COMPARISON OF A SMART MOBILE APPLICATION-SUPPORTED EVACUATION SYSTEM AND TRADITIONAL EVACUATION SYSTEMS

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ABSTRACT:

Today, there are a lot of large-scale buildings in which people spend time during the day. Navigating in these large-scale building has become problematic sometimes and people need a navigation service to reach the spots. Especially, it is relatively problematic to find an exit in the building in emergency cases such as fire, gas leak, flooding and terrorist attack. In this study, a dynamic, user-centric, real time and mobile application-supported smart evacuation system is proposed. The smart evacuation system has three different components: a positioning system, a navigating system and a mobile application. Positioning system that detects the location of the user in indoor environment. Navigation system that produces navigation instructions for the users by considering their personal features and changing conditions in the building during the fire. This navigation system is supported with an Artificial Neural Network that receives ten unique features from the user and six varying environmental conditions in the building and produce the most suitable escape route for the user according to conditions. Finally, a mobile application for Android devices provides a graphical user interface to access the smart evacuation system. The proposed smart evacuation system is compared with the traditional evacuation system and results are discussed in this paper. The smart evacuation system provides alternative individual escape routes for each user and it is also capable of changing the route dynamically during the evacuation process, whereas traditional evacuation systems present the same escape route to all types of user and cannot also change the routes during the evacuation process.

1. INTRODUCTION

Nowadays, there are a lot of large-scale buildings such as hospitals, airports, universities, malls etc. in which people must spend time during the day. Sometimes it is so difficult to find the way in these large-scale buildings and people need a navigation service to reach the spots that they want to go to. Especially, it is getting much more difficult to find an exit to the outdoor environment of building in emergency cases such as fire, gas leak, flooding and terrorist attack. However, in these emergency cases, congestion, panic and confluence occur in indoor environment of buildings when people try to find an escape route instantly and unconsciously.

Regarding evacuation in emergency cases, there are a set of studies in the literature those have been conducted by researchers to overcome these problems. However, these studies mainly focus general-purpose traditional evacuation systems which means they do not consider the personal features of evacuees, therefore, they are not capable of dynamically changing the escape route of an evacuee in unexpected incident on his/her route during the evacuation process. In this paper, in contrast to these traditional evacuation systems, we proposed a smart and mobile device supported evacuation system and we called it as the smart evacuation system. Our proposed smart evacuation system presents a user-centric, intelligent, dynamic and real-time navigation service to the evacuees over their smartphone in the emergency case, especially in the fire.

The smart evacuation system has three different components: a positioning system, a navigating system and a mobile application. Our positioning system detects the location of the user in indoor environment. Our navigation system runs on a web server and creates navigation instructions for the users by considering their personal features and changing conditions in the building during the fire. This navigation system is supported with an Artificial Neural Network, which receives ten kinds of personal features from the user and six varying conditions in the building and produce the most suitable escape route for the user. Finally, our mobile application for Android devices that provides an interface between user and smart evacuation system.

2. BACKGROUND

Since the indoor environment has continuously varying conditions during the fire, an evacuation system must have a dynamic structure, namely it can change the escape route for the user if necessary. When the fire is detected in the building, the evacuation system initially produces an escape route for the user. If an unexpected incident occurs, which poses risk for the user in the escape route, the evacuation system must provide an alternative route rather than sticking on the first exit route. Inoue et al. designed an indoor evacuation system for emergency cases that can run on a mobile device (Inoue et al., 2008). The designed evacuation system can detect the user's location by Bluetooth beacon. However, the system can produce an escape route at the beginning of evacuation process and cannot change it dynamically during the fire.

Another need for an evacuation system is to detect not only fire occurrence and temperature increase but also fire grow rate, carbon-monoxide rate, visibility distance and human destiny in the building in case of fire. Chu and Wu proposed a cloud-based fire evacuation system which locates the user through RFID (Radio-Frequency Identification) technology and finds the optimum escape route regarding only a few parameters that

are distance, temperature and congestion factors (Chu and Wu, 2011). However, an evacuation system must detect all the changing parameters in the building in case of fire.
Even though there exist various similar evacuation systems in the literature, they are mainly used for general-purpose navigation systems and not considering the personal features of the users for dynamic route assigning during the evacuation process. Therefore, an evacuation system must take some personal features of the user into the account as it calculates escape route. Because presenting the same route to all users for an evacuation system causes crowd, resulting in inappropriateness and difficulties at evacuation process. Researchers suggested a set of solutions to handle these problems.

Khalifa et al. proposed an indoor navigation system to guide the handicapped people in hypermarkets (Khalifa et al., 2010). Tsirmpas et al. designed an elderly and blind people oriented indoor navigation system (Tsirmpas et al., 2015). Blattner et al. developed an indoor navigation system, which uses Bluetooth signal transmitter, to assist the handicapped people in the building (Blattner et al., 2015). Koac et al. produced an augmented reality based indoor navigation system that determines the users' location and guides them with the natural signs such as exit signs, fire extinguisher location signs and appliances' labels in the building (Koch et al., 2014). However, these previous studies consider to use only a few personal features of the users. An evacuation system should not only consider a few user's personal features such as physical or visually disability but also should consider sex, age, body or the illnesses.

Additionally, an accessible user interface such as mobile application in smartphones, as we all have one, plays a crucial role to make an evacuation system usable by the evacuees during an emergency case. However, the existing evacuation systems generally lack accessible mobile interaction interface. For instance, Park et al. developed a real-time navigation algorithm for the staff-in-charge of rescuing the evacuees inside building in emergency cases (Park et al., 2009). But their system needs a mobile interface to interact with the users.

In this study, therefore, an intelligent, dynamic, real-time and mobile application supported evacuation system, which considers both dynamically changing conditions in the building at the fire and users' personal features, has been developed.

3. SMART EVACUATION SYSTEM

The proposed smart evacuation system includes three main components and an overview of the smart evacuation system is shown in Figure 1.

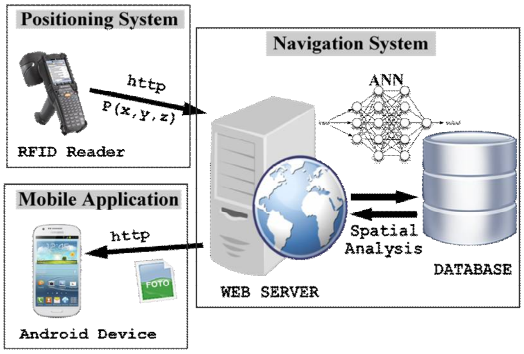


Figure 1. The overview of the smart evacuation system

The first component is the positioning system which determines the indoor position of the user with RFID technology. The second component is the navigation system which runs on a server and finds the most appropriate escape route for each user by exploiting an ANN model (Atila, 2013). The third component of the evacuation system is the mobile application that runs on the user's mobile device such as smartphone and tablet and navigates the user with verbal and visual instructions in the case of a fire.

3.1 Positioning System

The detection of user positon is realised with RFID technology in this evacuation system. RFID is a technology that transmits the identification number (ID) via radio waves (Khong and White, 2006). In RFID systems, the data is saved on an electronic tag and a RFID reader is required to read the data from this tag. The data transmission between the reader and the tag is done using magnetic or electromagnetic waves (Masse, 2004). The building must be equipped with the passive RFID tags (Bhuptani and Moradpour, 2005) and the user must carry an RFID reader device to provide location of the user to the system during the evacuation process.

In this positioning system, the location of the user is determined according to the geographical proximity approach. RFID reader held by the user reads the tags while the user is walking in the building and the strongest tag signal received is accepted the instant position of the user. The data of tag that represents the position of the user is sent to the navigation module on the server at each one second period. Thus, the system can track the movement of the user in the building.

3.2 Navigation System

The proposed navigation system generates a real-time navigation service by considering the personal features and real-time location of the user. The personal features are entered to the system via the mobile application on the user's mobile device. The navigation system also considers the changing indoor conditions in the case of a fire. These environmental conditions and personal features are expressed in Table 1.

Personal Features	Environmental conditions
Age	Temperature
Sex	Carbon monoxide rate
Physical disability	Visibility distance
Muscle and joint problem	Fire growth rate
Heard problem	Human density
Familiarity with building	Length of the link
Respiratory tract disease	

Having fire protection wear Having gas mask	

Table 1. The personal features and environmental conditions

The environmental parameters measured continuously by the sensors in the building. The building is assumed to be a smart building equipped with sensor network that measures these factors and sends them to the navigation system. The sixth factor, length of the link, is measured once before the system is established and saved to the spatial database in the server. These total 16 factors are the input parameters of the ANN running on the server. The ANN calculates the threat degree of each link in the building for the user in the case of a fire by considering these environmental and user-centric parameters. The threat degree may have 1,2,3,4,5 values that imply increasing risk level from 1 to 5. After ANN calculates risk levels of all the links for the user, the evacuation system aims to find the exit route that comprises of the minimum risk level links (Ortakci et al., 2016, Atila, 2013).

When the user connects to server for the first time on a smartphone, the user's personal features are sent to the navigation system. The navigation system receives the current position of the user as the starting point and calculates the shortest escape route that involves the links that do not pose any risk for the user in the case of fire. While positioning system periodically sends the location of the user at one-second-intervals, the mobile device periodically requests navigation directive from the navigation system at two-second-intervals.

3.2.1 Calculating Navigation Directives: The navigation system checks whether the user is on the calculated path. If the user goes on this path, the system sends the navigation directives to the user's smartphone at two-second-intervals. The navigation directives are produced by calculating perpendicular distance in the offset measurements (Atila et al., 2014). The directives and how they are calculated by the navigation system is shown in Figure 2.

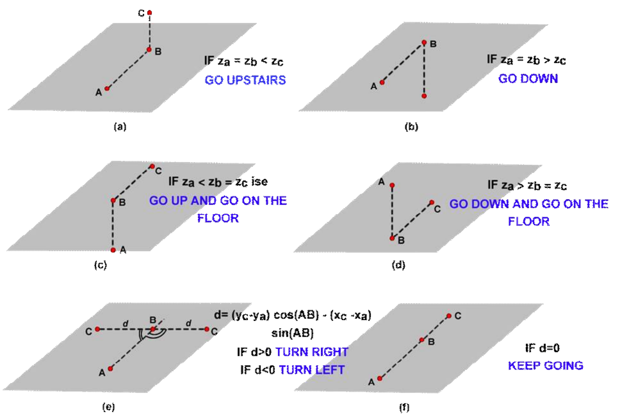


Figure 2. Directives of navigation system

If the user goes out of the calculated path, the navigation system recalculates an alternative path to the exit. A general work-flow of the system is given in Figure 3.

3.2.2 Spatial Database: In this study, Oracle Spatial Database was used to keep the spatial data of the indoor environments in the building. The Oracle Spatial component is used first in Oracle 10g and it provides many functions to handle the spatial data (Kothuri et al., 2008). SDO_GEOMETRY data type represents the spatial objects. While the nodes within the building were represented by the point object of SDO_GEOMETRY type, the path between two nodes was represented by the link object. Oracle Network Model (Murray, 2009) is used to define topological relationships of the nodes in the building. A node and a link table are required to generate a network model.

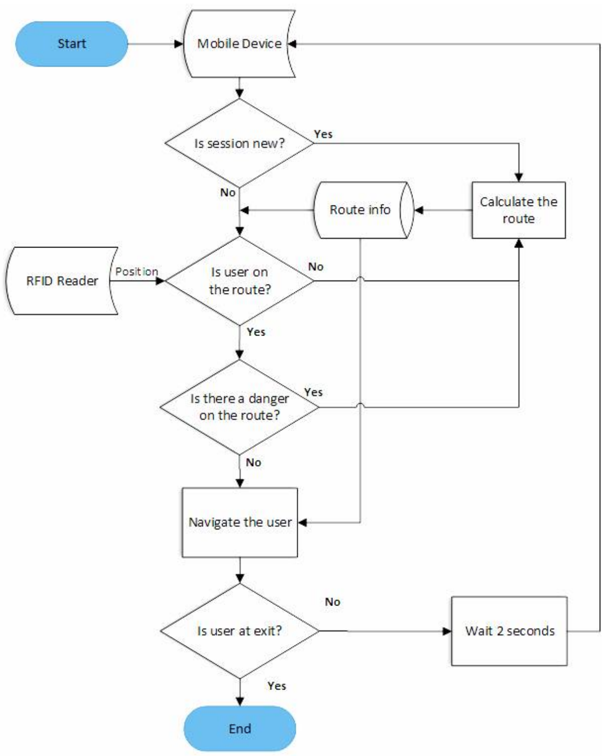


Figure 3. General work-flow of the smart evacuation system

3.3 Mobile Application

The mobile application provides an interface to the user for getting service from the smart evacuation system. The mobile application was developed for Android devices such as smartphone and tablets. The mobile application has an activity to set the personal features of the user. When the user downloads this application, s/he initially must define his/her personal features on this activity (Figure 4). When the mobile application is connected to the server for the first time, these features are sent to the server as input parameters of ANN so that the navigation system calculates the user-oriented escape route. Thus, the parameters pertaining to the user are transferred to the navigation system.

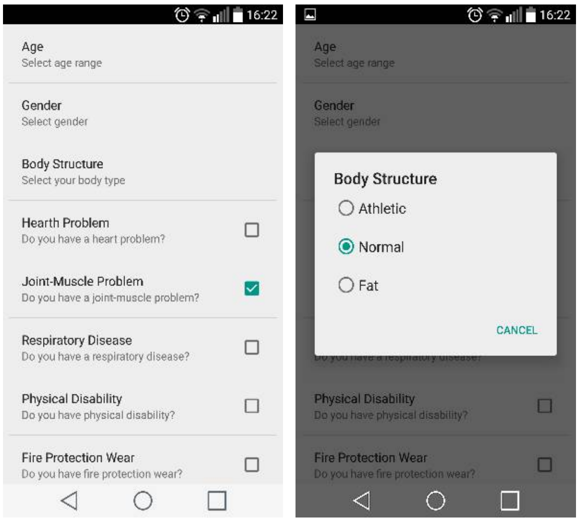


Figure 4. Settings screen of the mobile application

When the fire is detected in the building, the user must start the application manually on his/her smartphone. Then the application requests the navigation service from the navigation system on the server at two-second-intervals. After each request, the navigation system sends the audio and visual navigation notifications to the smartphone. The visual notifications involve the indoor environmental photos and the navigation signs indicating the direction to be followed. On the other hand, the navigation directives are vocalized to reinforce the navigation services for the users. Text-to-Speech library was used to vocalize the texts on the Android. In addition, the temperature of the next link and distance to the exit values are displayed on the screen of the smartphone.

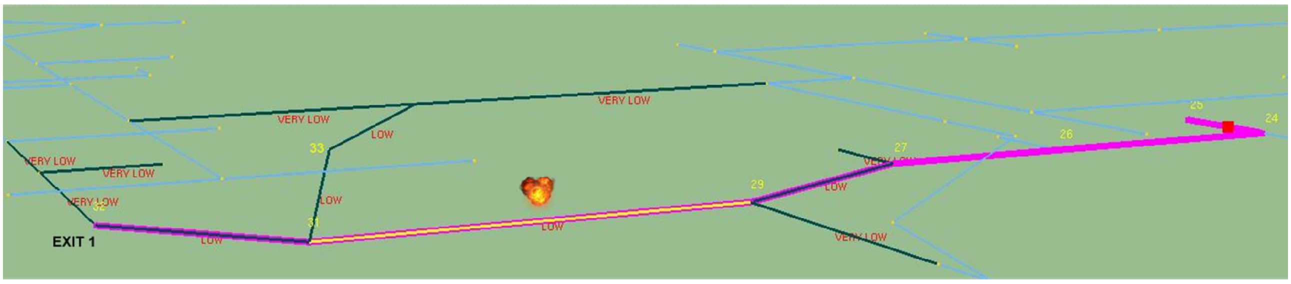
4. EXPERIMENTAL STUDY

The developed smart evacuation system was tested in the building of Engineering Faculty of Karabuk University. 63 nodes and 65 links were designated in the building for the test. 120 passive RFID tags were stuck on the floor of node zone to determine the 3D coordinates of the nodes. The users held ATID 870 Hand-Held RFID reader for positioning and LG G3 smartphone to run the mobile application. A fire simulation was organized on the server for the experimental study, since a real fire could not be started in the building. This simulation starts a fire in a link and spreads the fire around links in the building with a scenario. In the organized scenario, the fire first starts in 31st link (between 29th and 31st nodes) and it spreads towards 61$^{st.}$ (between 31st and 33th nodes) and 62nd links (between 33$^{th.}$ and 11st node), respectively as shown in Figure 5.

The smart evacuation system was tested on three user types. The personal features of these users are given in Table 2.

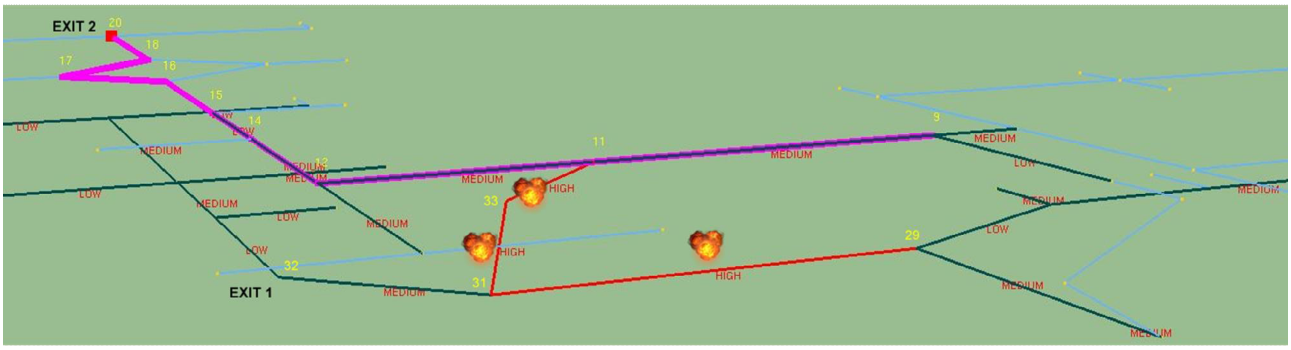
Feature Name	User-1	User-2	User-3
Age	65	40	25
Gender	Female	Male	Male
Body Structure	Fat	Normal	Athletic
Heart Disease	Yes	No	No
Respiratory Tract Problems	Yes	No	No
Muscle and Joint Problems	Yes	No	No
Physical Disability	No	No	No
Familiarity with Building	No	Yes	Yes
Fire Protection Outfits	No	No	Yes
Gas Mask	No	No	Yes

Table 2. The personal features of the user types



(a) First calculated escape path for user-1

(b) Escape path for user-1 at 21th second



(c) Escape path for user-1 at 65th second

Figure 5. Calculated escape routes for user-1

The evacuation process of user-1 is shown in Figure 5. When the fire started, user-1 was at the 25th node and run the mobile application of the smart evacuation system. The system generated the first escape path, the length of which was 56.2 m (Figure 5.a). The smart evacuation system initially searched for an escape route that comprised the links with VERY LOW risk level. However, the system provided the shortest path including LOW risk-level links since there is no alternative path including VERY LOW risk-level links to the exit.

While user-1 was walking along the path, the risk-level of the link between 29th and 31st nodes increased to MEDIUM. Therefore, the system generated a longer-distance but a more secure new exit path for the user-1 at the 24th second of evacuation process. The new path was containing a LOW risk-level link; thus, the general risk-level of the whole path was accepted as LOW risk-level and the total length of the new path was 90.15 m (Figure 5.b). Then, while the user-1 was walking along the second path, the risk-levels of some links on this path was increased to MEDIUM at the 79nd second of the evacuation process (Figure 5.c). However, the system presented the same exit path to the user since there was no more secure path to the exit for the user-1. User-1 was evacuated from Exit 3 at the end of 150 seconds. Some instance screenshots that was taken from the mobile application during the evacuation process are shown in Figure 6.

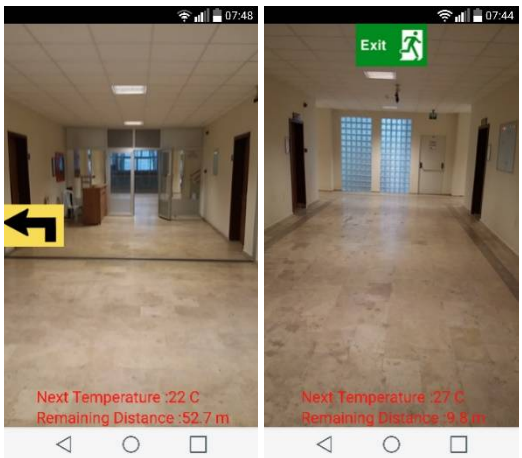


Figure 6. Screenshots of the mobile application

The smart evacuation system was tested by each user starting from the 25th node at the moment of the fire started. The details of the users' evacuations are given in Table 3.

Evaluation Parameters	User-1	User-2	User-3
Length of 1st Calculated Route (m)	56.2	56.2	56.2
Length of Last-Calculated Route (m)	118.7	118.7	56.2
Number of the Calculated Routes During Evacuation	3	2	1
Average Temperature on the Calculated Routes (°C)	26.5	27.1	32.1
Evacuation Time (sec.)	150	124	41

Table 3. The evacuation information of users

The system calculated the escape paths three times, twice and once respectively for user-1, user-2 and user-3 during the evacuation process. The system initially presented the same exit path, the length of which was 56.2 m, to all types of the users. Even though, the system generated different numbers of path for each user since the fire spread in the process of time and affected the users to a different degree, user-1 and user-2 were finally evacuated from the same exit by following the same path. User-1's path was calculated for three times since user-1 was an elderly, fat, female and patient with various diseases, whereas user-2's path was calculated twice. User-1's evacuation process took longer than others. The risk-level of the links may increase easily for user-1 relatively user-2 and user-3. On the other hand, user-3 was evacuated through the first calculated path since he was a young and athletic user with a gas mask and a fire suit. He was also familiar with the building. Although the fire affected the links on his path, the risk-level for this user did not increase easily.

5. CONCLUSION

We compared our proposed smart evacuation system with traditional evacuation systems. In this comparison, traditional system refers a non-dynamic (not able to dynamically change the escape route for a user) and non-smart (not able to consider the personal features of users). Traditional evacuation system presents the same exit path to all types of user and cannot also change the paths during the evacuation process. Therefore, the users were obliged to pass through the ablaze link or links and they were exposed to the temperature about 44°C in the fire simulation. On the other hand, our smart evacuation system provided alternative individual exit paths for each user and evacuated them out of the building confidently by considering their personal features and the changing conditions in the building. The comparison between traditional and smart evacuation system is given in Table 4. Maximum temperatures on their paths were 39°C, 37°C and 43°C respectively for user-1, user-2 and user-3. The maximum temperature on the provided path didn't pose high risk for each user.

In Figure 7, the variation of the temperature at the links during the evacuation of the users are given. The smart system evacuated user-1 and user-2 through the links whose temperature values were under 40°C due to fact that the temperature values over 40°C pose high risk for these users. User-3 could pass through the links even above 40 °C since he had a fire protection wear and gas mask. He was also evacuated from the building in the shortest time. The average temperature was 32.1°C on the User-3's path while it was 26.5°C and 27.1°C respectively for user-1 and user-2.

On the other hand, the smart evacuation system takes into account the increases in fire growth rate, carbon monoxide concentration, human density and the decreases in the visibility distance on the links as a parameter. These characteristics of our evacuation system turn it into a smart and dynamic evacuation system and make it unique and superior to other evacuation systems.

As a conclusion, unlike the traditional evacuation system navigates the users as if they are young, alethic and have gas masks, fire protection wears and no illness, our proposed smart evacuation system considers personal features of them and provides more confidential evacuation service than traditional systems.

Smart evacuation system also has a mobile interface that can run on the user's smartphone easily. The users do not need a detailed device group to be able to get a navigation service from the smart evacuation system. They only need to install a mobile application to their smartphones. The only limitation of the system is that the user needs to have an RFID reader during the evacuation process. However, supposing that the smartphones will also have RFID technology soon as they already have NFC (Near-Field-Communication) technology currently. So, this limitation will be eliminated, and our proposed system will be a candidate of an evacuation system for common use.

Evacuation Model	Users	Distance of Evacuation (m)	Average Temperature on the Route (°C)	Max. Temperature on the Route (°C)
Traditional Evacuation System	User-1 User-2 User-3	56.2	32.1	44,0
Proposed Intelligent Evacuation System	User-1	118.7	26.5	39,0
	User-2	118.7	27.1	37,0
	User-3	56.2	32.1	44,0

Table 4. Comparison of traditional and smart evacuation systems

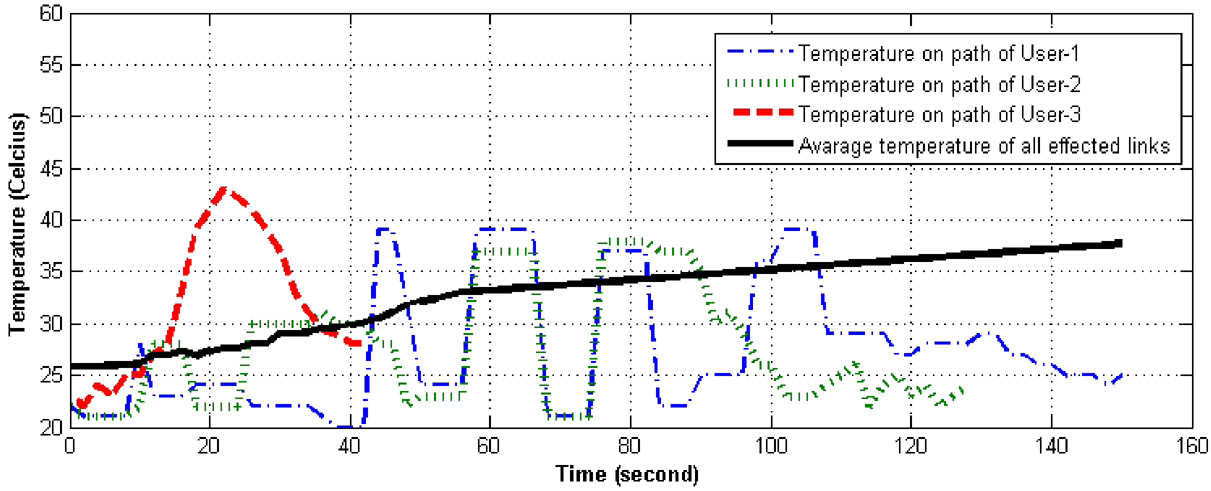


Figure 7. Variation of temperature on the paths of users

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