Resource-Aware Smart Home Management System by Constructing Resource Relation Graph

Ji-Yeon Son, *Member*, IEEE, Jun-Hee Park, Kyeong-Deok Moon, Young-Hee Lee

Abstract — *With the advent of smart home devices including Smart TV or smart appliances, home becomes smarter. Smart home is a complex environment where heterogeneous smart devices and appliances are connected to each other to provide various smart services. As the home environments become smarter and more complex, the need for an effective managing mechanism with minimum user's intervention is growing. However, just only putting together all the individual information of each resource is not enough, since it is very hard to catch out overall home situation without the relation information between the managed resources. In this paper, we propose a resource-aware management system with hierarchical smart home resource model, using the home context information which defines the information convergence model of heterogeneous home resources and builds a home knowledge by constructing a resource relation graph. The proposed system can accelerate deployment of advanced future smart home service features such as context-aware dynamic service composition, autonomous fault management systems. In addition, it allows cost effective remote maintenance system with highly convenient manageability. We implemented the prototype system of our proposed architecture and evaluated the performance on the query response time of home resources and relations in a real environment. Results showed that it has acceptable performance for navigating or control of home information and excellent improvements in terms of relation based search. We anticipate that the proposed system will bring the huge benefits not only to the consumers, home network service providers but also to the home network maintenance companies in terms of ease of management, and diagnostic effectiveness.*[1].

Index Terms — Home Resource Model, Smart Home Resource Management, Resource Relation Graph.

I. INTRODUCTION

With the advent of the smart devices including Smart TV and smart pad, the various types of service for smart home are expected to appear in the market. As the home environments become smarter and more complex with a flood of smart resources, the need for an effective management mechanism is growing for home resources. For smart home management, it would need rich information on home resources in order to analyze and understand overall smart home environment just as the human brain analyzes and determines comprehensively the situation that he or she looks at, hears, and feels. The information types of home resources can be divided into two categories, logical information such as the functions, status, control methods of device or service, and physical information such as building architecture, device location, and physical network topology. Most of home network middleware technologies like Universal Plug and Play (UPnP), LonWorks are restricted to manage only logical information in order to connect device to network automatically and provide functions for discovery and control of device which user wants. On the other hands, Building Information Model (BIM)[1], which is used for the design of building, presents only the information of static physical objects determined in the process of constructing such as wall or room, electric cable or pipe. However, in order to resolve home network faults occurred in complex environments and understand overall home situation, it is necessary to know the dependencies between resources [2] to determine a correct snapshot on the current status of home. It can be achieved by the total information associated the physical information such as the location of resources, network topology structure and the logical information such as resource control protocol, support functions, and resource usability.

This paper proposes a resource-aware smart home management system that manages the physical and the logical information dynamically for changing the status of device and the relations between resources in a smart home environment. The proposed system allows managing home to be more smart and autonomous by integrating the logical and the physical information. However, just by putting together of individually collected information of resources, it is difficult to understand overall home situation because intricate inter-relationships among the resources cannot be easily derived and defined. To determine the current home situation comprehensively, this paper analyzes the relations between home resources of various types. Using the relation information, the proposed system constructs a resource relation graph. The generated relation graph enables not only to trace the root cause of home network faults, but also to make relation-based search or control possible.

The resource-aware smart home management system consists of three layers. Interoperability Layer provides the

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interoperability to heterogeneous resources. Secondly, Resource Core Layer analyzes the relations between resources with various types and constructs the relation graph. Lastly, Resource Service Layer supports dynamic service compositions or fault handling services based on the graph constructed at Resource Core Layer.

The outline of this paper is as follows: Section 2 presents the related work and Section 3 defines home resource model. In Section 4, we describe the proposed architecture and followed by implementation details in Section 5. Section 6 explains the experimental results and finally makes a conclusion in Section 7.

II. Related Work

Several approaches have been presented for smart home resource management. Most of them are individual resource-centric management approaches such as device, network or service management. As a discovery method of heterogeneous home devices adopting each their own standard, T. Tanaka proposed the hybrid method which combines the active detection and the passive detection [3]. To overcome heterogeneity of devices, X. Gao proposed a generic information modeling (GIM) based on shared information data and common information model [4]. GIM defines management objects of each managed device and specifies the relationship of management objects from three different dimensions. But, aforementioned methods handle only the relations focusing on device management. M. Merabti also addressed the issue of device interoperability on managing distributed networked appliances in home network. The study proposed a middleware which consists of the service composition framework and technology adaptors used to communicate with devices [5]. For wireless home network management architecture, HOMEPLANE was proposed to support for high quality of service [11]. For service management of home, I. W. Lee addressed openness and scalability issues in continuous provision and upgrade of home services [6]. To solve the provisioning issue of home network services, T. Yamazaki proposed an intermediate service platform having a two-layer structure [7]. Similarly, F. J. Villaneuva proposed an OSGi-based service management framework including a tool chain [8].

For autonomic computing, policy-based management approaches have been proposed [9][10]. C. Schilling addressed the several features of wireless sensor network such as tens of thousands of network elements and the physical restrictions of the sensor nodes. Considering the restrictions of WSN, they proposed the MANNA policy-based management architecture. It consists of three management dimensions as functional areas, management levels, and network functionalities, to be the basis for a list of management functions. E. Topalis proposed an autonomous network management architectural model to control and monitor information of home automation network called the manager-agent model [12]. The information is acquired either on request by the management device or on event reporting initiated by a managed device. As similar approaches to achieve autonomic management, C. Y. Leong proposed a rule-based framework for heterogeneous subsystems management in a home environment [13].

Event-based management approaches detect the resource relations by an event correlation analysis. Event correlation is used by network and system administrators to make sense of a mass of network, system and service events [14]. M. Hasan [15] proposed a conceptual model for describing causal and temporal relationships between network events to determine the root cause of faults in network management. J. P. Martin-Flatin reviewed general lessons learned in event correlation. They addressed the limitation of event correlation methods for fault management since the integrated management of networks, systems, and services does not rely solely on event correlation. As they addressed, the event-based approaches can too depend on the occurred events and increase the complexity of event analysis for integrated management. Similarly, as a graph-based approach of service dependencies, C.Y. Lin proposed the automatic service activator/deactivator on the OSGi platform [16].

On the other hands, several context-aware management methods were proposed to provide intelligent services by changing of home situation. C. C. Hsu proposed a home resource management system with multiple inhabitants to avoid resource usage conflict [17]. The system uses home ontology to cover the characteristics of available resources such as living space partition, energy consumption. Based on the ontology, they use case-based reasoning to predict inhabitant resource requirement and use agent negotiation to find a common consensus resource allocation plan. Similarly, an ontology-based framework was proposed by E. Exposito for autonomous QoS management [18]. The framework integrates in the same semantic space both users and services' QoS point of views. They also presented a decision model based on this ontology aimed at optimizing the provision of QoS driven by the user preferences. As other context-aware management approaches, A. Roy proposed a predictive framework for location-aware resource optimization in smart homes [19][20][21]. They tried to minimize the uncertainty through optimal learning and prediction of the inhabitants' movement (location) profiles captured in the symbolic domain. The prediction is used to automated device control and proactive reservation of resources along the users' most probable locations and routes. The existing works mentioned above have the limitations of understanding entire home situation since manage only one of the logical or the physical information of home resources.

III. Home Resource Model

Home resource model is an abstract, formal representation of objects in home that includes their properties, relationships and the operations performed on them. The proposed system builds a home knowledge by analyzing the relations between objects based on home resource model. In doing so, it provides the basis of convergence model to manage the attributes and the functions of heterogeneous resources in various domains.

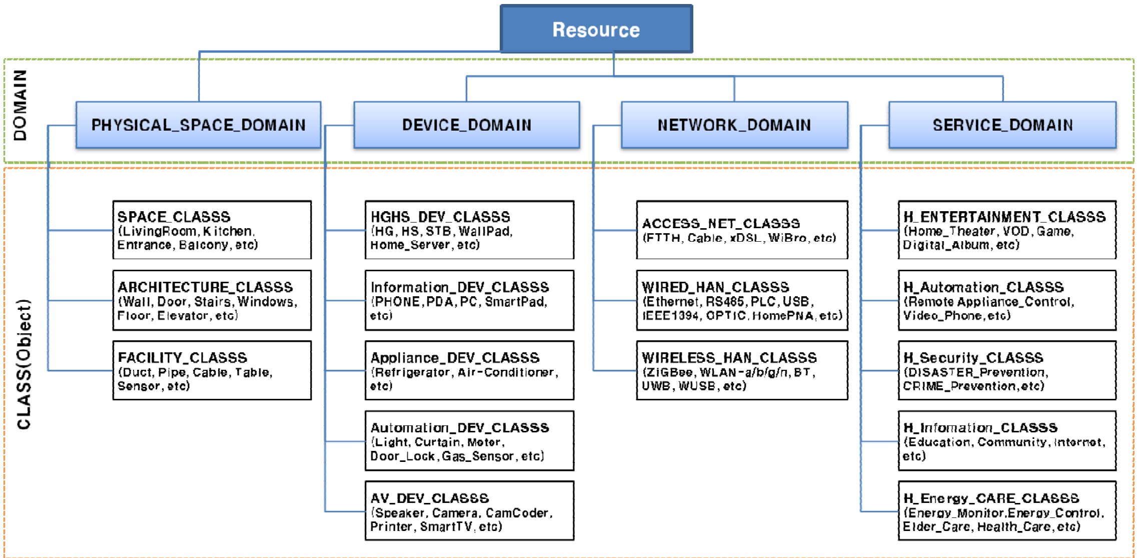

Fig. 1. Hierarchical Structure of Home Resource Object

A. Definition of Home Resource Object

We define all of objects constituting a smart home as home resource objects. They represent managed objects which can be used to accomplish home network services. In another words, the resource object can be not only device or service connected to home network, but also the physical spaces of house or network links. They include properties, status or control methods of resources.

A resource object has a one-to-one correspondence with a real-world component constituting home network services. It is created and managed using gathered data from one or more resource information providers. It has a hierarchical structure as shown in Fig. 1: domain, class and object.

The resource objects consist of common information part and domain-specific information part. The former contains common attributes provided by all of resources that are of a resource identifier, resource name, and resource type field. The latter contains the domain-related data and has a variable size depending on the domain type as Fig. 1. For example, in case of device domain, it includes the list of functions device support, physical address, current status of device, and so on. On other hand, in case of network link domain, it includes some properties only related to network domain such as topology, link traffic status or bandwidth information.

B. The Definition of Home Resource Relation

The home resource relation is an object which specifies a relationship among resource objects. In this paper, it only deals with the inter-domain relationships in order to avoid that complexity of a resource relation graph increases. The intra-domain relationships among resource objects are covered by the domain-specific information stored in resource objects. The resource relation is represented as *<relation identifier, relation name, relation type, resource identifier of the source object, a list of target resource identifier>*. The relation types are classified as LOCATE type to contain the physical location of resource, CONNECT type to show the connection to the network, and BIND type to represent the association between resource objects. As other relation types, there are INSTALL type, RUN type and EXECUTE type.

IV. HOME RESOURCE MANAGEMENT ARCHITECTURE

A. Management Architecture

The proposed system, namely Resource-aware smart home management system, provides an autonomic service and environments for dynamic resource composition by associating the features of logical and physical resources.

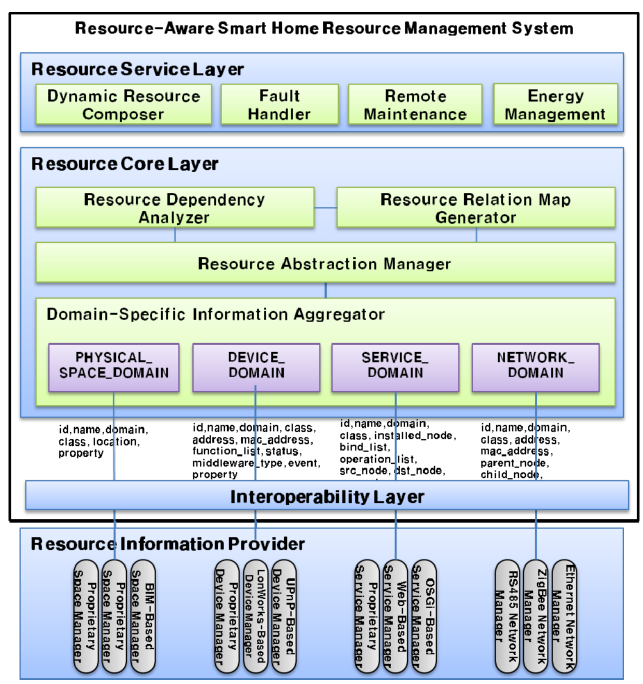

Fig. 2. Smart Home Resource Management Architecture

As depicted in Fig. 2, the proposed system consists of Interoperability Layer, Resource Core Layer and Resource Service Layer. Interoperability Layer provides the interoperability to overcome the heterogeneity of resources. Resource Core Layer abstracts resource objects based on the collected data, and analyzes the relationship between objects. It also constructs a resource relation map. The Resource Service Layer are domain-specific frameworks to support particular functions such as fault processing or dynamic resource composer using the resource relation map information in the core layer.

B. Domain-Specific Information Aggregation

The proposed system defines each domain by the resource type. For each domain, it aggregates the status data from resource information providers for understanding the current home situation. One or more resource information providers can exist according to the adopted technologies such as network or middleware. To get the architectural information of home, we use BIM which is a three-dimensional digital representation of necessary information in the whole processes of design, construction, and maintenance. BIM has advantages to allow for extracting different views such as quantity estimation, calculation and automatic 3D model generation from a building model for drawing production and other uses. BIM includes several properties of building components and facilities such as electric wiring, cables or pipes not only for geometry or architectural information of building. In order to get the physical space and facility information necessary for home resource management, the proposed system creates and manages BIM database. It is extracted from a BIM file including enormous amount of building information. BIM has limitations of monitoring resource information with dynamically changing status since it mainly handles static information determined in a design or construction process. The resources such as a device or a service can be changed at any time with living inhabitants. Therefore, the proposed system uses BIM database as one of the data source for obtaining static information of physical space. It provides a mashup model which aggregates dynamic resource information such as device or network links and integrates it with BIM.

C. Resource Abstraction

In order to handle heterogeneous resources having different properties according to each domain, we abstract them to resource objects defined by home resource model as shown in section III. Using these resource objects, the proposed system allows to construct the resource relation map and to maintain it in a consistent way.

D. Resource Dependency Analysis

As mentioned before, it is impossible to determine home situation exactly using only aggregated resource information from each domain without any user's intervention. Therefore, the proposed system analyzes the relationship between resources and creates the mapping information.

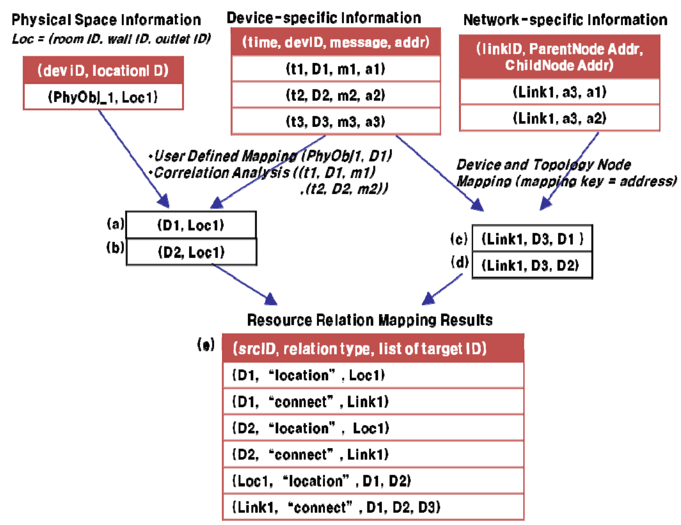

Fig. 3. Resource Relation Mapping Process

Fig. 3 illustrates the mapping process of resource relations between domains as an example. The location in a physical space domain is identified by (*room ID, wall ID, outlet ID*). *PhyObj1* is an instance of object ID allocated by the identification method of physical space domain. The mapping relation of *PhyObj1* can be defined by user. Through the explicit mapping by user, *(PhyObj1, D1)*, it knows that the location of *D1* is *Loc1* (a). When *D1* is a metering socket device, it can estimate that *D2* is plugged into *D1* socket by the correlation analysis between (*t1, D1, m1*) and (*t2, D2, m2*). Therefore, as (b) in Fig. 3, we are able to determine that the location of *D2* is *Loc1* which is the physical location of *D1*. On the other hand, the devices in device domain can be mapped with the parent or child node of topology links in a network domain. Using mapping key, as (c) and (d), we can come up with the mapping relation that the parent node of *Link1* is *D3* and its child nodes are *D1* and *D2*. By the above resource dependency analysis through (a) to (d), we arrive at the mapping results (e).

E. Resource Relation Map Generation

Using derived relationship between resources, resource relation map generator builds a home resource map of a graph model that represents the relationship among the home resources. The resource relation map consists of one or more resource map entities. A resource map entity is an instance of a relationship among objects consisting of at least two resource objects. Fig. 4 illustrates an example of home network resources. Fig. 5 is a resource relation map, which reflects the physical resource configuration with an example in Fig. 4.

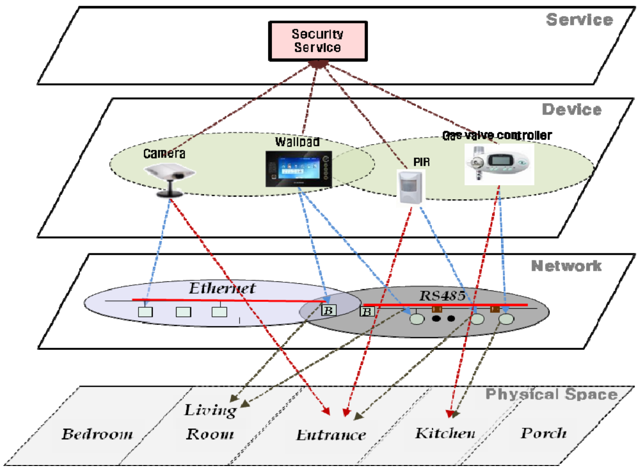

Fig. 4. Example of physical configuration

In Fig. 5, a resource object and a relation are represented as a rectangle node and a circle node respectively in a resource map. The label of the relation represents a relation identifier. An edge is directional, starting from a source relation object to one or more target resource objects. Fig. 5 shows that the security service binds to camera, Wallpad, PIR (Passive Infra-Red), and gas valve controller. The camera and Wallpad gateway are connected to Ethernet installed in the living room. PIR, gas value controller and Wallpad gateway are also connected to RS485 network link. Camera and PIR are located at the entrance and gas valve controller is located at the kitchen.

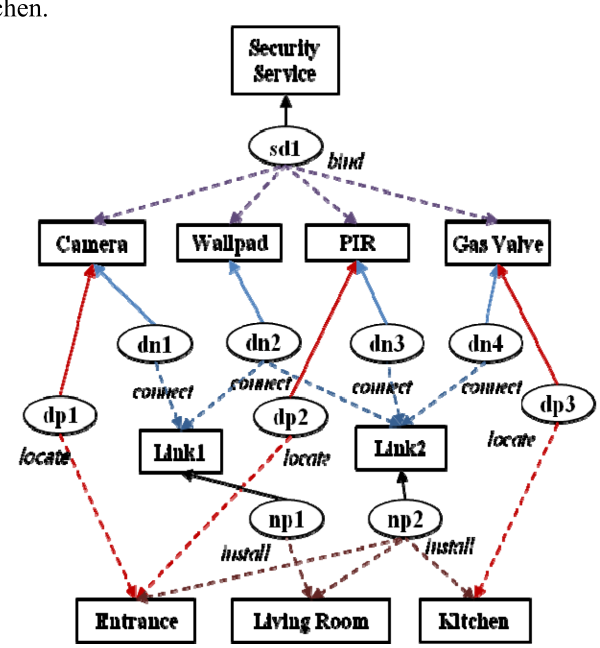

Fig. 5. Example of resource relation graph

Fig. 6 is a resource relation map constructing algorithm based on the analyzed inter-domain relationships between resource objects. Using this algorithm, the proposed system provides information on home resources and their relations. In addition, when a home network fault occurs, the resource relation map can be used to trace the root cause of the fault.

Algorithm : **ConstructResourceRelationMap** *(rolist)*

Input: *rolist* = {*RO(d, j), 0<=d<D, 0<=j<N*$_d$}
// *D* domains, N_d maximum number of resource objects in each domain *d*
Output: Resource Relation Graph *G=(V, E)*

```
V={Φ }, E={Φ }
// for each resource object in resource object list
FOR EACH ro ∈ rolist
  V = V U ro
  rel_list = getRelationFromBaseInfo (ro)
  // rel_list = { REL (src_ro, relation_type, target_ro_list) }
  IF exists rel_list THEN
     FORALL rel ∈ rel_list // for each relation of the resource
  object
       rel_type = getRelationType ( rel )
       FORALL ro' ∈ target_ro_list of rel
          Create edge e from ro to ro' with rel_type
          E = E U e
       END FOR
     END FOR
  END IF
END FOR
RETURN G
```

Fig. 6. Resource Relation Map Generating Algorithm

V. IMPLEMENTATION

We have implemented a prototype system for resource-aware smart home management architecture on the following test bed environment. The test bed environment comprises the resources managed under the typical unit for household as depicted in Fig. 7.

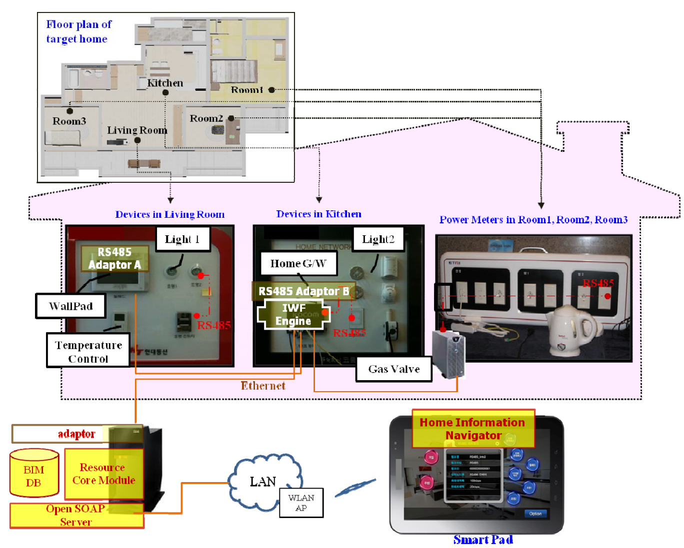

Fig. 7. Physical and software configuration of prototype system

As shown in Fig. 7, each layer in Fig. 2, Interoperability Layer, Resource Core Layer and Resource Service Layer are implemented on each different system. For Interoperability Layer, we implemented an interworking engine and adaptors according to the KS X 4501 which is the Korean home network interworking protocol standard. The interworking function (IWF) engine provides the XML rule-based message translation between multiple home network adaptors. The adaptors formulate a standard message format from their own middleware message format and transmit it to IWF engine. We implemented RS485 adaptors, BIM adaptor, and a null adaptor for the resource core module of the proposed system. Each adaptor was installed on Wallpad, home gateway, and desktop PC as depicted in Fig. 7. To get the home architectural information, we used a BIM database as a physical space information source. Resource Core Module is the main software module of the proposed system and is the implementation prototype of Resource Core Layer. It was developed in Desktop Linux (Fedora 11) on home or apartment complex server. The generated resource map information in the Resource Core Layer is provided by Web Services Description Language (WSDL) based open interface defined in Simple Object Success Protocol (SOAP) server. It enables remote access of home information using smart phone or smart pad. For Resource Service Layer, we implemented a home information navigating service using smart pad to search or control home resources and their relations.

Fig. 8 is a sequence diagram of all layers in the proposed system for initial setup and the searching step of home resources of target domain related to the specific resource.

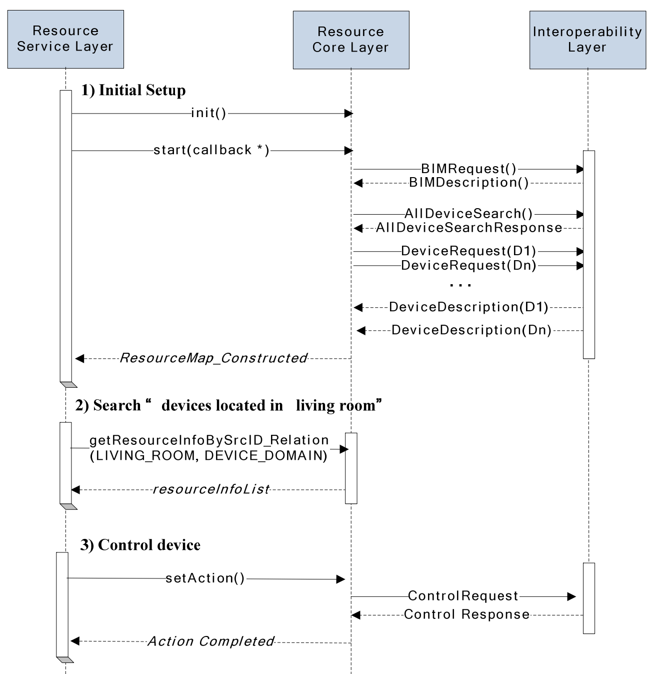

Fig. 8. Sequence diagram of the proposed system

As shown in Fig. 8, the initial setup is completed by receiving the callback event of resource map construction generated by analyzing home resource information aggregated through Interoperability Layer. Upon completion of the initial setup, it becomes possible to search and control home resource or relation information. Our system allows searching not only home resources, but also their relations while the existing management systems provide only query status or properties of home resource. It allows relation-based search or control such as "devices located in the living room", "devices connected to RS485", or "networks installed on the living room. Fig. 8 shows the search process of device resources related with "Living Room" resource. The home resource or relation information obtained by querying is presented by the following schema as shown in Fig. 9.

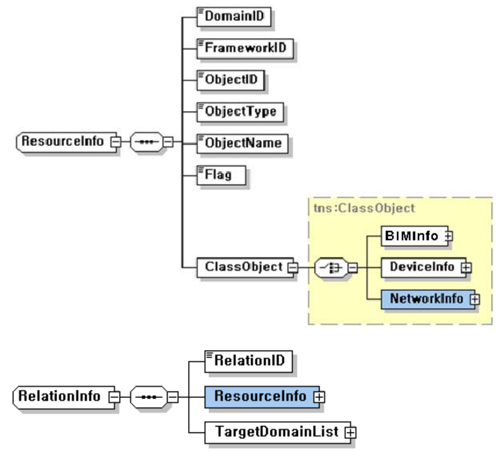

Fig. 9. WSDL message description schema of resource and relation information

Fig. 9 shows the WSDL based message description schemas of home resource and relation information. Using this schema, mobile clients such as smart phone or smart pad can navigate and control home resources remotely. Fig. 10 depicts the operation of home information navigating service on smart pad. It shows the recursive process of relation-based search and browsing.

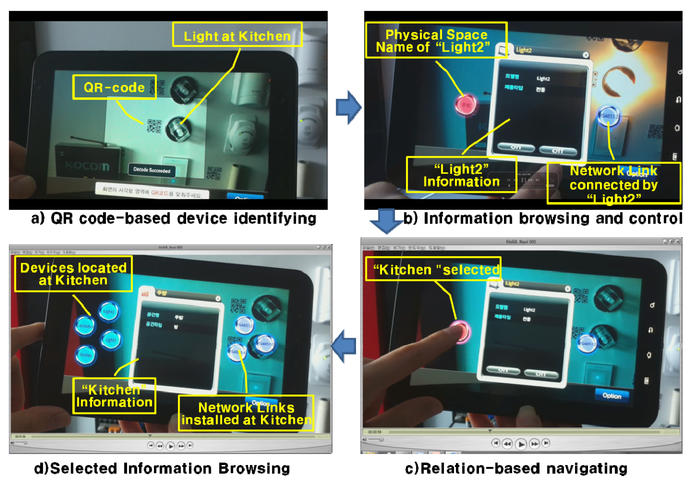

Fig. 10. The process of home information navigating on smart pad

As shown Fig. 10, the home navigator identifies a device using a two-dimensional matrix barcode (a). After obtaining the device ID through the barcode, it displays the indentified device name and its relation information via the SOAP server (b). Fig. 10 (b) shows the "light2" device information and the physical space name of the light device, "kitchen", with a red circle on the left side. On the right side, it shows the connected network link name of the light device, "RS485", with a blue circle. In addition, it is possible to switch on or off the light device "light2". If user pushes the red or blue circles on the display, the navigator transmits a query on the selected resource to the SOAP server and browses the related information again. In Fig. 10, the user selects the physical space "kitchen" (c). Fig. 10 (d) shows the selected kitchen information and devices located at "kitchen" on the left side, and network links installed at "kitchen" on the right side. The relation based navigating service in this prototype can be offered only when the relation map information is constructed among the physical space, device, and network.

VI. EXPERIMENTAL RESULT AND ANALYSIS

To evaluate the effectiveness of home resource management mechanism, we measured the response time for home information query. It was performed on a web page in the prototype system in Fig. 7. By measuring the response time of home resource and relation-based search, we can see that the proposed system provides smooth home information navigating and control. TABLE I shows the number of home resources which is created and managed in Resource Core Layer for experiments.

TABLE I
MANAGED RESOURCES FOR EXPERIMENTAL SETUP

Domain	Managed Resource Object	Number of Resources	Number of Relations
Physical space	Room 1-12, wall 1-62, power port 1-14, door 1-8, handrail 1-4, window 1-8, floor1, furniture 1-19,…	268	20
Device	Light 1-2, temperature control, gas valve, Wallpad, home gateway,, media server, media renderer, power meter 1-4	12	12
Network link	Ethernet link 1-6, RS485 links 1-14	20	3
Total		300	35

As shown in TABLE I, 300 home resource objects and 35 relations were used for experimental setup. TABLE II shows the average response time and the standard deviations of 10 response times on each command request.

TABLE II
COMMAND REQUEST/RESPONSE TIME

Command Request	Avg. Response Time (sec)	Standard Deviation
1) initial setup	55.6	0.51
2) get all *ResourceInfo* by domain	3.59	3.51
3) get *ResourceInfo* by ID	0.78	0.16
4) get all *RelationInfo*	3.96	0.20
5) get *RelationInfo* by relation ID	0.96	0.45
6) get *ResourceInfo* of target domain related to source resource ID	1.32	0.46
7) control device	1.7	0.48

In TABLE II, the testing was conducted using web pages and the results were displayed with a WDSL type message format. For asynchronous requests such as 1) initial setup or 7) control device, we measured the response time as the receiving time of callback event. The initial setup was completed by a receiving "resource map constructed" event as shown in Fig. 8. The initial setup took almost 1 minute because it had to wait enough time to receive all of resource description responses from multiple information providers by each domain. Once the resource map was built in Resource Core Layer, it is possible to respond to the user-initiated requests. The response times of 2) ~ 6) depended on the number of resource objects that should be contained. Especially, 2) resulted in high standard deviation because the variation of number of resources was large according to domain. The above experimental results showed that the proposed system can provide relation-based navigating or control service with a reasonable response time.

VII. CONCLUSION

This paper proposes a resource-aware smart home management system that accumulates home knowledge by analyzing and mapping the relations between objects based on the home resource model. It provides the basis of converging model for managing heterogeneous resources in various domains. To integrate home resources, the proposed system aggregates the physical and the logical resource information and abstracts it to resource objects. Between the resource objects, resource dependency is analyzed and constructed to establish a resource map. The generated resource map can be used for tracing the root cause of home network faults, dynamic service composition, or relation-based search and control.

Resource-aware smart home management system proposes an effective mechanism for managing home resources and presents a base architecture for autonomic services. The prototype system implemented in this paper was set up using the unit household with a testbed environment in order to access home resources by smart home devices inside or outside. According to the experimental results, we showed that the proposed system yields acceptable performance for relation-based navigating and control services.

In future work, we plan to develop a fault diagnosis and processing method based on the proposed system. It will help to prove how the resource relation map obtained from the proposed system is useful for smart home management and services.

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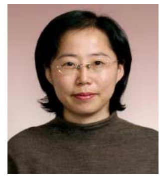
BIOGRAPHIES



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