Multi-user conflict resolution mechanisms for smart home environments (#79504)

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Multi-user conflict resolution mechanisms for smart home environments

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Context-awareness is an enabling technology of pervasive computing that allows context aware applications to adapt themselves in response to different contexts e.g. activity, location, temperature level, etc. An issue of users' conflicts may arise when multiple users want to access the same context aware application. This issue is focused here and a conflict resolution approach is proposed to resolve it. There exists multiple conflict resolution approaches in literature, however, the proposed approach uniquely takes into consideration the users’ special case contexts (e.g. illness of user) along with their priorities and preferences. The proposed approach is useful in cases where multiple users with multiple special cases try to access the same context aware application or service. To show the usefulness of the proposed approach, the proposed conflict manager is integrated with the UbiREAL (a simulated context-aware home environment). The integrated conflict manager utilizes different approaches (automatic, mediated and mixed) to resolve users' conflicts according to the involved situations that suit the needs of a family. The prototype evaluation shows that the users are satisfied with the proposed system and suggests that the use of users’ special case contexts in detecting and resolving the users' conflicts is essential and necessary in the context-aware smart home environments.

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ABSTRACT

Context-awareness is an enabling technology of pervasive computing that allows context aware applications to adapt themselves in response to different contexts e.g. activity, location, temperature level, etc. An issue of users' conflicts may arise when multiple users want to access the same context aware application. This issue is focused here and a conflict resolution approach is proposed to resolve it. There exists multiple conflict resolution approaches in literature, however, the proposed approach uniquely takes into consideration the users' special case contexts (e.g. illness of user) along with their priorities and preferences. The proposed approach is useful in cases where multiple users with multiple special cases try to access the same context aware application or service. To show the usefulness of the proposed approach, the proposed conflict manager is integrated with the UbiREAL (a simulated context-aware home environment). The integrated conflict manager utilizes different approaches (automatic, mediated and mixed) to resolve users' conflicts according to the involved situations that suit the needs of a family. The prototype evaluation shows that the users are satisfied with the proposed system and suggests that the use of users' special case contexts in detecting and resolving the users' conflicts is essential and necessary in the context-aware smart home environments.

1 INTRODUCTION

In 1991, Mark Weiser put forward the vision of ubiquitous computing Weiser (1991), now also known as pervasive computing. According to his vision, computing would move beyond desktop and be available everywhere invisibly to the users. In other words, pervasive computing is a computing paradigm that helps users in their everyday life activities (at work or at home) without requiring their attention or continues instructions from them. What makes this vision possible, among others, is context-aware computing also known as context-awareness. Context-aware computing uses users' contextual information to provide them with the service(s) of their interest or perform specific task on their behalf Abowd et al. (1999); Emmanouilidis et al. (2013).

Although, context-awareness is playing a central role in fully realizing the vision of ubiquitous computing, however, there exists various research challenges that need to be explored and investigated to broaden the scope of this interesting area. For example, user control, context inconsistencies, power consumption, conflicts among users, data privacy and security etc. Dhyani et al. (2022); Rao and Deebak (2022); Alsamhi et al. (2022). Context awareness related issues are currently being investigated by the research community, however, being a less mature research area, more in depth and focused research efforts are required to accomplish the Mark Weiser's vision of invisible computing.

Context awareness is an essential pillar of smart environments. A smart environment comprises of interconnected sensors, computing devices, appliances and services. The interconnected devices adapt themselves according to the contexts i.e. occupancy, activities, weather, location etc., to improve comfort, safety, and security for its occupants Vahdat-Nejad et al. (2013); Tiwari et al. (2022). Usually, a smart environment is well suited for a single user only and in case of multiple users it always face challenges

to effectively fulfil their needs. Multiple users try to share time, place, appliances and computational resources of the same environment and the environment needs to coordinate and manage resources to satisfy users needs.

Resolving multi-user conflict is one of the biggest challenges of the smart environments Hua et al. (2022). It arises when multiple users try to access a context-aware application customized for a single user only. For example, when a user A enters a living room, the room lighting and the temperature control applications adapt themselves according to her preferences but what if another user B enters the same living room and she has a different set of preferences for the lighting and temperature.

Smart home is one of the examples of the smart environments Tiwari et al. (2022). It adapts itself according to the family needs and helps family members to perform their everyday activities with minimal or no distraction. In the smart homes, commonly, priorities are assigned to the family members based on their roles i.e. the parents (father and mother) have higher priorities than their children, and the elder brothers and sisters have higher priorities than the younger ones etc. Even though the priorities have been assigned to the family members, still various conflicting situations may arise. For example, suppose if a father and his son are in a living room of the smart home whose temperature is set according to father's preference (e.g., cold environment) but the son is ill and the cold environment of the room may worsen his health conditions. Or in another situation where two brothers elder and younger are in a living room, the elder's preference is to dim the light while the younger is preparing for his examination. In this case, based on priorities, the environment will adapt itself according to the elder brother's preferences. Consequently, in this situation, it would be impossible for the younger brother to prepare for his examination. Many other such common conflicting situations may arise such as visits of the other families or friends at the home or the user herself is not interested in using the application(s) etc.

Commonly, smart environments use conflict resolution schemes to automatically detect and resolve users' conflicts without active users involvement. However, sometimes, there might come situations where users' involvement and discussion is required to resolve the conflicts. As advocated in the literature Del Rio (2022); Shin and Woo (2005a); Easterbrook et al. (1993); Poole et al. (1988); Shin et al. (2007b); Yu et al. (2006); Shin and Woo (2005b); Oh et al. (2005); Shin and Woo (2009b); Shin et al. (2008, 2010, 2007a), involvement of users in conflict resolution is essential because it increases the harmony of the home inhabitants. This requires the environment to recommend the users with the best possible resolution candidates to resolve a particular conflict based on the involved users' preferences and conflicting situations.

Although, these approaches effectively resolve users' conflicts, still lacking to handle many special situations like illness, exams, guests etc. (as discussed above).

In this research paper, we propose a conflict resolution manager to resolve different conflicting situations with special cases that occur in the smart home environments when multiple users share the same home environment.

Following are the contributions of this research:

- the proposed conflict resolution manager takes into account users' special cases like illness, guest visits, exams etc. for determining a resolution algorithm and an approach to be applied to detect and resolve the users' conflicts
- it is a novel approach to resolve users' conflicts based on users' special cases (to the best of our knowledge, none of the existing literature has considered user special cases in decision making of the selection of the resolution approach to resolve users' conflicts)
- users' conflicts are resolved using automatic, mediated as well as mixed resolution approaches
- mediation approach with decreased users' involvement is used to resolve users' conflicts for the special case users
- the users involvement during mediation has been decreased by allowing the applications to automatically adapt to the preferences of the special case users
- an important but neglected aspect is also considered i.e. in case if the user himself is not interested in the application available (this situation is considered important and embed in the proposed system to detect and resolve multi-user conflicts)

The proposed sytem has been implimented using Java language and tested and evaluated using usability testing method. The usability findings suggest that the proposed system is usable in detecting different conflicting situations with special cases and can provide comfort to users by conveniently resolving their conflicts.

The reminder of the paper is organized as follow: Section 2 presents related works that address the multi-user conflict resolution in smart environments. Section 3 presents our proposed approach to resolve the multi-user conflicts. The prototype implementation is discussed in Section 4, while the usability evaluation and its procedures are discussed in Section 5, followed by the results and discussion in Section 6. Conclusion remarks and future directions are presented in Section 7.

2 LITERATURE REVIEW

This section provides a brief overview of research works focusing on multi-user conflicts detection and resolution in smart environments. In the reviewed literature, it has been noted that three approaches are commonly used for detecting and resolving multi-user conflicts. Following subsections provide the detail of each of these approaches.

2.1 Automatic conflict resolution approach (ACRA)

Using this approach, researchers have focused on the automatic resolution of users' conflicts based on priority and/or preferences without active users' involvement. The authors in Haya et al. (2006) have outlined many such research efforts that only focus on priority-based automatic resolution of users' conflicts. In Ranganathan and Campbell (2003) the priorities are assigned to the actions (according to certain rules) and the system selects the highest priority action as the resolution of the conflict or it is selected based on the importance of the action. Some of the existing systems resolve the conflicts using conflict manager where the priorities are not only assigned based on their importance but also according to the user's preferred service, or by user specific way supported by "using history of user selections" Lee et al. (2007). Other researchers have just focused on resolving conflicts by maintaining conflicts history records and assigning the priorities based on that history Shin et al. (2005); Shin and Woo (2005a).

Some researchers have tried to resolve the conflicts by developing different algorithms (techniques), which use the priorities in some situations, and preferences in some other situations, or a combination of both depending on the profile and culture of the family. The approach in Groppe and Mueller (2005) has proposed three algorithmic strategies to resolve the conflicts (1) by fair principle, which is based on the preferences of the users, (2) use first, which assigns the priorities to the user who comes first to the environment and (3) by preference priority, where it gives priorities to the preferences and resolves the conflict by selecting the highest priority preference. The authors also suggest the need for considering the illness of the user to adjust priorities or preferences, by giving the highest priority to the ill user at the time of the conflict. The work in Park et al. (2005) considered the user preferences and intentions in resolving multi-user conflicts, and their algorithm minimizes the reluctance of all the users by computing the deviation in their preferences and applies the result that has the lowest deviation from what each user wanted.

The authors in Paulo Carreira (2014) resolved the conflicting situations automatically as Constraint Satisfaction Problem (CSP). Their system resolves the conflicts based on involved users' preferences using some constraints. The constraints are valid range of values for user preferences and services that enable performing the activity. In case of non-satisfiable constraints, the system assists the users in resolving conflicts by mediating of resolution candidates. The research work in Camacho et al. (2014) also used CSP for conflict resolution to find the appropriate resolution using constraints solving. The difference is that the latter used ontologies to detect and satisfy the constraints imposed on the environment. Ontologies are one of the mechanisms used in multi-user conflict detection in the smart environments that allow categorizing the devices according to their similarities (i.e. device type, device location, etc.) Elenius and Ingmarsson (2004). The work presented in Chaki et al. (2020) focused on multi-user conflicts detection and they formulated multi-user conflicts as ontology conflicts by detecting whether the conflict occurred in one application or in multiple applications, and whether the conflict is a functional conflict or a non-functional conflict.

The authors in Chaki and Bouguettaya (2020) used the concept of Entropy and Information Gain (IG) of information theory to gather the users' usage habits of the devices and services and developed an algorithm based on temporal proximity to detect the multi-user conflicts. The research work in Sikder

et al. (2020, 2022) developed `Kratos:` a multi-user and multi-device-aware access control mechanism. The system has three components: (a) users interaction component to allow users to specify their access control settings, these settings are converted into policies in the second component, (b) backend server, and (3) policy manager that analyzes these policies to negotiate the conflicts between users and generates final policies that will be used to resolve the conflicts.

2.2 Mediated conflict resolution approach (MeCRA)

There exists situations where it is very difficult to assign the priorities such as public spaces and gatherings. For such situations, the researchers have focused on resolving conflicts by considering the satisfactions of the majority of the users' preferences. MusicFX McCarthy and Anagnost (1998) is an arbitrator system that automatically selects the music station for the members of fitness center indirectly through their profiles. The system allows the users to influence (but not directly control) the selection of the music station through their preferences gathered from their profiles. Jukola O'Hara et al. (2004) is a music mediator system for public space that allows customers to influence the selection of songs being played in a cafe. The system provides the customers with a device on every table to mediate a list of songs for all the users on a shared display screen. It allows the customers to select the songs and after selection, it plays the most rated song. The system also allows the customers to upload their own songs to add to the list so that the other customers can rate them in future. This approach requires active participation of all the users to resolve the conflicts.

As compared to public spaces (like restaurants), private spaces (like smart home environments) require different kind of mediation as the home members can easily resolve the conflicts through discussion.

The authors in Easterbrook et al. (1993); Poole et al. (1988) argue that discussion is an effective and natural way to resolve conflicts. Through discussion, users exchange information and ultimately find a solution that includes an agreement containing preferences of all the users. The work in Shin et al. (2007b) proposed a user-centric conflict management system that considers different contexts and recommendations of a personal companion to resolve multi-user conflicts. The system allows users to select from the recommendations of their personal companions. Mediation process enables users to exchange their opinion regarding media content to be agreed upon an item that reflects all the users' preferences. The authors Shin and Woo (2005a), proposed Group Preference (GP) algorithm that merge the involved users' profiles and recommends a list of the users for discussion. The recommended users then discuss among themselves and agrees on a common content to resolve the conflicts. The authors in Yu et al. (2006) proposed a system that focuses on recommendations for digital TV. Their system merges the involved users' profiles and constructs a common profile that reflects the group preferred content. The system then recommends the common users content and based on users' feedback, it selects and plays the common program. The authors in Shin et al. (2007a) proposed a mediation technique using a recommendation based on a consistent media content of every user involved in the conflict and service profile. It rearranges the recommendations using GP algorithm and mediates it to the users as discussed in Shin et al. (2007b). In Oh et al. (2005) the authors proposed a system that resolves the users' conflicts based on service recommendations. When the conflict occurs, the service recommendation selects the highest preferred services and recommends them to the users. The system gathers users' feedback and adapts according to the users' selection after discussing the recommendations.

2.3 Mixed conflict resolution approach (MiCRA)

In a home environment where different conflicting situations may occur, resolving conflicting situations using one resolution approach will not produce satisfactory results. This arises the need for a system to support multiple approaches with multiple schemes to deal with different conflicting situations. The authors in Otto et al. (2006) proposed a system that resolves multi-user conflicts using an input control device through explicit user interaction. Their solution used different approaches to deal with multi-user conflicts such as (a) giving priority to that person only who has the input control device, (b) allowing the person who entered first into the environment to have the input control device, (c) giving a specific time to every person to have the input control device, (d) involving every person to actively participate in the conflicts through mediation using Personal Digital Assistant (PDA). In the last case, the system involves all the users even if they are not part of the conflicts and it then adapts itself according to the input to which all the users agreed on.

The authors of Shin and Woo (2005b) proposed a conflict manager that resolves the conflicts by either of two ways (1) assigning priorities to the users' contexts and choosing context based on the highest

priority at the time the conflict occurred and (2) providing recommendations to users based on their profiles and letting the users to select one of the recommendations. The authors of Shin and Woo (2009b) proposed a socially aware TeleVision (TV) through which the conflicts are resolved in either of two methods (1) automatically based on users profiles and (2) by recommending the users a common group profile. Their system provides a remote control that allows the users to mediate the final decision. The system then makes a final decision based on the users recommended common group profile.

The authors of Shin et al. (2008) developed a MiCRA that resolves conflicts in either of three ways (1) ACRA selection with priority, (2) through resolution with preferences and (3) MeCRA with profile merging. In the first approach, the system adapts according to the highest priority user if the difference in priorities of the involved users is less than a specific threshold value and the deviation between each user's preferred value and the group's best item is greater than a specific threshold value. The second approach is further divided into two approaches (a) if the context attribute is numerical (i.e. Air Conditioner), the best optimal solution is used (it is easy to compute the best optimal solution by computing the lowest deviation of each user's preferred value with the resolution result) and (b) if the context attribute is symbolic (i.e. fan speed) and the deviation of the user preferences is less than a specific threshold value, the group's best item is used as a resolution of the conflict. In the third approach, the system recommends the users with some resolution candidates based on their profiles merging. The users are then engaged into face-to-face discussion and select one of the resolution candidates. The work in Shin et al. (2010) resolved conflicts by either of two methods (a) using profile based automatic approach, and (b) by the use of social mediation. In social mediation approach, the users engage in negotiating for a proper resolution. The system has a balance model to evaluate a group feeling to reduce a discussion time.

2.4 Summary of literature

Literature review presented above suggests that a multitude of research has been conducted in the proposed research area, resulting in proposition of different resolution algorithms (based on priorities and/or preferences) and approaches (ACRA, MeCRA, and MiCRA) to detect and resolve multi-user conflicts. Some of the proposed algorithms are suitable for public spaces (e.g. restaurants), while others are suitable for the private spaces (e.g. homes). The importance of the MeCRA in the private spaces is stressed in the reviewed literature but the context-aware home environment dictates the need of minimizing the users involvement to reduce their distractions, especially in the situations where users may have special cases (i.e. illness, preparation for examination and guests). In the existing systems, if ACRA is applied for such special cases, it may lead to unpleasant results for those special case users. Moreover, if the MeCRA is applied, this will lead to discussion among home users and the result will most likely be the home users conceding their right to the special case users as a resolution for the conflicts to provide them comforts. Since, the users' special cases are temporary situations that might occur for specific amount of time. Through mediation, the family members show care for each other by conceding everyone's rights of using the applications especially the one who has special cases (i.e. illness). This allows the family to live in more harmonic situations by providing the special case users the feelings that the other home members are caring for them. However, to better resolve the conflicts, there is a need to decrease the users involvement during mediation.

In order to lessen the users involvement, mediation can be minimized by allowing the applications to automatically adapt to the preferences of the special case users. The same has been focused here in this research. Also, an important but neglected aspect is considered i.e. in case if user himself is not interested in the application available at the vicinity such as the TV (maybe because of work overburden or some other reasons). This situation is considered important and embed in our proposed approach to multi-user conflict detection and resolution. While the MiCRA to multi-user conflict detection and resolution has been used in the literature in which some conflicts are resolved using ACRA and others using MeCRA, none of the existing systems have considered use of special cases in the decision making of the selection of the resolution approach. The proposed approach takes into account special cases in determining a resolution algorithm and an approach to be applied to detect and resolve the multi-user conflicts in the smart home environment.

3 THE ARCHITECTURE OF THE PROPOSED SYSTEM

The architecture of the proposed system comprises three main components as shown in the Fig. 1 i.e. the UbiREAL (simulated sensors and applications), Users' Profiles and User Conflicts Manager.

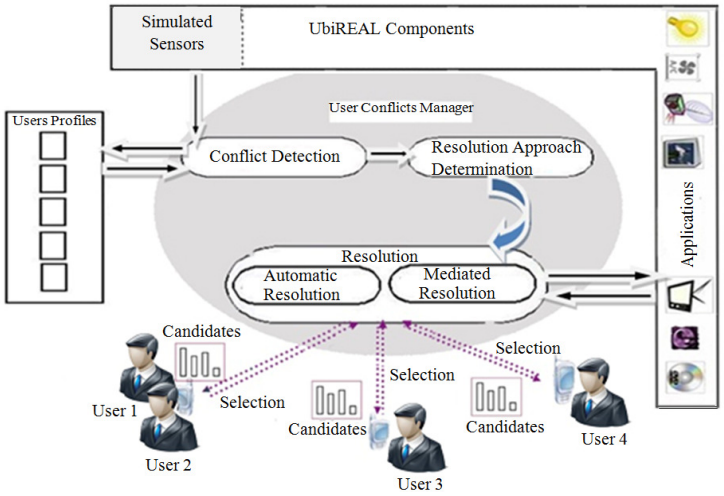

Figure 1. High-level architecture of the proposed system.

3.1 UbiREAL simulator

UbiREAL simulator Nishikawa et al. (2006); Alshammari et al. (2017) is one of the components of the proposed architecture. It includes built in simulated sensors and applications to detect devices, users' interaction with the devices, users' movements, their locations and tracking in the simulated home environment. The Applications part of the UbiREAL simulator is responsible for publishing the name of the devices and the actions that can be performed on these devices. Every device must publish its name and possible actions that can be performed on it as a variable name, which is passed as an argument to the application.

3.2 Users' Profiles component

It is a general-purpose component responsible for maintaining the users' profiles. Each user's profile contains the required information needed to be considered in resolving the conflicts among the users. For example, user names, their priorities and preferences for using different applications along with their special cases (if any).

3.3 Conflict Manager component

The conflict manager component is responsible for detecting and resolving the multi-user conflicts. Its working is assisted by three sub-components i.e. conflict detection component, determination approach component and resolution component.

3.3.1 Conflict Detection Component

It is responsible for detecting the conflicts among users when two or more users available in the same room. Its working involves obtaining users' location from the sensor component, gathering required information about the conflicting situations (like name of the users, the conflict location, and the involved users' profiles etc.) and passing these pieces of information to the determination approach component.

3.3.2 Determination Approach Component

It is responsible for selecting an appropriate resolution approach based on the information received from the conflict detection component.

An algorithm i.e. approach determination structure algorithm, has been designed to select an appropriate approach (from ACRA, MeCRA, and MiCRA) for the resolution of conflicts according to the occured conflicting situations, as shown in the Fig. 2.

The approach determination structure selects the ACRA in the following four cases

1. if there is no special case user involved in the conflicting situation
2. if there is only one special case user from the involved users
3. if there are multiple special case users and the deviation in their preferences is low

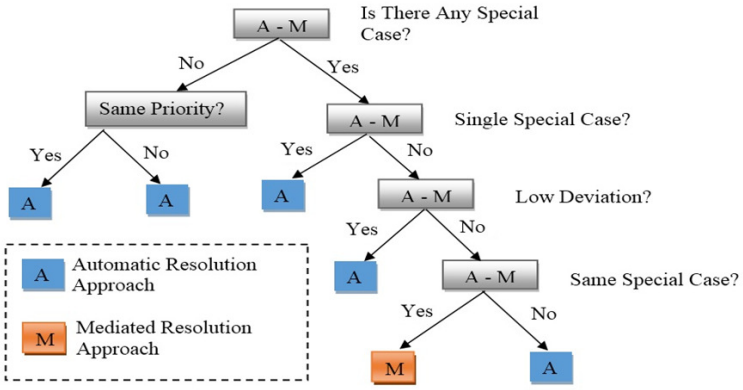

Figure 2. Approach determination structure.

4. if there are different special case users with a high deviation in their preferences

The MeCRA is selected when the involved users have the same special case and the deviation in their preferences is high.

Finally, the MiCRA is selected when there are multiple special case users with the multiple applications present in the environment and the ACRA is not applicable.

Once the appropriate resolution approach is selected, it is then sent to the resolution component to resolve the conflict.

3.3.3 Resolution Component

It is responsible for making the resolution about the detected conflict based on the selected resolution approach.

The conflict might be resolved automatically without active involvement of the users based on the information gathered from their profiles, or by mediating some resolution candidates based on the involved users' preferences, letting the users discuss among themselves and selecting the appropriate resolution from the resolution candidates. The application then adapts according to users' selection. The conflict manager, after resolving the conflict, passes the values to the application, which will adapt itself according to these values.

The following scenario example explains the working of the proposed architecture using approach determination structure.

Suppose two users with special cases are present in the same room and there are three appliances (light, temperature, and TV) in the room. One user is ill while the other prepares for examination. The proposed system will detect the conflict, gather the information about the users and the environment, and resolve the conflict as follows.

The ill user will control the temperature appliance, while the user preparing for examination will control the light appliance. As the TV appliance has equal impact on both the users' special cases, the MeCRA will be chosen for this appliance, which will generate some resolution candidates based on both the users' preferences and recommend them to the users. The users will then engage in discussion and select one of the resolution candidates and the system will adapt according to the users' selection.

4 PROTOTYPE IMPLEMENTATION

As a proof of concept, the proposed approach has been designed and implemented using Java language. Since, the main focus of the study is detecting and resolving user conflicts in smart environments, the proposed system does not provide any support for developing context-aware applications. Developing a real test-bed environment to test context aware applications is an expensive and time consuming process (it requires installing many sensors and appliances to meet the requirements of the smart environment), therefore, to implement the idea, a simulated smart environment using UbiREAL simulator has been used.

UbiREAL simulator Nishikawa et al. (2006) is a java-based 3D virtual environment that provides a suitable environment to test the context-aware applications and allows to visualize the state change of

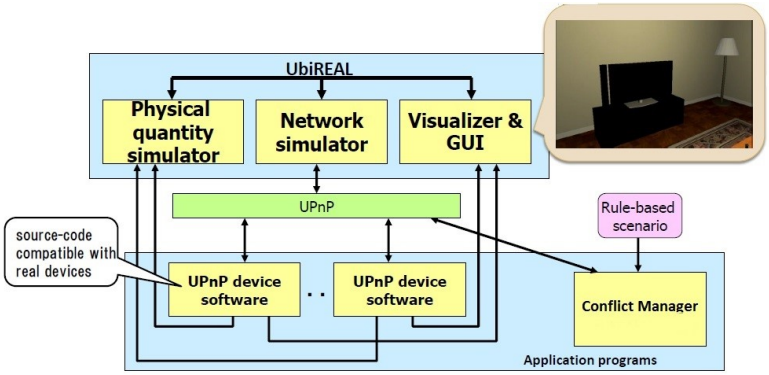

Figure 3. Structure of UbiREAL simulator.

```
<profile>
    <user>      <name>Mahmoud</name>                                    </user>
    <pref>      <specialcase>Ill</specialcase>
                <casevalue>true</casevalue>                             </pref>
    <pref>      <specialcase>ExamPrepration</specialcase>
                <casevalue>false</casevalue>                            </pref>
    <pref>      <specialcase>Guest</specialcase>
                <casevalue>false</casevalue>                            </pref>
    <pref>      <specialcase>WishToUseTheService</specialcase>
                <casevalue>true</casevalue>                             </pref>

     <action id="0">    <actionName>priority</actionName>
                        <value>1</value>                                    </action>
    <action id="1">     <actionName>LivingLamp1</actionName>
                        <value>2.4</value>                                  </action>
    <action id="2">     <actionName>LivingFanSetPower</actionName>
                        <value>1.0</value>                                  </action>
    <action id="3">     <actionName>LivingAirconSetPower</actionName>
                        <value>true</value>                                 </action>
    <action id="4">     <actionName>LivingAirconSetTemperature</actionName>
                        <value>30.0</value>                                 </action>
    <action id="5">     <actionName>LivingAirconSetHumidity</actionName>
                        <value>60.0</value>                                 </action>
    <action id="6">     <actionName>LivingTVSetPower</actionName>
                        <value>true</value>                                 </action>
    <action id="7">     <actionName>LivingTVSetChannel</actionName>
                        <value>5</value>                                    </action>
</profile>
```

Figure 4. XML-based user profile sample.

devices through the 3D GUI. UbiREAL simulator was made public with the source code in the year 2012. The proposed conflict manager is implemented on top of the UPnP component shown in the Fig. 3.

Fig. 3 indicates that the proposed conflict manager is integrated with UbiREAl simulator to detect and resolve the multi-user conflicts using the concept of UPnP protocol. This protocol allows the applications to implement their phases needed to develop an application compatible with the context-aware environment. The conflict manager is developed as UPnP client control point that subscribes to the events of the sensors to get the notifications about the devices state changes (context - specially the sensors - user locations). Based on this information along with users profiles (developed using XML as shown in Fig. 4.) a resolution is proposed to resolve the user conflicts.

A GUI was developed to edit the XML files for the users' preferences. As shown in the Fig. 5, the simple XML Editor has only two buttons (Open and Exit). When the open button is clicked, a new dialog appears that allows to choose one of the XML files to edit. The users are then able to specify their names and preferences through the GUI without the need to edit the XML file manually.

An another Java-based GUI was also developed to select the resolution from the recommended resolution candidates at the time when conflict occurs.

Fig. 6 shows the Java-based GUI that allows the users to select the resolution from the recommended resolution candidates.

5 TESTING AND EVALUATION

The proposed approach was tested and evaluated by performing the usability study of the implemented system.

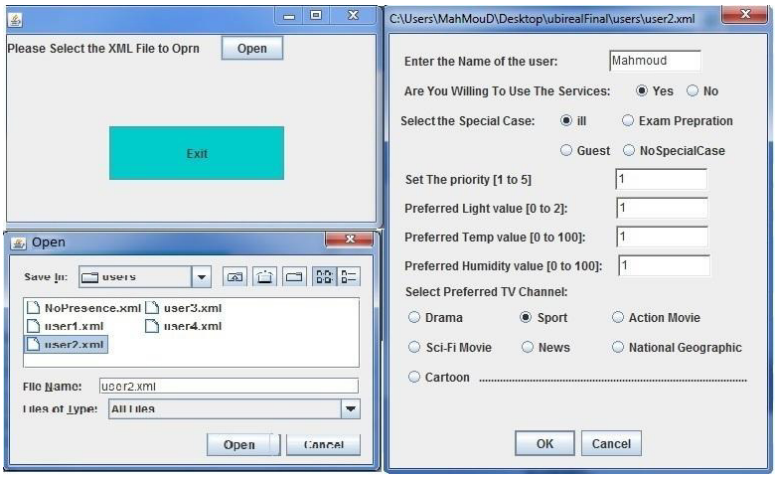

Figure 5. GUI for XML-based user profile editor.

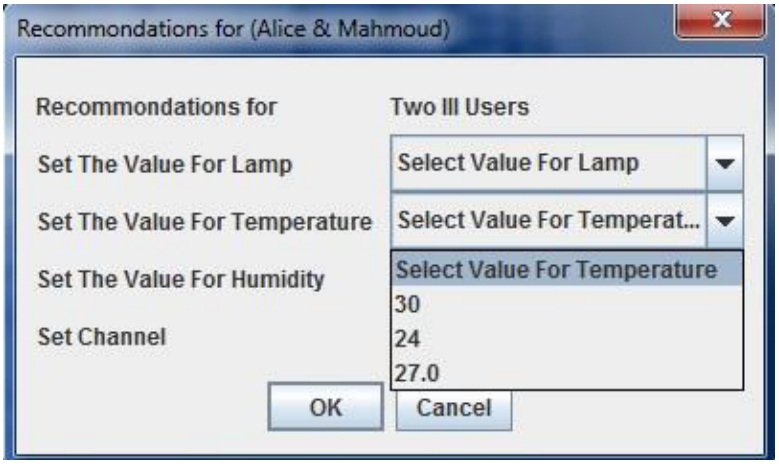

Figure 6. GUI for the recommendations of resolution candidates based on the involved users' profiles.

Figure 7. Living-room like environment in UbiREAL

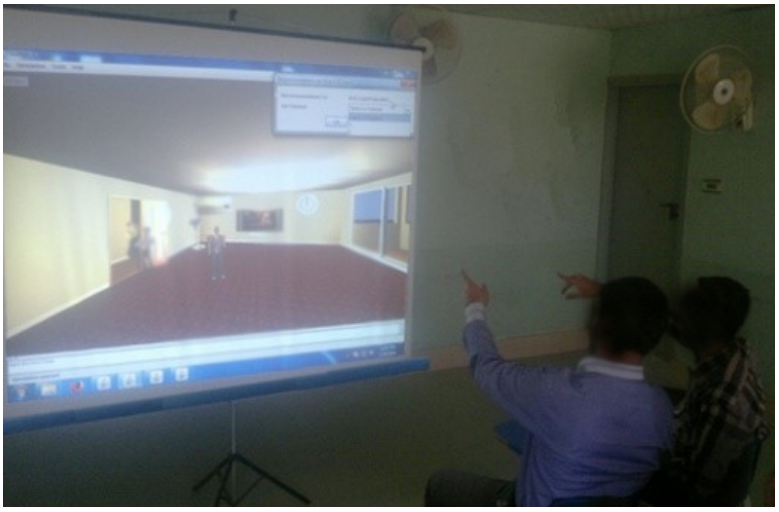

Figure 8. Users interaction with the simulated environment.

5.1 Usability Study

In order to perform the usability study on users, a virtual smart home environment was projected using UbiREAL, mimicking a real smart home environment (refer to Fig. 7). The participants were interacting with the smart home environment from the front by imagining that they are in the environment (refer to Fig. 8).

The participants of the usability study were divided into 22 groups and each group was consisted of four (04) participants. Every participant from each group was given a role to play according to their role in the family (i.e. parents were given a parent role; children were given a child role etc.). Based on roles, different scenarios were designed and for each group of participants the scenarios were executed twice. First time with a low deviation in the users' preferences, while the second time with a high deviation in the users' preferences.

The scenarios were designed to test the aforementioned resolution approaches i.e. ACRA, MeCRA and MiCRA. Using these approaches and based on users preferences, a resolution candidates was recommended by the proposed system. Based on the recommended resolution candidate and discussion among users an actor was appointed who was responsible for running the system, The actor was then told to apply the selected resolution candidate tp resolve the conflict.

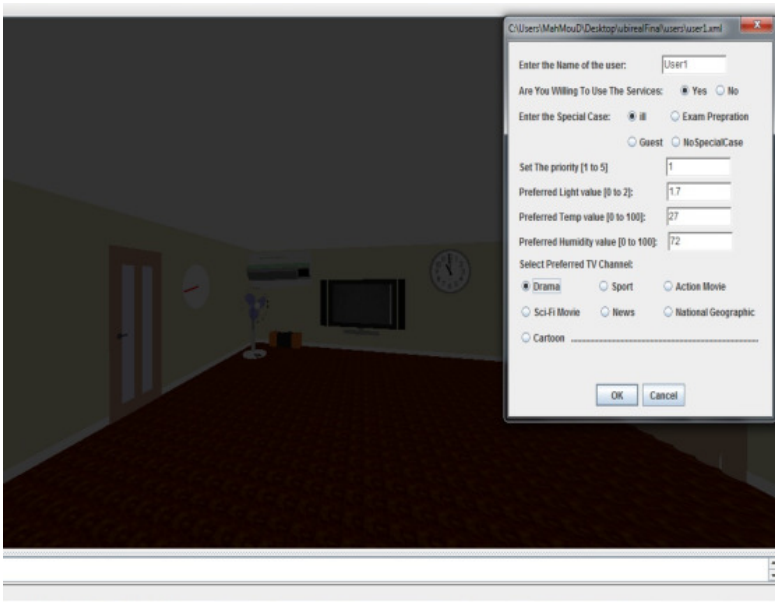

Figure 9. GUI utility for user's preference setting.

(a) Air Conditioner (b) TV Screen (c) Light Appliance

Figure 10. Projected (a) Air Conditioner (b) TV Screen (c) Light Appliance.

5.1.1 Working of UbiREAL Smart Home Environment

Initially, in case of recommendations, the recommendations were popped up on the screen of the projected smart environment.

A GUI based utility was added to set the preferences of the users (refer to Fig. 9). The settled users' preferences were saved as a separate profile for every participant. After the users' preferences have been saved, the experimental situation involving the applications and the degree of deviations in the users' preferences were controlled. Three applications (as shown in Fig. 10) were selected and projected on the wall screen by the simulation. (1) simulated Air Conditioner application (2) simulated Television application, and simulated Light application (refer to Fig. 10 (a), (b) and (c)). As the conflict occurred, the conflict manager detected that conflict and responded immediately to the ACRA or MeCRA resolution results.

5.1.2 Selection of Scenarios

To evaluate the performance of the proposed system with multiple applications and multiple users with different special cases, two different scenarios were selected. Considering multi-user conflicting home environment with different special cases, in these scenarios, every participant was given a role and a special case.

Scenario-I

The first scenario was selected with two family members and their two friends. The first user entered the environment was a home member and having an illness special case. The second user entered the environment was a friend of the first user who came to visit him at his home. The second user has a guest special case. The third user was the brother/sister (home member) of the first user, and she has an examination preparation special case. The fourth user was a friend of the second home member with

a guest special case but at that instance of time she was not interested in using the applications in the environment. This scenario was executed twice, first time with a low deviation in users' preferences and the second time with a high deviation in users' preferences.

Scenario-II

The second scenario was selected with four home members: a father, a daughter, and two sons. The first user entered the environment was a son with no any special case (normal). The second user entered the environment was the brother of the first user with an illness special case. The third user entered the environment was the father who is not interested in using any application running in the environment. The last user entered the environment was the daughter with the examination preparation special case. This scenario was also executed twice, first time with a low deviation in users' preferences and the second time with a high deviation in the users' preferences.

Explaining Scenarios

Every scenario (as mentioned above) was executed twice to examine the system's behavior of selecting the appropriate resolution approach based on users' special cases and the degree of deviations in the users' preferences. The reason of using only two scenarios in the usability study was to avoid users' exhaustion because every single scenario took around fifteen minutes to complete. Executing only two scenarios allowed us to get a reasonably realistic data without taking much time of the participants. In summary, the two selected scenarios provided the reasonable estimate to examine the three different approaches (i.e. ACRA, MeCRA, and MiCRA) in resolving the multi-user conflicts with the users' preferences and different special cases.

1. ACRA resolved the conflicts based on users' profiles without involvement of the users in the resolution processes.

2. MeCRA resolved the conflicts by involving the users in the resolution processes and recommending them some resolution candidates. The users' discussed among themselves and selected one of the recommended resolution candidates, which was applied as the conflict resolution.

3. MiCRA considers the resolution when the conflict occurs for multiple applications. In this case the system selects the ACRA for some applications and MeCRA for the others. Same here happened in these scenarios. When the conflict occurred in multiple applications, the MiCRA came into action and resolved the conflict by selecting ACRA for some of the applications and the MeCRA for the other remaining applications.

5.1.3 Test Experiments

The test experiments for the scenarios were conducted in a room, which simulated a living-room like environment. Before the start of the experiments, a little time was spent on the participants to brief them about the users' conflicts in smart environments and experiments needs to be performed to resolve them using the proposed system. The participants were briefed about different strategies used in resolving the conflicts automatically and also about the need of including the special cases in detecting and resolving conflicts. Furthermore, at the time of recruiting the participants, a brief introduction of the proposed system to each participant was also provided .

During conducting the experiments, following three questionnaires were administrated to the participants:

1. Pre-Test Questionnaire (PRTQ): This questionnaire was filled by the participants before conducting the test case. The purpose of this questionnaire was to collect the demographic information of the participants.

2. After Scenario Questionnaire (ASQ): This questionnaire was used to collect the users' opinion for different aspects of the proposed system.

3. Post-Test Questionnaire (POTQ): This questionnaire was distributed among the users to gather the broader aspects of the multi-user conflicts resolution with their feedback and suggestions.

As explained earlier, each experiment was consisted of two scenarios and each scenario was executed twice with the group of four users. To cover all the aspects provided in the proposed system, the first execution of each scenario was done with low deviations in users preferences, while the other was executed

with high deviation in users' preferences. Before the start of the experiments, the PRTQ was distributed among the participants to fill their demographic information. During the experiments, the conflict manager selected some of the resolution using MeCRA and recommended some resolution candidates to the involved users through which the the users had to select one of the candidates after discussion among themselves. Then the system adapted according to that selection. After completing the scenario each participant was given ASQ to gather the satisfactions of the participants with different aspects of the proposed system.

Finally after completing the test case, every participant was given a POTQ that contained only two questions, one about the approach that was adapted by the conflict manager in case no user has a special case. The other question was about the rating of the different resolution approaches and the users' experience while executing the scenarios.

All methods / experiments were carried out in accordance with relevant guidelines and regulations as well as all experimental protocols were approved by Ethics Committee of University of Sindh, Jamshoro. Ethics approval and participant consent was taken as per policy of the University of Sindh, Jamshoro. All subjects in the database were enrolled at the university and have given informed consent, and if under 18, consent was taken from parent and/or legal guardian. Additionally, all the subjects have given the right to withdraw form the study at any time. Furthermore, an informed consent was taken from all subjects and/or their legal guardian(s) for publication of identifying information/images.

Next section presents the results and analysis of the usability study of the proposed system.

6 RESULTS AND DISCUSSION

The usability analysis of the proposed system provides an assurance that the system is easy to use and the intended users are satisfied with its working mechanism in detecting and resolving multi-user conflicts.

Data obtained from both the ASQ and POTQ is the reflection of the participants' opinion about the system's overall performance. It indicates that the proposed system is highly efficient in selecting the appropriate resolution approach for resolving conflicts in different special case scenarios (refer to 5.1.2).

To analyze the usability of the proposed system and to capture the best discrimination of users, a 7-steps likert scale was used. In the 7-steps scale of the proposed system, the score 1 is the lowest performance (unsatisfactory performance) indicator, while the score 7 is the highest performance (the most satisfactory performance) indicator. In the literature of the usability evaluation, 7-steps and 4-steps likert scales have been frequently used. The score of 5.6 on 7-steps scale, and the score of 4.0 on 5-steps scale are very well known and considered for the system to be satisfactory and acceptable Nielsen and Levy (1994).

Graph shown in Fig. 11 is drawn from ASQs submitted by the participants of the usability study that provides the summary of the overall average scores about different aspects of the experiments i.e. conflict resolution in different scenarios using ACRA, MeCRA and MiCRA. Along with the users' satisfaction in terms of scores in the scales of 1 to 7 , the graph also provides the standard deviation of each approach. It is shown in the Fig. 11 that the highest average score i.e. 6.16 is achieved by "time taken to complete the resolution" aspect of the system to resolve the users' conflicts. The second highest average score i.e. 5.85 is achieved by the satisfaction of the users' with the ACRA. The appropriate selection of ACRA achieved an average score of 5.81 and the mechanisms used in the ACRA to solve the users' conflicts achieved 5.79 average satisfaction score. The lowest average scores were achieved by the satisfactions of the users with the MeCRA and the appropriate selection of the MiCRA, which achieved average satisfaction scores of 5.55, 5.51 respectively.

From the results presented in Fig. 11, it can be concluded that in the proposed system, the users preferred ACRA over MiCRA. This might be due to the fact that MiCRA is the composition of the MeCRA and the ACRAs that involve users directly in the resolution of the conflicts.

In contrast, the results presented in previous research efforts in literature (Otto et al. (2006); Shin et al. (2008, 2010); Wang et al. (2010); Shin and Woo (2009a,b); Shin et al. (2010); Shin and Woo (2005b)) indicate that users prefer (with higher satisfaction rate) the MeCRA over the ACRA in resolving the multi-user conflicts.

The reason might be that the previous researches did not consider different special cases in detecting and resolving user conflicts. Special cases regularly occur in smart (home) environments and without considering the special cases, a system chooses the MeCRA to resolve the conflict. Since, users preferences change as they get any special case, the change in the preference leads the system use the MeCRA to

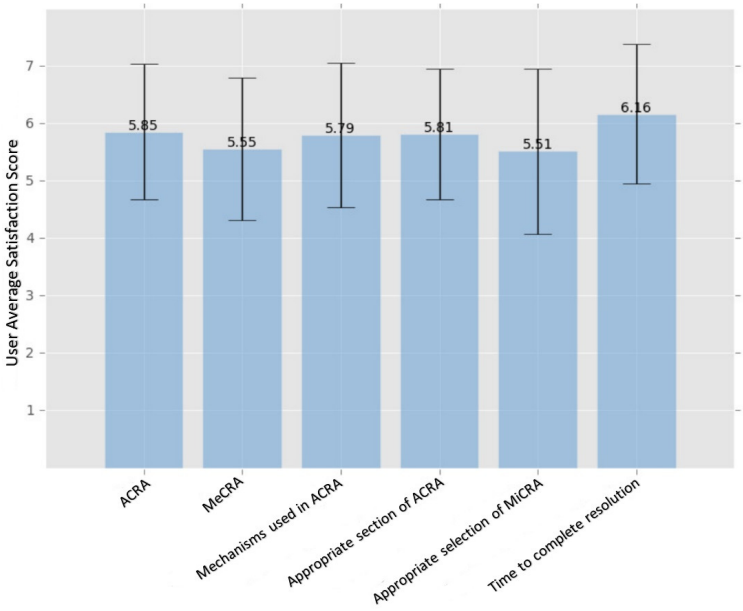

Figure 11. Overall average satisfaction of the users with different aspects of the proposed system.

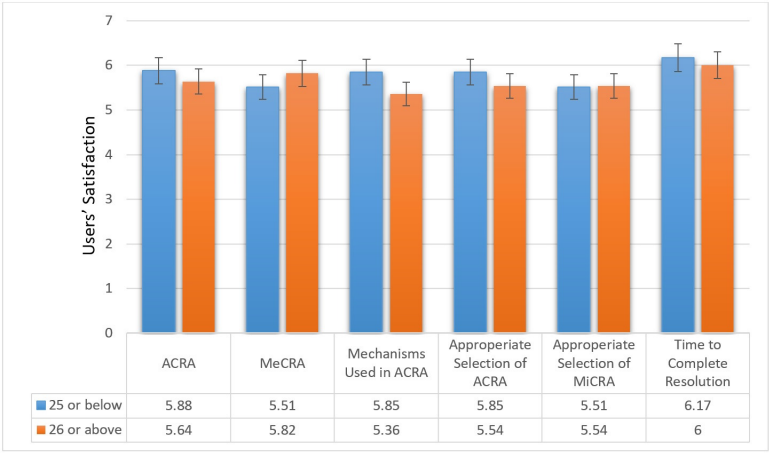

Figure 12. Age group wise analysis of the overall average satisfaction of the users.

resolve the conflicts. However, the special case users can not compromise on their preferences and mediation ends up with the system being allowed to adapt according to the special case user preferences. The same has been addressed through our proposed approach. Age wise group investigation and analysis of the obtained results is also performed. The results are divided into two groups according to the age of the participants. Fig. 12 shows the age wise group analysis of the results produced earlier.

Age wise group results show that the young people who are aged 25 years or below give higher satisfaction for all the aspects of the system, except MeCRA. It might be because the younger participants lived and were raised in the era after Mark Weiser's vision of pervasive computing Weiser (1991), which advocates fulfillment of users' tasks with no or a minimal user distraction.

7 CONCLUSION AND FUTURE DIRECTIONS

Context-awareness plays a central role towards fulfilling the vision of Pervasive Computing outlined by Mark Weiser Weiser (1991), there are various interesting research challenges in the field of context-awareness Chang (2013). Among other research challenges in context-awareness, an issue of user conflicts in context-aware environments is very interesting and being investigated by the research community.

We have identified that detecting and resolving the user conflicts in smart environments is essential. It enhances the system to support and coordinate the activities being performed by multiple users at the same time sharing the same space. Consideration of the special cases (illness, user preparing for examination, etc.) that the different users might have in context-aware environments, is very important in detecting and resolving the multi-user conflicts issue especially in the smart home environments. Despite their importance in multi-user context-aware environments, the existing works by not considering such special situations do not clearly exhibit a comprehensive solution for multi-user conflicts detection and resolution for the context-aware home environments as per requirement of the multi-user activities.

In this paper, we have proposed and implemented a multi-user conflict detection and resolution system that addresses the above-mentioned conflicting situations with the special cases. The system is able to meet the needs of the home members even if they have different conflicting situations that may change from time to time. The evaluation results clearly show that the proposed system is usable, and the intended users are satisfied with the working of the system.

We suggest that the work presented in this paper can be extended in following directions:

- The proposed work on multi-user conflicts targets smart home environments, where only family members are the users of the environments. In this case, solution provided in the form of mechanisms and supporting infrastructure cannot be exploited in other smart environments, e.g., smart office, thereby requiring researching into an issue of multi-user conflicts in other context-aware environments

- Detection of special case conditions (e.g. illness of the user) and automatic update of detected special case conditions in the user profiles: Currently, in the proposed work the information about special case conditions of the users is manually inputted into their corresponding user profiles. We suggest the development and integration of infrastructure that will interact with body sensors (e.g. temperature sensor) to detect special case conditions and update this information into its corresponding profile.

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