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A Pervasive Interconnection Technique for Efficient Information Sharing in Social IoT Environment

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Abstract

IoT is a vision of interconnected everyday objects and self-configuration wireless networks of sensors. In IoT environment, it is needed to share information pervasively without user's intervention. We propose a new interconnection technique for efficient information sharing in IoT environment considering social network. We present a method and algorithm which is based on not only the analysis of the human's social network but also the consideration of the device's sociality. Then we describe some scenarios and implement prototype system using the scenarios. Some experiments are conducted. From the experimental evaluation, we verified that our proposed technique is helpful in the efficient interaction between devices without any intervention of humans.

***Keywords**: Pervasive computing, Social networks, IoT, Information sharing*

1. Introduction

There are scientific evidences that a large number of individuals tied in a social network can provide far more accurate answers to complex problems than a single individual or a small group of individuals. The exploitation of such a principle has been widely investigated in internet-related researches. Some research have been proposed schemes that use social networks to search internet resources, to route traffic, to select effective policies for content distribution [1, 2]. With the evolution of internet technology, the concept of the social network is more and more applied in wide domain of information technology (IT).

People use more and more electronic devices at home, in their car or in the office, with the proliferation of smart connected devices [3].The Internet of Things (IoT) is a vision of interconnected everyday objects and self-configuration wireless networks of sensors [4]. In this vision everything can be represented digitally and it will be possible to attach information and logic to all things. The concept of IoT refers to the technology that enables the communication between different devices such as smart phones, IP(internet protocol) cameras, IP television, connected cars or personal health devices without or with limited user intervention [5].

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Figure 1. The Concept of IoT

In the environment of IoT, the communication is used for automated data transmission and measurement between mechanical or electronic devices. With the concept of IoT, the term *information sharing* is related with cases which involve*N* devices using various interconnection techniques. Like depicted in Figure 1, IoT applications in daily operations can be found in various areas, for instance, remote monitoring (*e.g.*, solar panels, commercial printer services), track and trace (*e.g.*, rental bicycles, fleet tracking), facility management (*e.g.*, elevators, energy management), vending segment (*e.g.*, vending machines), or metering (*e.g.*, utility meters). More and more application areas will arise in the future [6, 7].

In the IoT environment, everything between objects is blackboxed. As a result, most users are blind to its inherent features. However, when users want to share information in IoT environment, it is still needed a troublesome manual process done by people themselves. To solve this problem, we propose an efficient pervasive interconnection technique to process and share information in IoT environment.

For pervasive interconnection in IoT environment, we consider the convergence of two concepts, the social network and the IoT.So, in this paper, we describe a new concept of the social IoT as a pervasive interaction paradigm for the information sharing in the Web of devices. Our interconnection technique is based on not only the human's social network but also the device's sociality. We consider the sociality of each device as device's credibility for pervasively reliable information sharing in the environment of IoT. In order to decide the sociality of the device, we consider the spatial distance between wireless devices and the type of targeted devices (*e.g.* smart phones, tablet or wristband) as situational sociality. Moreover, we consider each device's history data (*e.g.* the type of the latest shared information or the profile list of the latest interconnected device) as historical sociality. Through the evaluation along with the development of the prototype, we verified that our proposed technique is helpful in the efficient interaction between devices with limited intervention of humans.

2. Related Works

IoT needs the technology that enables information sharing between different devices without or with limited user intervention. With the development of IoT, non-human objects such as smartphones enter social network and start imitating social relations with people [8, 9].Therefore, it is very important to consider not only the interaction of human-to-human but also the interconnection of device-to-device in order to share the information in the environment of IoT. Recently, there have been quite a number of research activities that investigate the potentialities of integrating social networking concepts into the environment of IoT. Convergence of the device-to-device and the social network is gaining momentum. This is due to the growing demands for carrying many desirable implications into a future world populated by intelligent objects permeating the everyday life of human beings [10].

Schemes based on social relationships for sharing information have been proposed to establish higher levels of trust and improve the efficiency and effectiveness of security solutions [11]. Some researches which takes advantage of the social network for data diffusion have been proposed [12, 13].Formo and Gårdman proposed the concept of a Social Web of Things as a mental model and an interaction paradigm for the IoT. In their study, the human mental model of social relations is a much richer and more intuitive way of understanding the “net workedness” that is so essential in an internet of things [7].The first idea of socialization between objects has been introduced by Holmquist *et al* [14]. In their paper, the focus was on solutions that enable smart wireless devices or mostly wireless sensors, to establish temporary relationships.

Recently, the idea that the IoT and the social networks are not apart from each other has begun to appear in the literature. Ning *et al.* envisions the future of the Internet as being characterized by what they name Ubiquitous IoT architecture, which resembles the social network-based frame work model. That work provides an insightful overview of the expected IoT network structure [15]. However, it does not aim at exploiting the characteristics of the social networks into the environment of IoT. Kranz *et al.*, describe implications of the integration between the IoT and the social networks [16].And Dmitry and Manfred introduced an approach for integrating sensors and social networks for social context-aware data discovery [17]. These studies, however, do not describe how the social relationships should be established between devices and does not propose any solution regarding the required architecture and the technology that is needed for the pervasive interconnection of the device-to-device without the intervention of humans. Iván *et al.*, presented a solution for providing social services on the vehicle based on IP multimedia subsystem and IoT capabilities. In the study, they developed a social service named Drive and Share which offers relevant information to vehicles in the environment of IoT [18]. Although the vehicular services have the common feature that the IoT environment in which the service is applied, however, the study did not fully consider the feature. Because of this overlooking, the troublesome intervention of humans is continually required for the interconnection of the device-to-device.

As described in above, there are many studies about the integration of the social network and the concept of IoT. However, most of these studies have not yet considered the technique to limit the intervention in order to efficiently share information between devices. Therefore, the study about the technology that makes it available to pervasively share information between devices without the intervention of humans is required in the era of IoT.

3. Pervasive IoT Interconnection Techniques for Information Sharing

In this paper, for pervasive interconnection of the device-to-device, we consider the convergence of two concepts, the social network and the IoT. We describe a new concept of the social IoT as a pervasive interaction paradigm for the information sharing in the Web of devices. Also, we propose an interconnection technique which is based on not only the analysis of the human's preference but also the consideration of the device's sociality for the efficient information sharing in IoT environment.

In our proposed technique, we mainly take care of two key points. Firstly, for the efficient and reliable information sharing, we consider social network analysis, the type of devices and the analysis of device's sociality. The device's sociality is decided based on the spatial distance between devices. Secondly, for the personalized human-centric information sharing, we concern the preference of each user in order to find a device with which more accurate and personalized information is shared.

Algorithm 1 is defined for our proposed technique. The algorithm requires inputs which are profiles of the targeted user and the targeted device which are currently used by the targeted user. And two sets of other device's profile and other user's profile are required as inputs of Algorithm 1.Algorithm 1 is consisted of four steps.

Algorithm 1. *Pervasive IoT interconnection for information sharing*

Input:, target useru_{target}, targeted deviced_{target} , *DP* is the set of *N* device's profile, *UP* is the set of *N* user's profile, the threshold of device sociality θ_{ds}

Output: The list of Top-*N*devices*final_candiates*

1.*first_filtered_candidates*←a memory space for the list of candidates filtered with the device's sociality

2. *second_filtered_candidates*←a memory space for the list of candidates filtered with the user's preference

3. **foreach**device,$dp_i \in DP$**do**

4. $sociality_i \leftarrow MachineSociality(d_{target}, dp_i)$

5. **if** $sociality_i \geq \theta_{ds}$**then**

6. *first_filtered_candidates*← mp_i

7. for each device,$dp_j \in$ *first_filtered_candidates***do**

8. **for each**$up_j \in UP$**do**

9.$similarity_j \leftarrow UserSimilarity(d_{target}, up_j)$

10. **if** $similarity_j \geq \theta_{ds}$**then**

11. **if**up_j's own device$mp_j \in$*first_filtered_candidates***then**

12. *second_filtered_candidates* ← mp_j

13. **for each**device, dp_k ∈*second_filtered_candidates***do**

14. $credibility_k \leftarrow SocialMachineCredibility(d_{target}, dp_k)$

15. *final_candidates*←*RankingDevices*(dp_k, $credibility_k$)

16.**return***final_candidates*

The first step is for defining the sociality of each device. The function *Device Sociality* calculates the value of the device's sociality based on the spatial distance. In *Device Sociality*, RSSI (Received Signal Strength Indication) is considered as the device's sociality. RSSI is a measure of the power level that a wireless device, such as WiFi, is receiving from the radio infrastructure at a given location and time. Many studies have considered RSSI for defining location of devices in the indoor environment [19]. Also, the widely considered feature of RSSI is that the higher the RSSI the better the quality and speed of the communication through the wireless devices. In the case of our study, we use RSSI in order to measure the relationship of device-to-device.

$$\theta_{ds} = \frac{\sum_{i=0}^{n} RSSI_i}{n} \times 0.1 \qquad (-1 \leq \theta_{ds} \leq 1) \tag{1}$$

In Algorithm 1, θ_{ds} is the threshold of the value of device's sociality. Equation (1) is a calculation for θ_{ds} and n is the number of all devices which are belonging to the set of devices. Through the first step, devices which are not socially closed to the targeted device are filtered out. With the consideration of the current each device's location as the sociality, we could develop the technique which make it possible to reliably and pervasively get a device interconnected to other devices in the IoT environment.

The second step is for the consideration of personalized human-centric interconnection of device-to-device. To decide whether a device can share suitably interesting information with the targeted device, we consider the similarity between user's preferences. In Algorithm 1, the function *User Similarity* returns the value of the similarity of the targeted user and another user up_j. $similarity_{ij}$ depicted in Equation (2) is the value of similarity of usersu_i and u_j.And$similarity_{ij}$is calculated with the measurement of Euclidian distance.

$$similarity_{ij} = \frac{(I_i - C_{ij}) \times (I_j - C_{ji})}{\sqrt{(I_i - C_{ij})^2 \times (I_j - C_{ji})^2}} \tag{2}$$

In Equation (2), I_i is the frequency of information experienced by a user u_i. And c_{ij} is the frequency of information commonly experienced by a user u_i and u_j. With the consideration of user's similarity, we could decide which a device has the relatively high chance to share interesting information with targeted user's device. For example, if the preference of a user u_i is relatively similar with the preference of a useru_j,the deviced_i being a user u_j' own might be considered as proper device to share information with a user u_i's device. So, with the second step in Algorithm 1, we could make it feasible to generate appropriate interconnection of device-to-device with the consideration of the personalized human-centric information sharing.

The third step is for deciding whether the device is more credential than other devices belonging to the set generated through the first step and the second step of the Algorithm 1. The main function in the third step is *Social Device Credibility*. *Social DeviceCrediblity* calculates the value of each device's social credibility. Equation (3) is for the calculation of device's social credibility.

$$credibility_i = socialParticipation_i + deviceSimilarWeight_i. \tag{3}$$

We assume that the device's credibilityis closely related with the main factor which decides the efficiency of the pervasive interconnection of device-to-device. To estimate whether the device is more credential or not in the device-to-device environment, we consider two features, $socialParticipation_i$ and $deviceSimilarWeight_i$.The first part of $crediblity_i$ is the device's historical sociality,$socialParticipation_i$.The$socialParticipation_i$defined in Equation (4) indicates how the device d_i has been participated in information sharing in the environment of IoT.

$$socialParticipation_i = \frac{1-d}{n} + d \times \sum_{d_j \in DN(d_j)}^{n} \frac{socialParticipation_i}{Link(d_j)} \tag{4}$$

The $s\ ocialParticipation_i$ in Equation (4) is based on the widely used social network analysis, PageRank [20]. For the calculation of $socialParticipation_i$, we assume that the device which has higher frequency of information sharing is more credential than other devices which have relatively lower frequency of information sharing. For the processes of the third step in Algorithm 1, we use the history data of each device in order to figure out each device's frequency of information sharing. In other words, we could generate the device social network based on the history data. For example, if the fact that the deviced_i was lately interconnected with the deviced_j is stored as history data, we could define the social relationship between the pair of adevices d_i and d_j. Based on the generated device social network, we measure how the device participates in the information sharing with the device belonging to the social network of devices.

In Equation (4), n is the total number of devices which are belonging to the social network of devices *DN*. The function $Link_{m_i}$ returns the number of edges from the node of the deviced_i to other device nodes. d is the probability that thedeviced_i which has been interconnected with the deviced_j could connect to the other deviced_k.

The typical feature of IoT is mobility. In the environment of IoT, objects are constantly and dynamically changed in the location, channel of interconnection or the targeted object with which the object is connected. So, we consider this mobility feature of IoT as the probability value d in order to calculate$socialParticipation_i$ depicted in Equation (4). In general, as many studies about the analysis on the link structure use the value of *d*with 0.85, we also regard *d* as 0.85 in our study.

The second part of $crediblity_i$ is$deviceSimilarWeight_i$. In the environment of the IoT, there are not only various types of devices from tiny devices like the node of electrocardiogram (ECG) to home appliances such as IP refrigerator or smart TV but also diverse type of information like media, texts or images. So, techniques for the pervasive interconnection have to consider these varieties of the environment of IoT in order to efficiently share information between devices. For example, because the deviced_i is digital photo frames, the device$d_i$cannot share information of which type is video. With this case, the interconnection between the device d_i and a music player d_j is not proper and the information sharing between these devices is worthless. With our proposed Algorithm 1, we assume that for efficient information media sharing, the type of each device has to be considered in the interconnection technique. So, $deviceSimilarWeight_i$ is for increasing the quality of sharing information with the consideration of the type of each device. Equation (5) measures deviced_i's$deviceSimilarWeight$.

$$deviceSimilarWeight_i = \frac{\sum_{d_i,d_j \in DP}^{n} ic_{ij}}{ic_i} \tag{5}$$

In Equation (5), ic_i is the frequency of the interconnection from the deviceic_i to other devices. Andic_{ij} is the number of the interconnection from the targeted deviced_i to other devices which have the type being same with the deviced_j. If the device d_k has the frequent interconnection with the device d_j, *deviceSimilarWeight* of the device d_i which has the type identical to the type of the device$d_j$is relatively high. With the value of *deviceSimilarWeight* calculated through Equation (5), we make it feasible to pervasively and accurately share information between devices without the intervention of humans.

4. Pervasive Media Sharing System Prototype

We develop the system prototype in which our proposed technique is applied. Through the system prototype, we estimate the feasibility of our proposed technique in the environment of IoT for pervasive media sharing with the limited intervention of humans.

4.1. Sample Scenarios

In this section, we present sample scenarios which are mainly about the interconnection of the device-to-deice for pervasive information sharing in the environment of IoT. Atzori *et al*. described the number of meaningful scenarios in the IoT [21].Our sample scenarios are modified from scenarios of [21]. Figure 2 provides a sketch of our sample scenarios.

Figure 2. The Sketch of the Sample Scenarios

The sample scenarios depicted in Figure 2 is described in the following.

① JB's home is located in the block where is built according to advanced eco-friendly principles. In the block, each houseis equipped with a smart meter and sensors in order to manage and measure energy consumption during the whole day. By means of the social IoT network, the smart meter is able to exchange information on the energy usage with reference to identification of the energy providers that best match the house needs, identification of the household appliances. A light in any house changes the color according to the energy saving level obtained by its owner. Relationships of the social IoT are exploited in this scenario.

② Jessie is a sales representative that frequently moves by car around the city to meet her customers. Unfortunately, the traffic has increased in recently making her driving more and more problematic. However, by exploitingthe social IoT network, her car is able to gather information in real-time about traffic congestion along possible routes and to choose the best path to get to the meeting in the scheduled time. Finding the appropriate source of interesting information in the social IoT network is easy for the car by the pervasive IoT interconnection technique proposed in our study.

③ Hannah has just bought a new notebook. At the beginning, she has a hard time to connect to some network equipments such as printers or faxes. By exploiting the relationship of other devices belonging to the social IoT network with our proposed interconnection technique, Hannah's notebook can find a mate of the device that has already addressed the same configuration issues and fix the problems.

4.2. Implementations

We implement prototype systems using scenarios in Section 4.1, to verify the feasibility of our proposed technique. Figure 3 shows overall architecture of our prototype system.

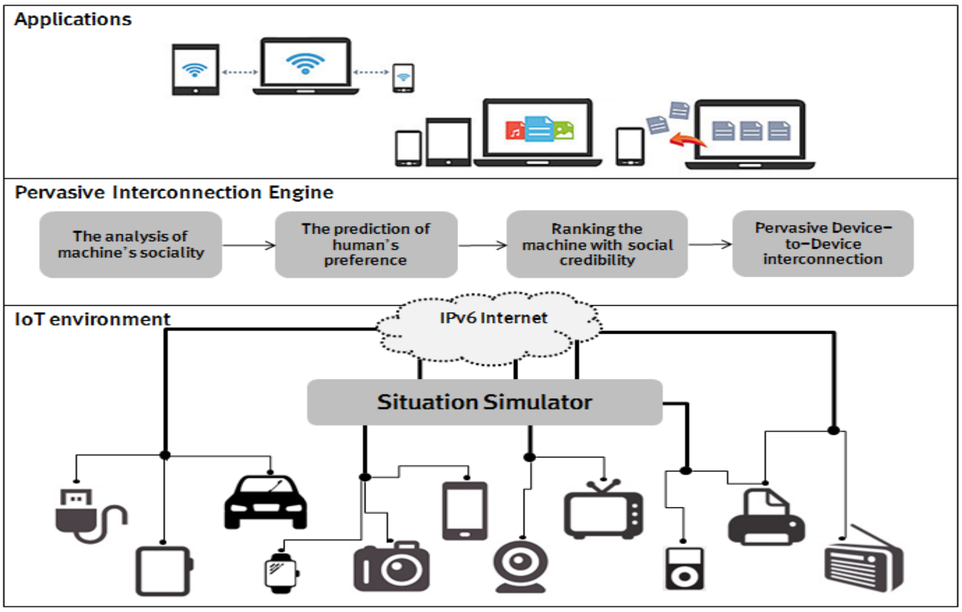


Figure 3. Overall Architecture of Prototype System

In the IoT environment shown in the bottom of Figure 3, there are various devices which are able to connect the Internet. In our prototype system, we implemented a situation simulator. The situation simulator generates the situation in which our scenarios are applicable. Pervasive IoT interconnecting engine depicted in the middle of Figure 3 is the core of our prototype system. The pervasive IoT interconnection engine is implemented using our technique proposed in this paper. The pervasive IoT interconnection engine is consisted of four steps which are described in Algorithm 1.

Table 1 describes the implementation environment with which the overall prototype system is developed. With the implementation environment described in Table 1, we implement a Web-based situation simulator, pervasive interconnecting engine and applications which are flexibly applicable on two widely used mobile OS, iOS and Android.

Table 1. Implementation Environment

Components	Implementing tools
Situation simulator	MS SQL, IIS(Internet Information Services), .NET SDK, C#, Visual Studio 2015
Pervasive interconnecting engine	JDK 7, Java, Eclipse
Applications	JDK 7, ADT Marshmallow(Android Development Tools), iOS SDK, Java, Object C, Eclipse, Xcode

For the verification of the proposed technique, we especially more consider Scenario 3 than other scenarios. So, the measurement of device sociality in Figure 5(a) and the number of experimental results depicted in Chapter 5 are all based on Scenario 3.

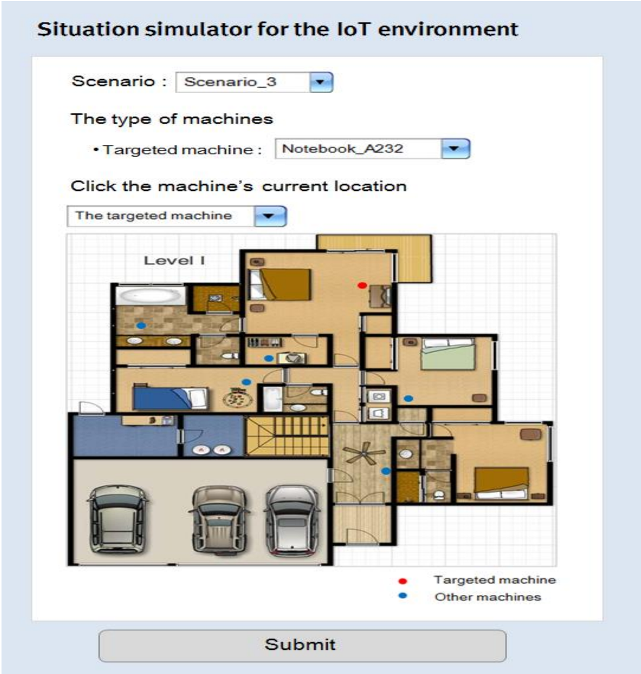
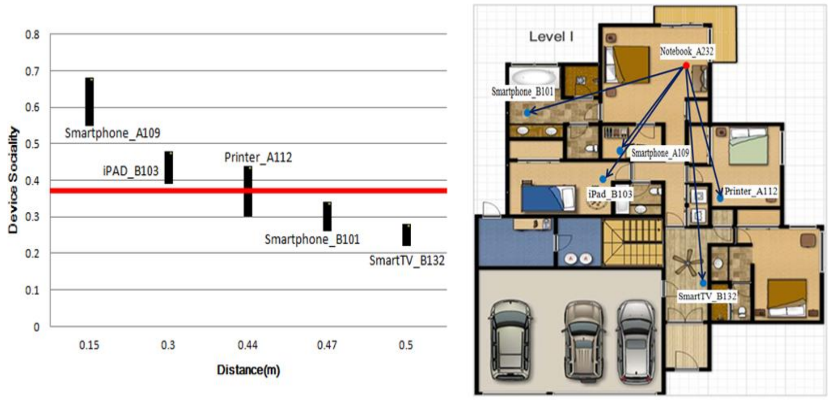


Figure 4. The Situation Simulator for the Scenario 3

Figure 4 shows the situation simulator. Withit, we take the verification of our proposed technique based on the situation 3 described above. So, we define the location of the targeted notebook and other devices with the situation simulator.



(a) The measurement of device socialites (b) Location map for device socialites

Figure 5. The Analysis of Device Socialites

Figure 5(a) shows the measurement of each device's sociality based on the location of the device, *Notebook_A232* depicted as the red circle in Figure 5(b). Like shown in Figure 5(a), the device sociality mainly depends on the distance from the targeted device.

(a) The existing application (b) The proposed application

Figure 6. The Comparison between Two Applications

Also, as we defined the equation for the device sociality with values of device's RSSI, the higher value of the device sociality means that it is possible to share information between devices with better quality and faster speed. The horizontal line means the value of device's sociality described in Equation (1). So, in the case of the measurement shown in Figure 5(a), three devices, *Smartphone_A109*, *iPAD_B103* and *Printer_A112* are only considered as candidate devices for the interconnection to the targeted device, *Notebook_A232*.

Figure 6 shows the comparison between the application of the existing device retrieval and the application in which our proposed interconnection technique is applied. As shown in Figure 6(a), the existing application randomly retrieves the list of devices with signals received from other devices near a targeted device. On the other hand, the application implemented with our pervasive interconnection technique provides the list of devices which are sorted by each device's creditability. In the list, the higher a device is placed in the list, the more possible the device might be interconnected with the targeted device. For example, in Figure 6(b), the device, *Printer_A112*has the highest possibility to interconnect with the targeted device, *Notebook_A232* among other devices listed in Figure 6(b). Also, while the existing application lists all devices near the targeted device, *Notebook_A232*, the application implemented with our pervasive interconnection techniqueretrieves only three devices. These tree devices could be considered more reliable, personalized and credential than other devices which are filtered out through our proposed technique.

5. Evaluation

To efficiently verify the performance of the prototype implemented with the proposed technique, we conducted the comparative experiment on the two prototypes named respectively as *Proposed* and *Existing*. While the prototype *Existing* just simply lists devices near a targeted device, the prototype *Proposed* retrieves the list of devices sorted with our proposed technique. After the list of devices is retrieved, the prototype *Existing* randomly select a device to connect to the targeted device. Otherwise, the prototype *Proposed* select the device which is located in the top of list. Then, two prototypes respectively send a message to the selected device for sharing information between the selected device and the targeted device. In the experiment, also, we consider two factors of the information sharing between devices. The one is the efficiency, and the other is the accuracy for the information sharing in the environment of IoT.

Firstly, for the verification of the efficiency of the information sharing, we evaluated the performance of two prototypes in terms of the time required to share information between devices. Figure 7 shows the result of the comparative experiment on the efficiency for the information sharing.

In Figure 7, the x-axis is consisted of three targeted devices which are respectively described in three scenarios, Scenario 1, Scenario 2, and Scenario 3. Before the experiment, we assumed that the required time depicted in Figure 7 as the y-axis, is total time required to find appropriate devices, in order to make connection between devices and forward information from a device to the other device. We measures the required time of the each scenario. Through the result of the experiment for the efficiency, we know that the prototype, *Proposed* requires less time to share information between the particular device and the targeted device than the prototype, *Existing*. Because the prototype, *Existing* randomly selects a device belonging in the list of retrieved devices, if the attempt to make the connection from the selected device to the targeted device is fail, the prototype retries the process of finding devices, selecting a device and sending a message to a selected device consuming more and more time to share information. On the other hand, as the prototype *Proposed* just selects the device located in top of the list which is retrieved with our proposed technique, it is highly possible to make the interconnection between the targeted device and the selected device at a time without waste of time.

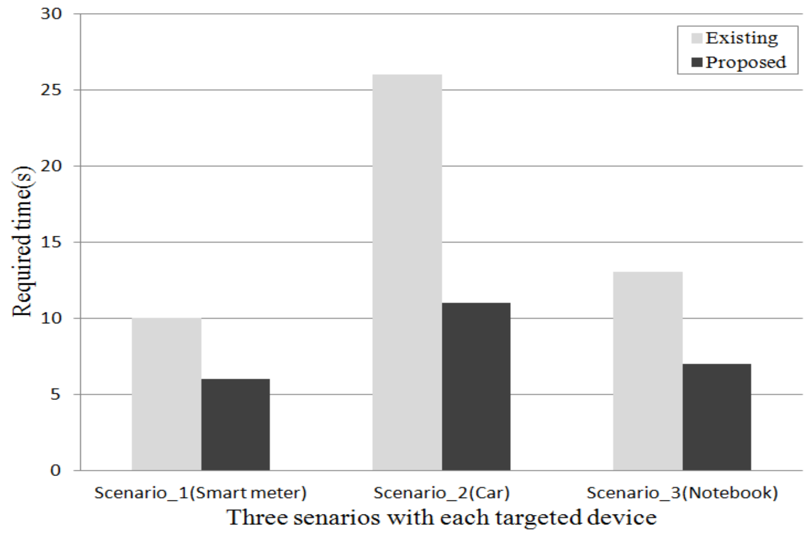


Figure 7. The Result of the Comparative Experiment on the Efficiency

Finally, to verify the accuracy of the information sharing, we evaluated the performance of two prototypes in terms of the error rate occurring in the process of the sharing information. In the environment of IoT, while there might be various types of errors, we only consider the number of error types in our experiment. In other words, we assume that each scenario described above has a proper device to share information with the targeted device. For example, in the case of Scenario 2, because the targeted device is a car and the user of the car wants to share information about traffic congestion along possible routes, the connection between the car and a printer is not accurate. So, this case is regarded as the one of an error in information sharing in our experiment. Figure 8 shows the result of our comparative experiment on the accuracy of two prototypes.

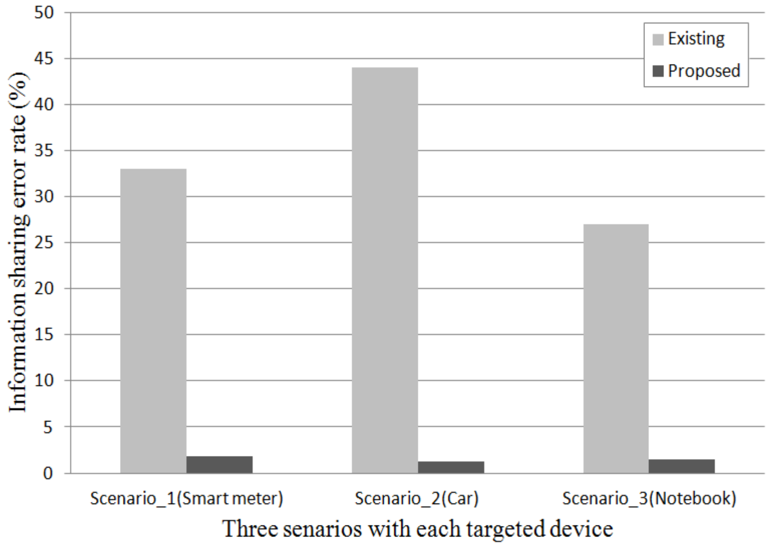


Figure 8.The Result of the Comparative Experiment on the Accuracy

In Figure 8, the x-axis is consisted of three targeted devices which are respectively described in three scenarios, Scenario 1, Scenario 2, and Scenario 3. Through the result of the experiment for the accuracy, we know that the prototype, *Proposed* has lower error rates in all scenarios than the prototype, *Existing*. Because the prototype, *Existing* randomly selects a device belonging in the list of retrieved devices, the chances of failure are more higher than the failure chance of the prototype, *Proposed*. Otherwise, the prototype, *Proposed* only selects the device which is located in the top of the retrieved list. As the selected device is considered as the most proper device among other devices in the list by the Algorithm 1, the connection and information sharing between the targeted device and the selected devices is mostly successful.

6. Conclusion

In IoT environment, it is needed to share information pervasively without user's intervention. In this paper, for pervasive interconnection in IoT environment, we consider the convergence of two concepts, the social network and the IoT.

Firstly, for the efficient and reliable information sharing, we consider social network analysis, the type of devices and the analysis of device's sociality. Secondly, for the personalized human-centric information sharing, we concern the preference of each user in order to find a device with which more accurate and personalized information is shared.

This paper described our proposed method and algorithm. To estimate the feasibility of our proposed technique, we implemented prototype system using our scenarios. Also, we conducted the comparative experiment on the prototype system. Through the experiment, we could verify that our proposed technique make it possible to pervasively share information between devices without the intervention of the human with the way of more accuracy and more efficiency.

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