Abstract—Off-the-shelf smart devices and applications are expected to be pivotal in the coming need for massive home care. Deployment and integration of these systems in the same household may result in unplanned interactions involving users and entertainment, communication, and health-related devices. These unplanned interactions are a major concern when, for example, communication or entertainment applications interfere with the behavior of health-related devices. We present a novel graph-based approach for representing the expected behavior of off-the-shelf smart devices and applications, their interactions, and for detecting interference in home care settings. Our graph-based interference detection approach is integrated in the Safe Home Care reflective platform, which allows reifying the state of off-the-shelf systems and simulating home care scenarios.

Keywords—Interference-free, Safe Home Care, Ubicomp.

Background

The deployment of pervasive computing applications into a large number of households raises challenges such as security, privacy, economic viability, and interferences or feature interactions (FI) between the pervasive computing applications of the household. Ubiquitous computing environments [1] are becoming common-place in the daily lives of users with Off-the-shelf systems (COTS) like smart televisions, drug dispensers, home automation systems, and entertainment devices supporting users at home. COTS will enable ubiquitous computing to be deployed into a large number of households: these will be purchased spontaneously by users in shops and will not be designed for a specific household. Also, they are not prepared to interwork in the same space without previous managed integration. We assume that COTS in ubiquitous computing has a list of states and behaviors. State corresponds to a particular COTS condition at a specific time, e.g., a phone is ringing or a drug dispenser notifies a missed medicine intake. States provide top-level information of what is happening/occurring on the system. Behavior corresponds to a time sequence, i.e. temporal dependency, between States of a running COTS. For example, when the phone receives a call (s1) it starts ringing (s2), since the user decides to take the call (s3), the phone stops ringing (s4). When the user hangs-off the phone, the call ends (s5). \(<s_1, s_2, s_3, s_4, s_5>\) is a sequence of states that depicts an expected behavior of the COTS\(_{Phone}\). When COTS are in use, they may interact with each other through several media, e.g., concrete environmental variables such as brightness, temperature and sound, or more abstract variables such as the user perception. Interaction has two effects: i) some COTS system states will affect specific media and ii) other COTS states will be affected by these media.

Hence, the natural or expected behavior of COTS, is the behavior the system has when it is deployed in a household without any other COTS or the designed behavior planned by the manufacturer. Thus when combining several COTS in the same place, the expected behavior of an COTS may interact with the natural behavior of others COTS through a shared media, resulting in possible unexpected behavior. There are two types of interaction: i) safe/benign or useful interactions, when two COTS systems affect the same media, resulting in desirable behavior, e.g., two COTS are attempting to increase the living room’s temperature; and ii) unsafe/malign when they produce an undesirable behavior, e.g., two COTS interact constantly with the living room’s lights, one switching it on and the other turning it off. This problem is known as FI [2]. Calder et al. admitted that FI could be considered as an interference between services or features [3]. Here, we consider that each COTS provides a service for the smart-space (SS). The problem appeared first in the telecommunications field, and has been extended to pervasive computing [4]. They propose a solution to ease the integration of independent systems in an intelligent space. They detect resources, e.g., environmental sensors or actuators, that can be shared between systems. Intelligent space manages concurrent access to resources using system priorities and protocol interworking techniques to avoid unsafe/malign interference. Kolberg’s approach focuses on interactions between different systems, not considering the user as a possible source of interference [4]. Also, [5] proposed a framework for describing and reason about the problem of interference in ubiquitous places. We use this framework’s model in our approach. Similarly to [4], we capture the state of the system and its applications. However, we use a graph model representation to implicitly represent the behavior. Moreover, we gather information about the environment and represent the user implicitly in graphs, i.e., possible interactions between COTS.

Approach and Results: FI Detection

Graph representations are well understood and mainly used to provide flexible representation for modeling behavior, e.g., Petri-net, Bayesian Network, Markov Models or UML representations. We adopt a graph representation to represent COTS state and their dependencies, i.e., temporal and media interactions in the SS. A graph node represents a unique COTS state. The expected behavior of each deployed system is represented into the Graph of Expected States (GoES) (see Figure 1a). This approach is extensible to several COTS systems and facilitates the addition of new element graphs or state sequences. During simulation [6], we capture the sensed states of all COTS in the Graphs of Observed States (GoOS) (see Figure 1b). GoES represents how systems should

Authors are with the INESC TEC, FEUP, University of Porto, R. Roberto Frias, 378, 4200-465 Porto, Portugal; email: {csoares,rmoreira,rmorla,jtorres,pmsobral}@inescporto.pt.
behave without interferences and the GoOS represents the current/observed system behavior. In Figure 1a, all possible behaviors are: \( S_1S_2 \), \( S_3S_4 \), \( S_5S_6S_7S_8 \) and \( S_6S_7S_9 \). We also consider that states \( S_3 \) and \( S_5 \) will affect, respectively, medium \( m_1 \) and \( m_2 \). States \( S_7 \) and \( S_9 \) will be affected, respectively, by medium \( m_1 \) and \( m_2 \). Misbehavior Detection: Intra-system Approach: this approach tries to identify systems with an affected behavior. The intra-system approach has three steps [7]: i) classify – creates a graph with observed COTS states; ii) pruning – based on the knowledge of expected state, identifies unexpected states; and iii) reasoning – identifies unexpected behavior or malfunctions using the pruned results. For example, assume that the current GoOS sequence is \( S_3S_6S_5S_7S_1S_2 \) (see Figure 1b). Based on these two graphs (Figure 1a and 1b) the pruning algorithm removes the complete GoES path sequences from the current GoOS: \( S_3S_5 \) and \( S_1S_2 \). The result set is: \( S_6S_7 \) because as expected the behavior \( S_6 \) or \( S_9 \) was not observed; this parsing algorithm was named: State Pruning Algorithm (SPA). SPA extracts all expected state sequences from the observed behavior; when the result of the SPA algorithm is not an empty sequence of states, then it assumes: i) FI occurs and was identified; ii) state sequences or malfunctions were not captured in the existing GoES (poor knowledge model), which should be re-drawn. Interactions Detection: Inter-system Approach: we identify the interactions using an inter-system analysis. For example, in Figure 1a, we identify a priori two possible interactions. First, interaction happens when the state \( S_3 \) on COTS1 occurs, affecting the medium \( m_1 \); and respectively could affect/interact with the state \( S_7 \) on COTS2. The second interaction happens when the state \( S_5 \) on COTS1 occurs, affecting the medium \( m_2 \); and respectively could affect/interact with the state \( S_8 \) or \( S_9 \) on COTS2. This approach involves two steps: i) parse the model - identify all dependencies of all COTS’s states with the media (COTS state to media,) and ii) model search - will identify relations between COTS’s states through a shared medium (COTS state to COTS state). Misbehavior and Interaction Identification: Combined Approach: combined approach is a merge of intra and inter-system. We take as input all the possible/ offline interactions that could occur between the COTS. We apply a filter chain: i) online interactions, ii) misbehavior identification, iii) spatial dependencies (under work) and iv) temporal dependencies (under work). First filter will remove all the offline systems during the observation. Second filter will identify all the possible causes of an FI using intra-system. Hence, we know, which medium could have been affected and identify, which online COTS has affected it. We identify possible real-time COTS causes of FI subsequently try to prevent them to occur. Also, the other subset, of this filter, returns all the possible interactions that occur through a shared media, that do not affect the expected behavior of an COTS. In this particular case, the type of interactions could be safe/benign, and may not affect the expected behavior of the COTS. Usually, this does not mean that they were interacting in a good way, e.g., consider a system is switching on the light and the other is turning off the light; both are working as expected, but at the same time they are manipulating repeatedly the light on an improper way, causing some inconvenience to the user. The proposed approach: i) detect misbehavior of individual COTS in the household, ii) detect a priori potential interaction between several COTS through common shared media, and iii) detect causes of misbehavior occurrences in the household (using identified anomalies in i) and online potential FI (using subset from ii) the observed COTS states are introspected through physical sensors (e.g., sound, presence, temperature and brightness sensors) and concrete SNMP-based agents (e.g., ongoing VoIP call, missed medicine intake, etc.). We assume, that we previously know the expected behavior of COTS; the introspection are not subject to noise, i.e., hence, we are able to determine all state occurrences of each COTS. We evaluate our interference detection algorithms in different interaction scenarios where several COTS systems interact together in the same home SS [7]. We are extending our approach to improve Fd detection and resolution using new kinds of filters: spatial and temporal. Moreover, our future work will also focus on distinguishing the safe and unsafe FI and finally to perform usability tests with elderly and also caregivers.

Table I

<table>
<thead>
<tr>
<th># Scenarios</th>
<th># Outcomes</th>
<th>Feature Interaction Detection Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Intra-system</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
<td>53%</td>
</tr>
</tbody>
</table>

REFERENCES


