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Expected Response Time Model Considering Churn Rate for Dynamic IoT Devices

Jinman Jung[1], Hong Min[2] and Junyoung Heo[3*]

[1]Department of Information and Communication Engineering, Hannam University, Daejeon, Korea; jmjung@hnu.kr
[2]Department of Computer and Information Engineering, Hoseo University, Cheonan, Korea; hmin@hoseo.edu
[3]Department of Computer Engineering, Hansung University, Seoul, Korea; jyheo@hansung.ac.kr

Abstract

Background/Objectives: IoT has dynamic characteristics that the devices are freely joined or leave the networks. In this paper, we propose an expected response time model in a dynamic IoT environment. **Methods/Statistical Analysis:** We analyze the expected response time of an IoT query for star, tree, and mesh topologies. We evaluate the proposed model by comparing how it affects to response time according to the network topology and the bounce rate. **Findings:** We found that the impact of churn rates shows significantly different results under various topologies. Thus, churn rate is an important consideration in dynamic device replacement procedure that replaces a faulty device with a relatively healthy device. **Improvements:** Our analytical tool can be used for a decision mechanism of the IoT node that will operate most effective for time-critical IoT applications.

Keywords: Churn Rate, Dynamic Networks, Device Replacement Procedure, Response Time, Time-critical IoT Application

1. Introduction

The Internet of Things (IoT) have been rapidly developed recently and its basic idea is the pervasive presence around us of a variety of things including sensors, actuators, mobile phones, and so on which can interact with each other autonomously and cooperate with their neighbors to reach common goals for users[1]. In IoT technology interaction and communication among machines are emerged, which extends from the previous technology focused on interacting and communicating among users or between users and machines. To do this, most devices are equipped with a data processor, a wire/wireless communication module, data storage, and etc. The development of this technology immediately affects users' dally lives and enlarges its application area to various fields including U-health, E-learning, object monitoring, and so on. For instance, we can minimize the energy consumption at home by integrating the Internet of Things with home energy monitoring system because this home energy monitoring system supplies power at right time, in right place based on analyzing continuous real-time measurement[2].

One of the key issues of the application based on IoT is extracting the analysis result from huge amount of collected sensing data and recognizing user's context from recent incoming sensing data to provide customized real-time service[3]. Therefore, the response time is one of the most important criteria of user satisfaction on IoT service. We also consider dynamical change of IoT devices which comes from their resource constraint and mobility, as a result some devices leave from the network and some device join to the network for replacing broken-down or left devices[4]. In this paper, we design a network infrastructure suitable for providing real-time application services and propose a model for predicting the response time of user queries considering leaving and joining devices to the network.

**Author for correspondence*

The topology that is the way nodes in the network are arranged and connected to each other is one of important issue in designing IoT applications. It is difficult to have a coherent and stable view of the topology because the wireless media- and mobility-related parameters are changed dynamically in IoT network[5].

The topology of IoT is typically categorized to three types; star, tree, and mesh as shown Figure 1[6]. In a star topology, all the nodes are connected to one central node, which is typically also used as the gateway to the Internet. It means that the nodes are normally located at only one hop distance from the central node so redundant data can be collected from different sensors. The central node is in charge of post-processing such information. In a mesh network, every node can connect to multiple other nodes. One or more nodes in the network serve as an Internet gateway. The benefit of a mesh topology is that it can extend the range of the network through multiple hops, while maintaining low radio transmission power. They can also achieve better reliability by enabling more than one path to relay a message through the network. A tree topology connects one star network to other star networks. A simple computer set up on a network using the star topology, connected to another network using the star topology. In both mesh and tree topologies multi-hops communications take place[7].

There are many studies on the performance analysis as the changing of topological structure in terms of the throughput or the energy consumption. In[8], the authors analyzed the performance of smart home network as changing the topology. They found that varied topology should be depended on the different nodes scale and loads from simulation results. In[9], the authors proposed a new constructing approach for a weighted topology to keep balance on the energy consumption of the entire network of the IoT and to avoid energy holes. In[10], the authors showed simulation results on the network performance considering the topological structure. They found out the relationship between the topological structure and the delay time, and the loss tolerance. The difference between our approach and existing studies is that our model focuses on the response time and churn rate.

2. Response Time Estimation Model Considering Churn Rate

In this section, we analyze the expected response time of an IoT query for star, tree, and mesh topologies and then, we compare the results with different parameters. We assume that the measured round trip time between IoT server and coordinator is a constant in the high-speed networks. If bandwidth of the channel is B, one-to-one transmission time is 1/B. We also investigate the churn-rate impact on response time by deriving the expected response time of an IoT query for each topology.

IoT applications have a significant problem with an unexpected delay of the query caused by IoT nodes' leaving and joining the network. The unexpected delay can be mitigated by a dynamic device replacement procedure that replaces a faulty device with a relatively healthy device. We investigate the unexpected delay under star, tree, mesh topologies in terms of response time while taking into specific consideration the churn rates[11,12].

2.1 Star Topology

A star topology consists of one coordinator node, to which all other IoT devices are linked. Normally, IoT nodes are

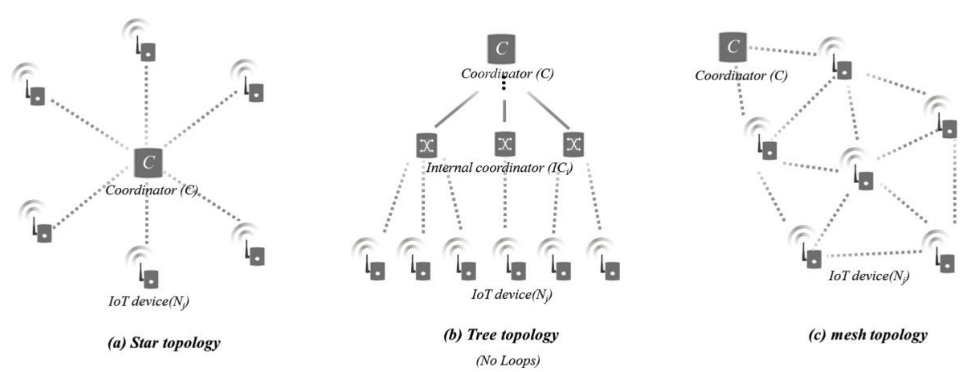

Figure 1. Network topologies for IoT applications.

located at one-hop distances from the coordinator. This coordinator acts as a gateway for all other nodes. An example of this topology is the Wi-Fi network hub. If an IoT query is sent to any node in the star topology without any failure, the response time is identical to transmission timeτ τ between coordinator and the IoT node. However, if a failure occurs due to the topology changes, the recovery time *r* for dynamic device replacement procedure is issued in the coordinator, and has to re-send repeatedly its query. In this case, $E[t] E[t]$ can be given by three distinct terms: *x*, *r*, and $E[t] E[t]$ recursively. To be precise, let *X* be a random variable denoting the time to failure transmission time, which is exponentially distributed with parameter λ (λ > 0), and let$f_X(x) f_X(x)$ be the probability density function (pdf) of *X*. The conditional response time can be written as:

$$E[t] = \begin{cases} \tau(x \geq \tau) \\ \square \\ x + r + E[t](x < \tau) \end{cases} \quad \textbf{(1)}$$

By the law of total expectation,

<Half of the equation is missing kindly check>

We assume that IoT nodes join and leave at the rate λ, which follows the Poisson distribution. Because the IoT node is a neighbor of coordinator under the star topology, the probability of the link to be available within the time interval t can be given as$e^{-\lambda t}$ $e^{-\lambda t}$. By substituting $\lambda e^{-\lambda x}$ $\lambda e^{-\lambda x}$ for $f_X(x) f_X(x)$, where $\lambda > 0$ $\lambda > 0$, we obtain,

$$\begin{aligned} E[t] &= \frac{\tau + \int_0^\tau (x + r - \tau)\lambda e^{-\lambda x} dx}{1 - \lambda \int_0^\tau e^{-\lambda x} dx} \\ &= \frac{\frac{\lambda r + 1 - \lambda r e^{-\lambda\tau} - e^{-\lambda\tau}}{\lambda}}{e^{-\lambda\tau}} \\ &= \frac{\left(e^{\lambda\tau} - 1\right)(1 + \lambda r)}{\lambda} \qquad (3) \end{aligned}$$

2.2 Tree Topology

A tree topology is consists of a dedicated coordinator as a root, sub-coordinators, and leaf nodes. The sub-coordinator connects to the coordinator through a high-speed, wide bandwidth network. Typically, the IoT nodes are leaf nodes that transmit data to sub coordinator on a demand basis. Hence, IoT nodes are multi-hop count to the coordinator. This type is an extension of star topology to support scalability and flexibility. If there are no errors, the response time between coordinator and a IoT node is c_1 c_1 +τ τ assuming that most of the IoT queries can be transmitted to sub-coordinators in constant time c_1 c_1. The conditional response time with tree topology can be written as equation (4)

$$E[t] = \begin{cases} c_1 + \tau(x \geq c_1 + \tau) \\ \square \\ x + r + E[\tau](x < c_1 + \tau) \end{cases} \quad \textbf{(4)}$$

Substituting $c_1 + \tau$ $c_1 + \tau$ for τ τ in equation (3), where $c_1 > 0$ $c_1 > 0$, the expected response time for tree topology can be simplified to equation (5).

$$E[\tau] = \frac{\left(e^{\lambda(c_1+\tau)} - 1\right)(1 + \lambda r)}{\lambda} \qquad (5)$$

2.3 Mesh Topology

In mesh topology, it enables a multi-hop communication in which IoT nodes also serve as relay for other nodes. The intermediate nodes must provide multi-hop routing services to communicate with one another. Therefore, the average path length between coordinator and IoT nodes c_2 c_2 is a more important measure under the mesh topology. Without errors, the response time between coordinator and IoT nodes is $c_2\tau$ $c_2\tau$ for a path with c_2 c_2.

$$E[t] = \begin{cases} c_2\tau(x \geq c_2\tau) \\ \square \\ x + r + E[t](x < c_2\tau) \end{cases} \quad \textbf{(6)}$$

The path availability is also the product of the individual link availabilities of the c_2 c_2 hops. Thus, the probability density function for c_2 c_2 hop path can be simplified to

$$f_X(x) = c_2 \lambda e^{-c_2 \lambda x}$$

The expected response time can be represented by

$$E[\tau] = \frac{\left(e^{c_2{}^2\lambda\tau} - 1\right)(1 + c_2\lambda r)}{c_2\lambda}$$

3. Evaluation of the Model

In this section, we describe the change of the expected response time based on equation (3) as the bounce rate. Figure 2 shows the comparison result for three different network environments when the recovery time is equal to one (r=1). This plot shows the expected response time of star, tree, and mesh topologies according to the churn rates for one hop transmission time $\tau = 0.1$. In this figure, we can see that the expected response time for star topology performs best among evaluated topologies under same environment. Meanwhile, the expected response time for mesh topology increases exponentially as the churn rate increases due to the data retransmission.

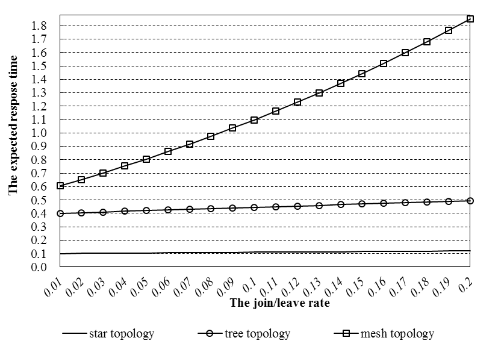

Figure 2. The expected response time according to churn-rate for one hop transmission timeτ= 0.1.

Figure 3 shows the plot of the expected response time under different churn-rates. The one hop transmission time τ of star, tree, and mesh topology is 0.5, 0.1, and 0.05, respectively. When churn rate is low, the mesh topology can be more effective compared to both the star and tree topologies. However, the difference of expected response time between star topology and tree topology remains more or less constant regardless of the churn rate.

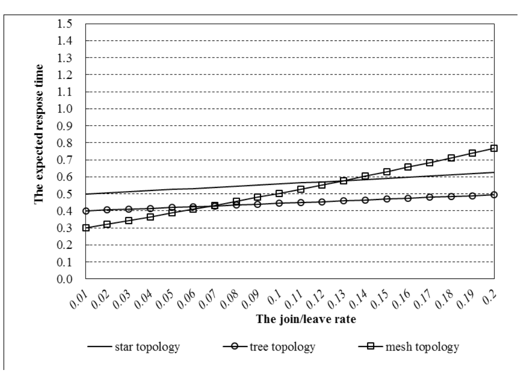

Figure 3. The comparison of expected response time under different churn-rates. The one hoptransmission time$\tau$of star, tree, and mesh topology is 0.5, 0.1, and 0.05, respectively.

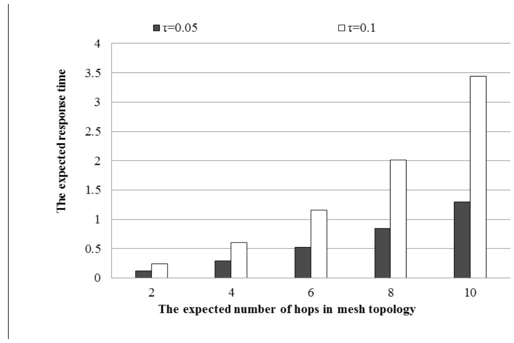

Figure 4. The expected response time in the mesh topology according to number of hops.

Figure 4 shows a different response time according to the number of hops under the mesh topology when one hop transmission time τ is 0.05 and 0.1, respectively.

However, the transmission speed in one-to-one affects the expected response time, which worsens as number of hops increases meaning that systems under low bandwidth are more sensitive to multi-hop mesh topology. Note that the change in $\tau = 0.05$ was not as severe as that in $\tau = 0.1$

Therefore, we should use the proposed response time estimation model considering the churn rates during dynamic IoT node management process to obtain a more accurate expected response time and improve the user satisfaction in terms of the response time. The analytical tool can be used for a decision mechanism of the IoT node that will operate most effective for time-critical IoT applications.

4. Conclusions

For IoT services, a dynamic device replacement procedure is executed to replace a faulty device with healthier one and to send queries successfully. Since IoT services have various operational characteristics under different topologies, the impact of churn rates shows significantly different results under varying network dynamics.

We presented an expected response time model considering churn rate. Our analysis can be used to decide alternate IoT nodes that will mitigate the latency during the device replacement procedure, taking into account their traffic condition.

5. Acknowledgement

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6. References

1. Atzori L, Lera A, Morabito G. The Internet of Things: A survey. Computer Networks. 2010 Oct; 54(15):2787–805.
2. Kelly SDT, Suryadevara NK, Mukhopadhyay SC. Towards the implementation of IoT for environmental condition monitoring in homes. Sensors Journal. 2013 Oct; 13(10):3846–53.
3. Gubbi J, Buyya R. Internet of Things (IoT): A vision, architectural elements, and future directions. Future Generation Computer Systems. 2013 Sep; 29(7):1645–60.
4. Ra HJ; Kim SD. Unconventional Issues and Solutions in Developing IoT Applications. Korea Information Processing Society. 2014; 3(10):337–50.
5. Zorzi M, Gluhak A, Lange S, Bassi A. From Today's Internet of Things to a Future Internet of Things: a Wireless- and Mobility-related View. IEEE Wireless Communications. 2010 Dec; 17(6):44–51.
6. Reina DG, Toral SL, Barrero F, Bessis N, Asimakopoulou E. The Role of Ad Hoc Networks in the Internet of Things: A Case Scenario for Smart Environments. In Internet of Things and Inter-Cooperative Computational Technologies for Collective Intelligence. Springer Berlin Heidelberg. 2013; 89–113.
7. Reiter G. Wireless connectivity for the Internet of Things. White paper, Texas Instruments. 2014 Jun; 1–13.
8. Zhang C, Luo W. Topology Performance Analysis of ZigBee Network in the Smart Home Environment. In proceeding of the Fifth International Conference on Intelligent Human-Machine Systems and Cybernetics. 2013 Aug; 2:437–40.
9. Zhang DG, Zhu YN, Zhao CP, Dai WB. A new constructing approach for a weighted topology of wireless sensor networks based on local-world theory for the Internet of Things (IOT). Computers and Mathematics with Applications. 2012 Sep; 64(5):1044–55.
10. Hu W, Chen T. Simulative research on the function of internet of things basing on the changing of topological structure. Multimedia Tools and Applications. 2015 Oct; 74(19):8445–54.
11. Ahmed SAM, Ariffin SHS, Fisal N. Overview of wireless access in vehicular environment (wave) protocols and standards. Indian Journal of Science and Technology. 2013 Jul; 6(7):1–8.
12. Madhumitha P, Johnsema B, Manivannan D. Domination of Constrained Application Protocol: A Requirement Approach for Optimization of Internet of Things in Wireless Sensor Networks. Indian Journal of Science and Technology. 2014 Mar; 7(3):296–300.