at rate μ_s.

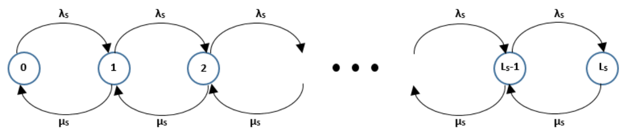

Figure 3. Markov Reward Model for SDTE

SDTE aggregates sensor data and sending them to the MEC servers for processing. In fact, SDTE prepares the input of PDE queue. If SDTE queue is full of requests, the new request will be blocked. Tab. II shows the reward rates for calculating the request blocking probability and mean number of requests in the SDTE queue.

Table II
Assigned reward rates for calculating measures in SDTE sub-model

Measure	Reward Rate
Request Blocking Probability	1 for state L_s 0 for other states
Mean number of Requests	i for state i where $0 \leqslant i \leqslant L_S$

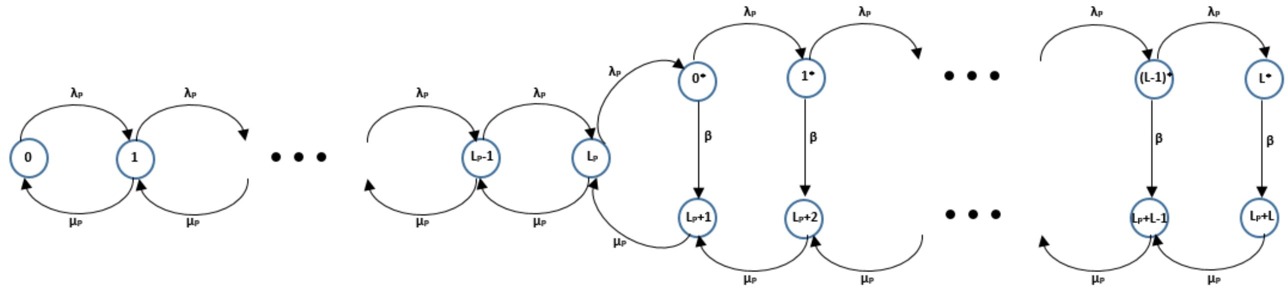

Figure 4. Markov Reward Model for PDE

On the other hand, steady state probability can be computed by (1).

$$\pi_i = \left(\frac{\lambda_S}{\mu_S}\right)^i \left[\frac{1}{\sum_{j=0}^{L_S}\left(\frac{\lambda_S}{\mu_S}\right)^j}\right] \quad (1)$$

In the Tab. II, we calculated the steady state probability by $\sum_{i=0}^{Ls} r_i \pi_i$. We also calculate the E[T_S] by applying the Little's Law [18] in (2).

$$E[T_s] = \frac{\sum_{i=0}^{L_S} i\pi_i}{\lambda_S(1-P_{bs})} \quad (2)$$

B. Processing Data Engine (PDE) sub-model

In PDE sub-model, sensor data will be processed by the MEC servers which are connected to the base station by fiber optics. Fig. 4, illustrates the PDE sub-model in the Markov Reward Model approach. Sometimes new requests cannot be processed by the virtual machine due to full loading. In this case, a new VM should be provisioned with β startup rate. We apply SHARPE tools for calculating the expected measures.

In this sub-model, λ_p is the representative of processing request or effective arrival rate of sensors data. μ_p is the service rate of MEC servers. We suppose that the arrival rate follows the Poisson process, therefore, the time between two consecutive requests follows the exponential distribution. This assumption is also considered for the service rate. Note that, these assumptions help us to apply the Markov chains. In real world, we can experiment the arrival and service rate in the typical hospital and map behavior of them to the statistical distributions.

In fig. 4, the states are shown the number of requests which are currently in the system. On the other hand, some numbers have a star symbol. It means that, the current virtual machine is full and these requests should be forwarded to the new virtual machine. Because of startup delay for creating new VM, these states transit to the new states with β rate.

C. Control Data Transmission Engine (CDTE) sub-model

CDTE sub-model is used for sending control signals towards patients. In fact, this sub-model is similar to the SDTE sub-model. However, λ_c and μ_c are using instead of λ_s and μ_s respectively. Calculating the blocking probability and mean response delay are similar to the SDTE sub-model too.

V. Numerical Results

The proposed models were evaluated in case of request blocking probability and mean response delay. We first apply SHARPE software package to solve models. Furthermore, we conducted a discrete-event simulation by MATLAB to verify the numerical results. At first, to achieve 97 percent for confidence level, the confidence interval was calculated and number of simulation runs were determined.

SHARPE software package calculates the P_{bs}, P_{bp}, P_{bc}, E[T_s], E[T_p] and E[T_c] on each sub-model by solving the steady state equations. Our MATLAB discrete event simulation also computes the average number for these mentioned values.

Request Blocking Probability and Mean Response Delay are computed by (3) and (4) respectively.

$$P_b = P_{bs} + (1- P_{bs})*P_{bp} + (1- P_{bs})*(1 - P_{bp})*P_{bc} \quad (3)$$

$$E[T] = E[T_s] + (1- P_{bs})*E[T_p] + (1- P_{bs})*(1 - P_{bp})*E[T_c] \quad (4)$$

Various parameters are influencing in the mean response delay and request blocking probability. *1) Arrival rate:* This parameter is very important. Therefore, we consider the effect of arrival rate on the outputs. We suppose that arrival rate is varied from 50 to 1050 request per hour. *2) Service rate:* We suppose that mean time to service or 1/μ is equal 5 seconds for each request. *3) VM startup rate:* We suppose that mean time to start a VM is equal 30 seconds. *4) Queue lengths:* Due to importance of this parameter, we varied length of buffer from 10 to 100. *5) Number of VMs:* MEC servers are consisted of some servers and each server could run some of virtual machines. Due to simplicity, we only consider the sum of VMs which are running all servers.

Note that, markers in the figures display the simulation results and dash lines are used for SHARPE outputs. Moreover, number of VMs is located between parentheses and buffer size is located between brackets.

In fig. 5, we study the impact of arrival rate variation in request blocking probability in the presence of different number of virtual machines.

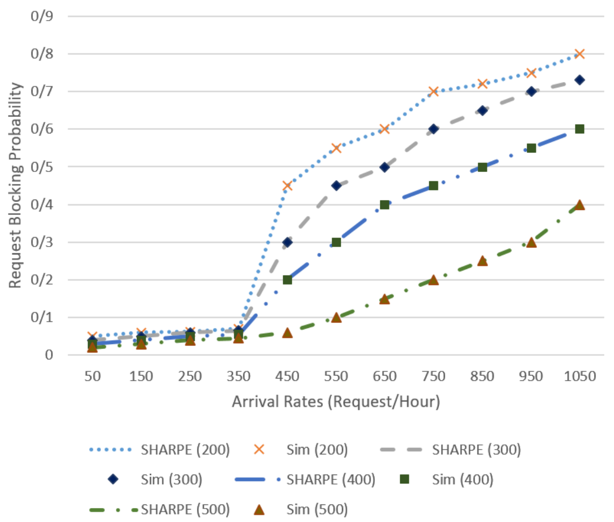

Figure 5. Request Blocking Probability with respect to arrival rate and number of VMs

Dashes lines show the SHARPE numerical results and markers are the representative of MATLAB simulation outputs. The numbers in the parentheses display the number of virtual machines.

Fig. 5 illustrates that request blocking probability increases suddenly after reaching arrival rate to 350 request per hour. Although, increasing number of virtual machines alleviates this phenomenon. However, the request blocking probability is still increasing.

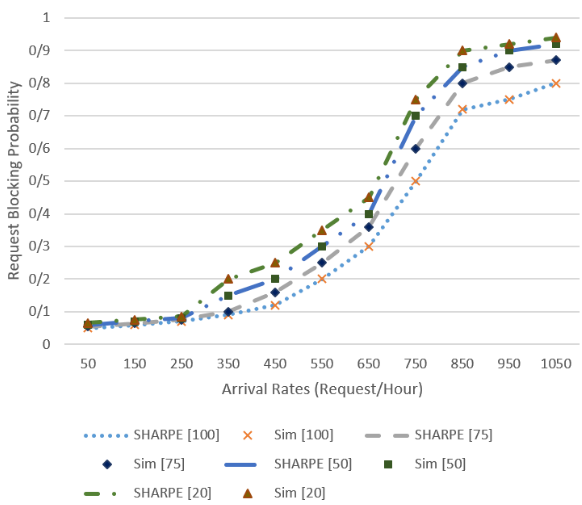

Figure 6. Request Blocking Probability with respect to arrival rate and buffer size

The numbers in the brackets display the size of queues buffer. Fig. 6 shows the request blocking probability behavior when request arrival rates is variable. In fig. 6, queue length of each sub-model is also variable. As shown, increasing buffer size helps the system for less blocking.

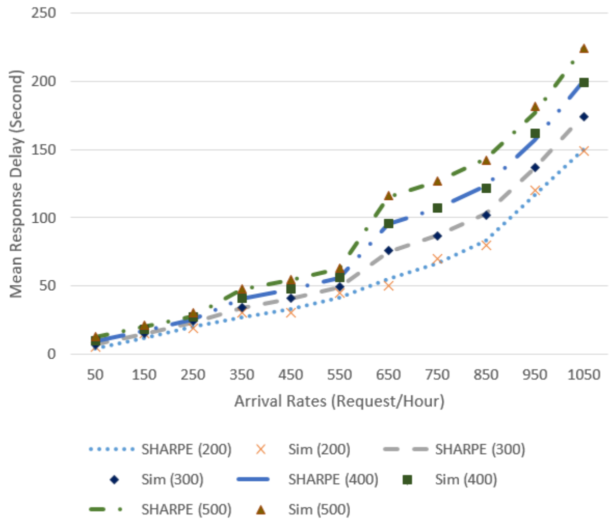

Figure 7. Mean response delay with respect to arrival rate and number of VMs

Fig. 7 displays the mean response delay when arrival rates is variable. Furthermore, we consider the impact of number of virtual machines on mean response delay.

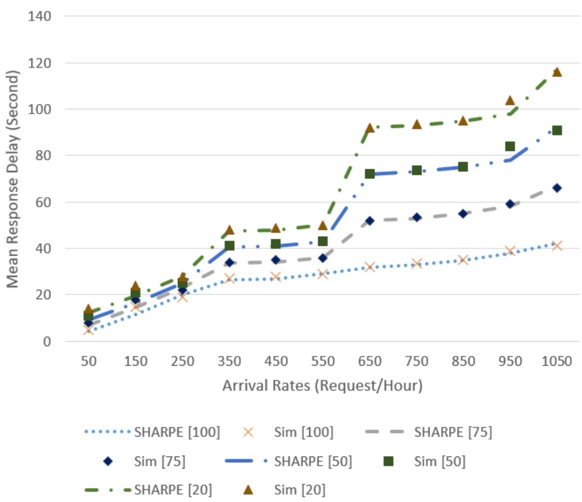

Figure 8. Mean response delay with respect to arrival rate and buffer size

In fig. 8, we show the effect of arrival rates and queue size to the mean response delay. The figure illustrates the strong impact of buffer size to decrease the mean response delay. When buffer size is equal 100, the mean response delay does not exceed from 40 seconds.

VI. CONCLUSION AND FUTURE WORKS

In this paper, we modeled the performance of body area network in mobile edge computing paradigm. We evaluated the impacts of some parameters such as workload, buffer length and service rate on mean response delay and request blocking probability. The current performance model consisted of three stochastic sub-models. Each of which are shown by Markov Reward Model. Models are solved by SHARPE software package. Moreover, numerical results are verified by discrete event simulation. Results illustrate the impact of mentioned parameters on the outputs. For the future, we plan to expand the model for general BAN instead of using hospital environment. Furthermore, considering effect of connection failure on performance models is our future work.

REFERENCES

[1] A. Pantelopoulos and N. G. Bourbakis, "A survey on wearable sensor-based systems for health monitoring and prognosis," IEEE Trans. Syst. Man, Cybern. Part C (Applications Rev., vol. 40, no. 1, pp. 1–12, 2010.

[2] M. Chen, S. Gonzalez, A. Vasilakos, H. Cao, and V. C. Leung, "Body area networks: A survey," Mob. networks Appl., vol. 16, no. 2, pp. 171–193, 2011.

[3] H. Cao, V. Leung, C. Chow, and H. Chan, "Enabling technologies for wireless body area networks: A survey and outlook," IEEE Commun. Mag., vol. 47, no. 12, 2009.

[4] J. H. M. Bergmann and A. H. McGregor, "Body-worn sensor design: what do patients and clinicians want?," Ann. Biomed. Eng., vol. 39, no. 9, pp. 2299–2312, 2011.

[5] M. R. Yuce, "Implementation of wireless body area networks for healthcare systems," Sensors Actuators A Phys., vol. 162, no. 1, pp. 116–129, 2010.

[6] R. Buyya, C. S. Yeo, S. Venugopal, J. Broberg, and I. Brandic, "Cloud computing and emerging IT platforms: Vision, hype, and reality for delivering computing as the 5th utility," Futur. Gener. Comput. Syst., vol. 25, no. 6, pp. 599–616, 2009.

[7] M. Armbrust et al., "A view of cloud computing," Commun. ACM, vol. 53, no. 4, pp. 50–58, 2010.

[8] P. Popovski et al., "Ultra-reliable low-latency communication (URLLC): principles and building blocks," arXiv Prepr. arXiv1708.07862, 2017.

[9] J. Zhang, W. Xie, F. Yang, and Q. Bi, "Mobile edge computing and field trial results for 5G low latency scenario," China Commun., vol. 13, no. 2, pp. 174–182, 2016.

[10] K. S. Trivedi and R. Sahner, "SHARPE at the age of twenty two," ACM SIGMETRICS Perform. Eval. Rev., vol. 36, no. 4, p. 52, Mar. 2009.

[11] D. C. Hanselman and B. Littlefield, MATLAB; Version 4: User's Guide. Prentice Hall PTR, 1995.

[12] Z. Khan, S. Sivakumar, W. Phillips, and B. Robertson, "QPRD: QoS-aware peering routing protocol for delay sensitive data in hospital body area network communication," in Broadband, Wireless Computing, Communication and Applications (BWCCA), 2012 Seventh International Conference on, 2012, pp. 178–185.

[13] A. Varga, "Using the OMNeT++ discrete event simulation system in education," IEEE Trans. Educ., vol. 42, no. 4, p. 11--pp, 1999.

[14] R. D'Errico, R. Rosini, and M. Maman, "A performance evaluation of cooperative schemes for on-body area networks based on measured time-variant channels," in Communications (ICC), 2011 IEEE International Conference on, 2011, pp. 1–5.

[15] F. Martelli, C. Buratti, and R. Verdone, "On the performance of an IEEE 802.15. 6 wireless body area network," in Wireless Conference 2011-Sustainable Wireless Technologies (European Wireless), 11th European, 2011, pp. 1–6.

[16] J. Y. Khan, M. R. Yuce, and F. Karami, "Performance evaluation of a wireless body area sensor network for remote patient monitoring," in Engineering in Medicine and Biology Society, 2008. EMBS 2008. 30th Annual International Conference of the IEEE, 2008, pp. 1266–1269.

[17] C. Li, H.-B. Li, and R. Kohno, "Performance evaluation of IEEE 802.15. 4 for wireless body area network (WBAN)," in Communications Workshops, 2009. ICC Workshops 2009. IEEE International Conference on, 2009, pp. 1–5.

[18] K. S. Trivedi, Probability and statistics with reliability, queuing, and computer science applications, vol. 2002. .