

Performance Analysis of IoT System using Sleep Server Technique



Manas Kumar Rath, Prasanta Kumar Swain, Jibendu Kumar Mantri

Abstract: Modern day living is driven by wireless sensor networks (WSN) as a component of ubiquitous technology. Internet of things (IoT) is a backbone network which enables the sensors to communicate with each other and with machines attached to that network through internet. The growing applications of system automation impose to users to use IoT. However, performance prediction turns out to be a challenge to manage the computing resources in IoT due to dynamic need of the user applications. We have proposed a model based on queueing theory approach for performance analysis of multi-server based IoT enabled system. We have proposed a M/M/C/Sleep where the working server is in OFF state when there is no data packets to serve and switched to ON through set-up phase if there are some data request for service. The performance indices are derived for cost analysis in terms of power consumption.

Keywords: IoT, queueing model M/M/C/Sleep, WSN.

I. INTRODUCTION

The Internet of Things (IoT) is likely to contain enormous numbers of sensors, smart physical objects, machines, vehicles and devices that require occasional data exchange and wireless Internet access. Cellular networks are likely to perform an essential role to deliver first mile connectivity for a large sector of the IoT. Subsequently, the next development of cloud networks is not only intended to offer tangible performance improvement in terms of data rate, network capacity, energy efficiency and latency but also to support massive transfer and Internet access for the massive number of spatially-spread connected things [1-7].

The M/M/C queue is a significant model from the perspective of applications. This type of model study allows us to obtain the insight into the advantages of having numerous parallel servers (processors). For $C = \infty$ obviously no queue arises; the M/M/ ∞ and more generally, the M/G/ ∞ may be used to model.

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The state of the system is completely characterized by the number of jobs in the system [8-14]. Let P_n denote the equilibrium probability that there are n jobs in the system. Similar as for this model uses M/M/C/Sleep queue where there is a frequent state change to the servers from OFF to ON with idle (sleep) and waiting jobs as shown in Fig. 1.

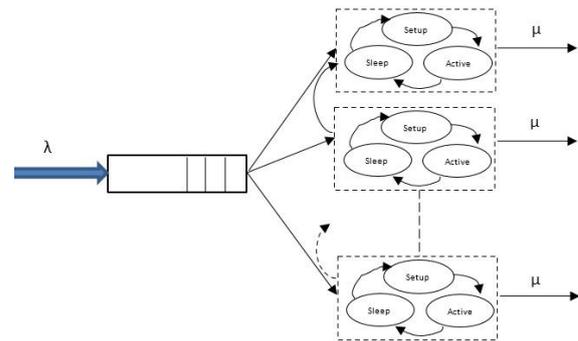


Fig. 1: Proposed System model for multiple server IoT system.

To depict the IoT performance, mathematical models are required to simultaneously increase the performance of the massive presence of IoT devices as well as the traffic condition per device. There exist a several number of servers at the data centers to process the IoT respective services and these servers are expected to consume a huge amount of energy. Thus, the main issue to manage by minimizing the power consumption by these servers with acceptable service levels needed for the users. It is found that with the existing technology of power consumption, an idle server is still consuming about 60 percent of its highest while processing jobs. To save power, one of the widely used methods is to turn these idle servers to sleep mode. However, sleep servers want some setup time to be triggered during which requests are not processed but consume power. By studying this situation, a power-saving trade-off happens between its performance and power saving [15]. This trade-off inspires the study of multi-server queues with sleep mode.

The rest of this paper is planned as follows. Section II describes the system model based on sleep and setup mode. Performance indices are presented in Section III. The mathematical results to demonstrate the usefulness of the proposed model are discussed in Section IV. Finally, the conclusion is discussed in Section V.

II. SYSTEM MODEL

We have proposed a M/M/C/Sleep queueing systems for IoT system with ON-OFF strategy as shown in Fig 2.



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In this strategy, the data packets arrived at rate λ following Poisson process. We undertake that the service time of data follows an exponential distribution with mean $1/\mu$. In this structure, when a service ends its processing, it is turned off instantly if there are no waiting data packets. Otherwise, it directly takes a waiting data to process. If there is an OFF state server available, it is immediately turned ON and the job is Positioned in the buffer with the arrival of a packet. However, a server desires a few of setup time to be triggered so as to serve the waiting jobs. We undertake that the setup time uses exponential distribution with mean $1/\alpha$. With an assumption of two processes in the system, such as receiving service and buffer state waiting for a server in setup process. Under this condition, if the service finishes before the setup, the waiting data packet is served instantly by the active server and the server in setup process is turned OFF.

Let j denotes the data packets in the system and i denote the active servers. Function $\min(j-i, c-i)$ is the amount of servers in setup process. The active servers count is smaller than or equal to the data packets count in the assumed system. Consequently, in this model the possible states of the server are either OFF, BUSY or SETUP. We adopt that waiting data packets are served according to a first-come-first-served (FCFS) manner and modeled as an M/M/C/Sleep queue. The exponential assumptions for the inter-arrival, setup time and service time allow us to construct a Markov chain and steady state analysis has been done. For simplicity, we assume number of servers in the system $i=2$ and data packets in the system $j=3$.

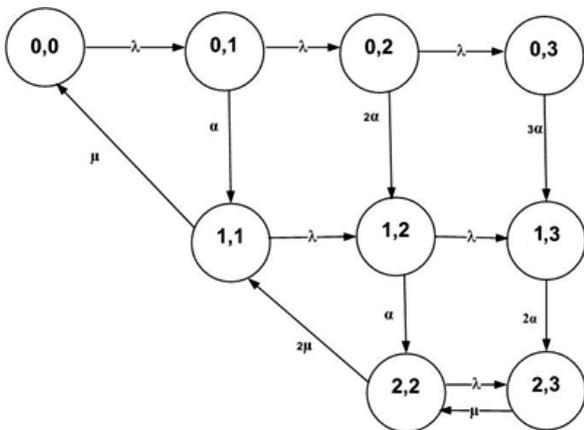


Fig. 2: State transition diagram

Using probabilistic argument from state transition diagram we obtain the following balance equations:

$$\begin{aligned} \lambda P_{(0,0)} &= \mu P_{(1,1)}, \\ (\lambda + \alpha) P_{(0,1)} &= \lambda P_{(0,0)}, \\ (2\alpha + \lambda) P_{(0,2)} &= \lambda P_{(0,1)}, \\ 3\alpha P_{(0,3)} &= \lambda P_{(0,2)}, \\ (\lambda + \mu) P_{(1,1)} &= \alpha P_{(0,1)} + \mu P_{(1,2)} + 2\mu P_{(2,2)}, \\ (\lambda + \alpha + \mu) P_{(1,2)} &= 2\alpha P_{(0,2)} + \mu P_{(1,3)} + \lambda \mu P_{(1,1)}, \\ (2\alpha + \mu) P_{(1,3)} &= 3\alpha P_{(0,3)} + \lambda P_{(1,2)}, \\ (\lambda + 2\mu) P_{(2,2)} &= \alpha P_{(1,2)} + \mu P_{(2,3)}, \end{aligned}$$

$$\mu P_{(2,3)} = 2\alpha P_{(1,3)} + \lambda P_{(2,2)},$$

Normalizing condition for the given model is:

$$P_{(0,0)} + P_{(0,1)} + P_{(0,2)} + P_{(0,3)} + P_{(1,1)} + P_{(1,2)} + P_{(1,3)} + P_{(2,2)} + P_{(2,3)} = 1$$

We can calculate the state probabilities ($P_{i,j}$) from the state balanced equations are as follows:

$$\begin{aligned} P_{(1,1)} &= \frac{\lambda}{\mu} P_{(0,0)} = \rho P_{(0,0)}, \\ P_{(0,1)} &= \frac{\lambda}{\mu + \alpha} P_{(0,0)} = k P_{(0,0)}, \\ P_{(0,2)} &= \frac{\lambda k}{2\alpha + \lambda} = mk P_{(0,0)}, \\ P_{(0,3)} &= \frac{\lambda^2 k}{3\alpha(2\alpha + \lambda)} P_{(0,0)}, \\ P_{(1,2)} &= R P_{(0,0)}, \\ P_{(1,3)} &= \frac{\left[\mu \left(\frac{[\lambda + 2\mu L] - [\alpha R]}{\lambda} \right) - [\lambda L] \right]}{2\alpha} P_{(0,0)}, \\ P_{(2,2)} &= L P_{(0,0)}, \\ P_{(2,3)} &= \frac{[\lambda + 2\mu L] - [\alpha R]}{\mu} P_{(0,0)}, \end{aligned}$$

$$\text{Where } k = \frac{\lambda}{\lambda + \alpha},$$

$$n = \left[(\lambda + \alpha + \mu) - \frac{\mu \lambda}{2\alpha + \mu} \right],$$

$$\rho = \frac{\lambda}{\mu}, m = \frac{\lambda}{2\alpha + \lambda},$$

$$R = \frac{(m2\alpha k) + \left(\frac{\mu 3\alpha \lambda k m}{3\alpha} + \lambda \rho \right)}{n},$$

$$L = \left(\frac{(\lambda + \mu)\rho - \alpha k - \mu R}{2\mu} \right).$$

From the normalizing condition we get the value of $P_{(0,0)}$ can be calculated as:

$$\begin{aligned} P_{(0,0)} &= \left[1 + k + mk + \frac{\lambda^2 k}{3\alpha(2\alpha + \lambda)} + \rho \right. \\ &+ R + \frac{\left[\mu \left(\frac{[\lambda + 2\mu L] - [\alpha R]}{\lambda} \right) - [\lambda L] \right]}{2\alpha} \\ &\left. + L + \frac{[\lambda + 2\mu L] - [\alpha R]}{\lambda} \right]^{-1}. \end{aligned}$$

III. PERFORMANCE INDICES

Let P_i denotes the stationary probability with i number of active servers, i.e.

$$P_i = P \sum_{j=1}^3 P_{i,j}$$

Let $E[A]$ be the mean number of active servers and $E[S]$ be in setup mode. Then we have, active servers,

$$E[A] = \sum_{i=1}^2 iP_i = \sum_{i=1}^2 i \left[\sum_{j=1}^2 iP_{i,j} \right]$$

$$E[A] = P_{1,1} + P_{1,2} + P_{1,3} + 2P_{2,2} + 2P_{2,3}$$

Mean number of active servers,

$$E[S] = \sum_{i=0}^2 \sum_{j=1}^3 \min(j-i, 2-i) P_{i,j}$$

$$E[S] = P_{0,1} + 2P_{0,2} + 2P_{0,3} + P_{1,2} + P_{1,3}$$

The rate of switching from OFF state to ON state in the steady state i.e. the average amount of switching from OFF state to ON state per unit time,

$$E[S_r] = \sum_{i=1}^2 i\mu P_{i,i}$$

$$E[S_r] = \mu P_{1,1} + 2\mu P_{2,2}$$

The switching rate from OFF state to ON state is same to that from the states ON to OFF in steady state,

$$Cost (on - off) = C_a E[A] + C_s E[S] =$$

$$C_a (P_{1,1} + P_{1,2} + P_{1,3} + 2P_{2,2} + 2P_{2,3}) +$$

$$C_s (P_{0,1} + 2P_{0,2} + 2P_{0,3} + P_{1,2} + P_{1,3})$$

Similarly, we state that cost of the equivalent ON-IDLE model, i.e., M/M/C derived of setup times. After defining the equivalent model, it is informal to create a new consumption of power for this model as follows:

$$Cost (on - idle) = C_\rho C_a + C(1 - \rho)C_i$$

A server desires a cost of C_{sw} as each time it is switching ON and OFF. So, for this cost, we also deliberate the following function of total cost:

$$\begin{aligned} TotalCost (on - off) &= C_a E[A] + C_s E[S] + C_{sw} E[S_r] \\ &= C_a (P_{1,1} + P_{1,2} + P_{1,3} + 2P_{2,2} + 2P_{2,3}) + C_s (P_{0,1} + 2P_{0,2} + 2P_{0,3} \\ &\quad + P_{1,2} + P_{1,3}) + C_{sw} (\mu P_{1,1} + 2\mu P_{2,2}). \end{aligned}$$

IV. NUMERICAL ANALYSIS

In this section, the performance indices of proposed system are presented graphically. The result is analyzed by considering various parameters for the mathematical model.

In each of the numerical examples, we set $\mu = 1$, $C_a = C_s = 1$ and $C_i = 0.6C_a$. The evidence for $C_i = 0.6C_a$ is that about 60% of its peak processing, a job is still being consumed by an idle

server. For this, a more investigation of the cost function with respect to the setup time C_s is needed.

Fig. 3 shows the behavior of setup rate (α) with mean number of active servers $E[A]$. In can be seen that with increase in number of active servers the setup rate increases as more time is needed to activate servers. But by reducing the traffic load (ρ) number of active servers can be reduced. Hence, it can be concluding that under controlled traffic condition by reducing the setup rate mean number of servers can be reduced.

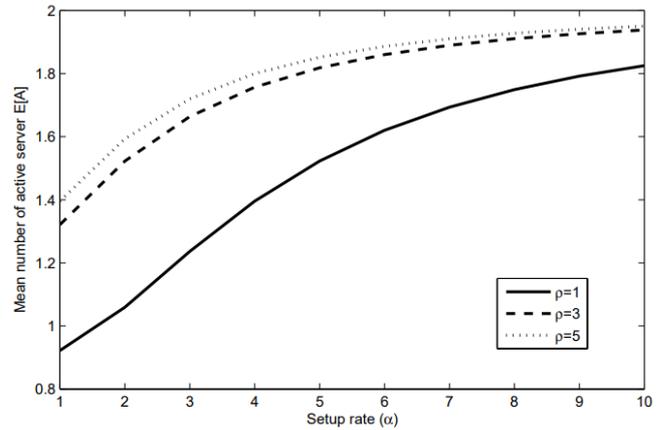


Fig. 3: Setup rate(α) Vs Mean number of active server $E[A]$

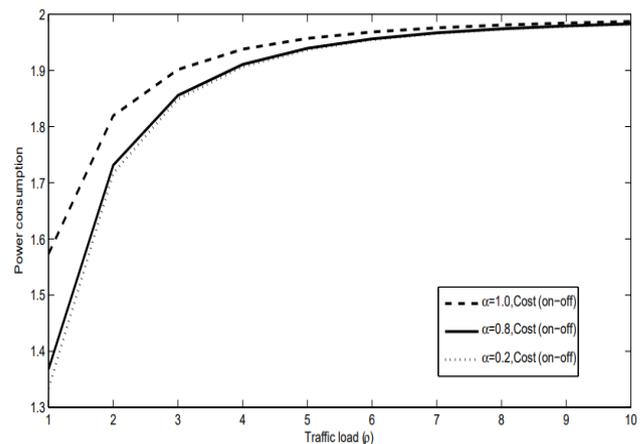


Fig. 4: Traffic load (ρ) Vs Power consumption

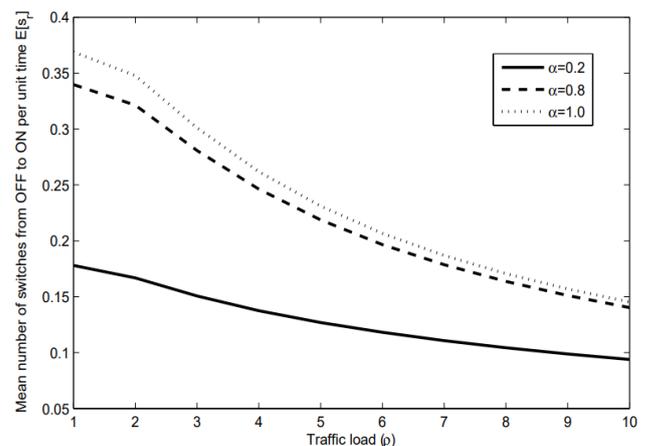


Fig. 5: Traffic load (ρ) Vs Mean number of switches from OFF to ON per unit time $E[S_r]$

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Fig. 4 represents the effect of traffic load on power consumption in case of ON-OFF policy. It can be observing that increase in traffic load results in increase of power consumption.

On the other hand, we can find that increase in setup rate increases the power consumption in all values. For a high traffic density, the power consumption is found to be equal in all values of setup rate. Hence, for high traffic density by choosing low setup rate can reduce the consumption in ON-OFF policy.

Fig. 5 investigated the rate of switching property $E[Sr]$ i.e., the average number of switches per a time unit against the traffic intensity. We can perceive that the switching rate decreases with ρ in comparatively substantial traffic management. The cause is as almost all the servers are OFF in light traffic management while the servers with state ON in heavy traffic has a high percentage i.e. in this traffic management, there is ON state in almost all servers. This indicates that with increase to the traffic intensity does not lead to increase further the switching rate. But with increase of setup rate the switching rate increases. Hence to achieve a smaller number of switches, a trade up between setup rate and traffic load is necessary.

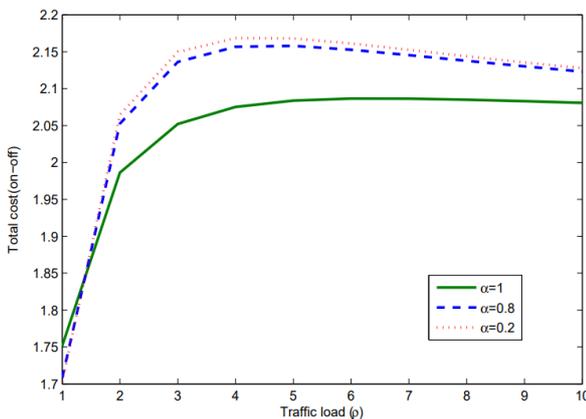


Fig. 6: Traffic load (ρ) Vs Total Cost (on-off)

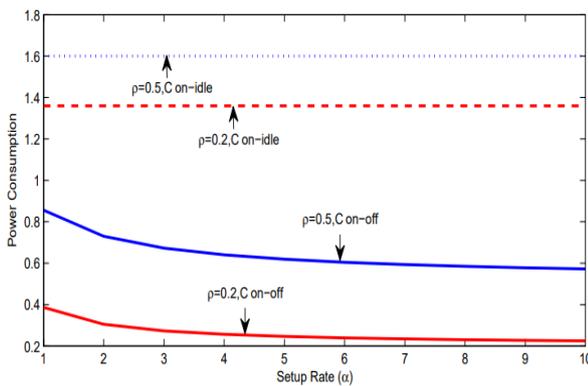


Fig. 7: Set of rates (α) Vs Power consumption

A variation of traffic load with total cost (on-off) with different setup rate is shown in Fig. 6. With increase of traffic load the power consumption increases hence increase in total cost (on-off). We can observe that with heavy traffic total cost remains constant for all cases of setup rate. This is because most of the servers are remain active to serve the heavy traffic. Also, high setup rate lowers the total cost as

number of switches (ON-OFF) decreases. This proposes that from the ON-OFF policy of switching rate is preferable in a comparatively light traffic for decreasing total cost.

Fig. 7 inspects the power consumption cost functions as Cost (on – off) and Cost (on – idle). We notice that the power consumption shrinkages as the setup rate rises for both the policies. It can be seen that ON-OFF strategy beats the ON-IDLE for any traffic load. The cause is that the servers used are in setup mode for almost the entire time when the setup time is tremendously long.

V. CONCLUSION

In this paper we have offered a thorough analysis of the M/M/C/sleep model with ON-OFF and ON-IDLE strategy for IoT system with multiple servers. Using Markovian steady state analysis, we have derived explicit solutions for different state probabilities and power consumption (Cost factor) for ON-OFF and ON-IDLE policy. Our results through numerical expressions have presented around the insights into the system performance. We also have got a parameters range under which the ON-OFF strategy beats the ON-IDLE strategy.

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