Adopting Model-Driven Development for Integrated Services and Appliances in Home Network Systems

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Abstract

The technology of a home network system (HNS) allows integration of several kinds of home appliances to provide a user with value-added integrated services. Development of the integrated HNS services requires implementation of the appliance components (with APIs) and the services, according to each home-network environment. There are various implementation standards such as DLNA, ECHONET, OSGi and Jini for the HNS applications. Therefore, even if a developer can choose the optimal one, it's very difficult to develop the integrated services by composing a new HNS implementation. In this paper, we propose a model-driven development of integrated HNS service applications. In our former manuscript, platform-independent design language for verifying HNS service scenarios was proposed. Our model-driven development method uses this design language as a meta-model of integrated HNS services. By model transformation to concrete implementation together with verification by SMV(Symbolic Model Checking), productivity and quality of this kind of HNS applications are improved.

1 Introduction

A *home network system* (*HNS*) is an emerging domain of ubiquitous applications that intends to provide users with smart and convenient *home services* [12][18]. A HNS consists of multiple *networked appliances*. The appliances include general household appliances and sensors, such as TVs, DVDs, ventilators, air-conditioners, thermometers, which are connected to LANs at home. Each appliance usually exhibits a set of *device control interfaces* (i.e, *APIs*) to the network, by which the users or external software agents can control the appliances via the network. Each appliance

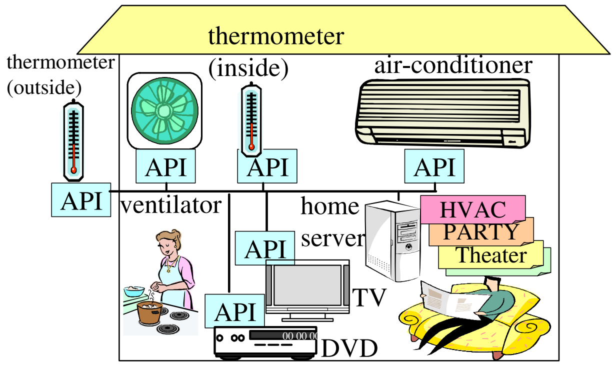


Figure 1. An Example Home Network System

communicates with others through an underlying *HNS protocol*.

An advantage of HNS lies in *integration* of features of multiple appliances via the network. For instance, integrating a thermometer, a ventilator and an air-conditioner would implement energy-saving air-conditioning service, typically called an HVAC service as illustrated in Figure 1. Similarly, orchestrating a TV, a DVD player, speakers, lights and curtains would implement *Theater services*, where a user can watch movies in a theater-like atmosphere through a single point of operations. Thus, integration of appliances realizes various value-added services [14][15]. We call such services *integrated HNS services*.

Multiple implementation platforms are currently being proposed to develop such HNS applications [9], such as DLNA [3], HAVi [7], ECHONET [4], Jini [10], OSGi [17], and X-10 [22]. Developers need to choose the optimal combination of HNS implementation standards for each HNS application. Such complexity on heterogeneous platform erodes quality and productivity of application development. Especially, in integrated HNS service, service quality, reliability, and maintainability are critical subjects, because this kinds of applications are closely related to a user's everyday life.

Software quality, such as portability, maintainability and reliability are usually guaranteed only in a specific platform, since HNS applications are usually developed based on a single implementation platform, conventionally. As a result, several problems, such as quality deterioration and increase of development cost, may be caused by the complexity of multiplatform environment.

Therefore, in the domain of HNS applications, the mechanism, which does not depend on a specific platform, of verifying the service quality and reliability, is important. Development framework which supports various implementation protocol and generation of actual implementation artifacts will greatly improve the quality and productivity of the created HNS application.

In this article, we propose MDD(Model-Driven Development) framework to support verifying platform-independent model of integrated services with SMV(Symbolic Model Verifier), and to generate actual implementation artifacts semi-automatically. Our MDD framework adopts an application architecture [8] which can integrate multiple HNS standards together. This architecture provides abstraction and encapsulation of appliance features in service component layer. The exhibited features can be accessed with common interface from external. The combination of the features is published as an integrated service.

In our MDD framework, we apply rule-based transformation to platform-independent model to appliance components and integrated services. In an appliance component, since a skeleton independent of device/middleware is directly generated, developers implement only device/middleware-specific parts. In an integrated service, since the whole of implementation artifacts are generated automatically. It becomes possible to develop high-quality integrated HNS services at low-cost by combining verification process and code generation process.

We actually implemented a HVAC service with our MDD framework. System model which defines appliances and home environment in HNS, is transformed to a program skeleton of each appliance component for Java Web services. Service model which presents concrete scenarios for integrated services, is transformed to an integrated service implementation for Perl script. We show a part of generated source codes in Section 4.

In Section 2, we state about the application framework which can use several HNS standards, and integrated HNS service models which does not depend on any platform and can be verified and model checked by SMV. In Section 3, our MDD framework and transformation rules from service and system models to actual implementations are denoted. In Section 4 and Section 5, we introduce actual development about HVAC service. Service model and system model of HVAC is inputted to our MDD framework, and outputted actual implementation artifacts.

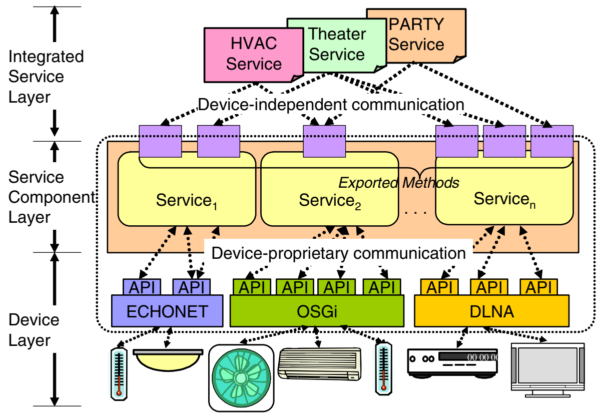


Figure 2. Integrated HNS Service Application Architecture

2 Integrated HNS Service

As shown in Section 1, there exists various middleware implementation standards for HNS application. In [8], we proposed a new HNS application architecture for integrated service illustrated in Figure 2. In this architecture, the service component layer aggregates the features of the appliances as a set of *services*, and exports the services to the network with *exported methods*. Such self-contained and abstracted appliance features can be accessed from external in a device-independent manner without considering platform complexity.

Moreover, in [11], we established platform-independent models verifiable with SMV(Symbolic Model Verifier [13][20]) for integrated HNS services. HNS applications need to be verified carefully because they are related to our daly-life (For instance, wrong invocation of appliance feature whose power supply should be turned on beforehand). Such wrong integrated service in HNS may exert danger on a user. So it is important to verify integrated HNS service.

In the following Section 2.1, we state about some important definition to express integrated HNS service model. The full specification is found in [11]

2.1 Model of Integrated HNS Services

Our integrated HNS service model consists of a system model and a service model. Figure 3 is an example of the system model which denotes a part of constitution of the

```
SYSTEM my_home {

  TYPEDEF
    tPower       {ON,OFF};# power
for all appliances
    tAC_Temp     {18..28};# for
AirConditioner
    tAC_Mode     {COOLING,FAN};
    tTemp        {15..40};#
Temperature

  ENVIRONEMT env {
 # Environment around the room
   PROPERTY
          tTemp Temp_in;
          tTemp Temp_out;
}
 APPLIANCE AirConditioner {
    PROPERTY
      tPower   power:=OFF;
      tAC_Temp tempSetting := 24;
        #Temperature Setting for
air conditioner
      tAC_Mode modeSetting :=
COOLING;
        #Mode Setting for air
conditioner
    METHOD
      void ON() {
        PRE     true;
        POST    power=ON;}
```

```
void OFF() {
        PRE     true;
        POST    power=OFF; }

void setTemperature(tAC_Temp temp) {
        PRE     power=ON;
        POST    tempSetting=temp;
        ENV_W   env.Temp_in;}
      void setMode(tAC_Mode mode) {
        PRE     power =ON;
        POST    modeSetting = mode;
        ENV_W   env.Temp_in;}
    }
 APPLIANCE Thermometer_inside {
    PROPERTY
      tPower power:=OFF;
      tTemp  currentTemp;
    METHOD
      void ON() {
        PRE     true;
        POST    power=ON;}
      void OFF() {
        PRE     true;
        POST    power=OFF;}
      tTemperature measureTemp() {
        PRE     power=ON
        POST    currentTemp=env.Temp_in;
        ENV_R   env.Temp_in;
        RETURN  currentTemp;}
  }
}
```

Figure 3. Example of System Model Description

```
DEPLOYED_SYSTEM my_home;

SERVICE HVAC(tAC_Temp user_temp){

  VAR
    tTemperature Ti_temp,To_temp;
     #Local variable
  APPLIANCE
    AirConditioner,
Themometer_inside,
Thermometer_outside, Ventilation;

  CONTENT
    WHILE (END()=0) {# For
repeatedly

running
      Thermometer_inside.ON();
      Thermometer_outside.ON();
      Ti_temp :=
Thermometer_inside.measureTemp();
      To_temp :=
Thermometer_outside.measureTemp();
      AirConditioner.ON();
```

```
AirConditioner.setTemperature(user_
temp)

      WHILE (Ti_temp > user_temp) {

AirConditioner.setMode('COOLING');
        IF (Ti_temp > To_temp)  {
          WHILE (Ti_temp > To_temp)
{
            Ventilation.ON() ;
            Ti_temp :=
Thermometer_inside.measureTemp();
            To_temp :=
Thermometer_outside.measureTemp();
           }
           Ventilation.OFF() ;
         }
       }

AirConditioner.setMode('FAN');
     }
     Thermometer_inside.OFF();
     Thermometer_outside.OFF();
     AirConditioner.OFF();
}
```

Figure 4. Example of Integrated HNS Service Model Description

HVAC service stated in Section 1. Like this, the system model defines HNS constitution of arranged appliances and home environment.

The `TYPEDEF` section declares types commonly used in the system. The proposed language supports three types: *Boolean* (i.e., {`true,false`}), *integer*, or *enumeration*. An integer type is specified by the range between upper and lower bounds, e.g., {`18..28`}. An enumeration type is defined by enumerating concrete elements, e.g., {`ON,OFF`}.

The `ENVIRONMENT` section defines an environment object. In our HNS model, the environment consists of only environment properties. In Figure 3, `tTemp Temp_in` express the variable for temperature inside the home and its type.

All appliances deployed in the HNS are declared in multiple `APPLIANCE` sections (blocks), each of which defines an appliance object. An `APPLIANCE` block comprises of definitions of properties and methods of the appliance. The appliance properties are specified in the same way as in the `ENVIRONMENT` section. Each method is described in a `METHOD` subsection.

In the case of `setTemperature` method of AirConditioner, return value is `void` and argument is `temp` (its type is `tAC_Temp`). Each method has `PRE, POST, ENV_R, ENV_W, RETURN` as its attributes. `setTemperature` method requires that `power` property value is `'ON'` before its execution. This attribute is defined as `PRE` (pre condition). `POST` (post condition) describes property name and its value which changes after method execution. Namely, invocation of `setTemperature` changes value of `tempSetting` to value of `temp` (argument of `setTemperature`). `ENV_R` shows environment properties monitored by a sensor device (in the case of Thermometer_inside, `measureTemp` method monitors `Temp_in` in environment property). On the contrary, `ENV_W` shows environment properties affected by appliance method. The method of `setTemperature` affects `Temp_in`. `RETURN` specifies the value to be returned, which can be specified by a property or an expression (e.g., `currentTemp` (This property is defined as an appliance property)).

Figure 4 illustrates a service model example of the HVAC service. In this example, HVAC service has an argument `user_temp` (the type is `tAC_Temp`). In `VAR` section and `APPLIANCE` section, variables and appliances used in the service are declared. In `CONTENT` section, actual integrated service statements are shown. Basically, the statements are sequentially executed one-by-one from top to bottom, as in the ordinary procedural programming language.

`end()` and `exit()` are pseudo functions. `end()` returns true (1) when *the user terminates the service* (e.g., with a termination signal from the user agent). `exit()` models a system call by which *the system terminates the service*. These allow the developer to specify explicitly when or by whom the service is terminated.

These system and service model can be translating into the well-known SMV language. Once translated, the SMV tool automatically and exhaustively verifies the integrated service against any properties specified in CTL(Computational Tree Logic). Thus, we can effectively detect design flaws in integrated services.

2.2 Application Development of Integrated HNS Services

As we stated in the beginning of this section, we proposed an application architecture and models. Our application architecture makes it possible to use together the appliances implemented by various standards. Our models realize integrated service verification at design level. However, there is no relationship between models and implementation in integrated HNS services. So, it is not guaranteed that a HNS application is exactly developed according to the models.

In order to implement the artifacts with a validated model, it is important to support application development by a development framework such as code generation. Moreover, it is expected that this kind of support is effective in the field of the appliance component in which the feature of the same specification is implemented by multiple appliances in many cases. For example, the method of `ON/OFF` is implemented by various kinds of appliance. Such common feature specifications are often used by same kinds of appliance.

Implementation of integrated services needs to be updated corresponding to variation of appliances and methods. So, the more complicated service scenarios become, the more deteriorated their quality, such as maintainability and reusability, is.

To improve these problems, we adopt MDD method for integrated HNS service development.

3 Model-Driven Development of Integrated HNS Services

Model-Driven Development (MDD) is a promising approach to address platform complexity and express domain concepts effectively [19]. MDD combines the following two technologies:

(1) DSML(Domain Specific Modeling Languages): whose type systems formalize the application structure, behavior, and requirements within particular domains.

(2) Transformation Engines and Generators: analyze certain aspects of models and then synthesize various types of artifacts, such as service interface, simulation inputs etc.

MDA [2], Software Factories [6], and MCSD [21] are representative MDD technologies which generate implementation artifacts from models.

In this article, we propose MDD framework for integrated HNS services.

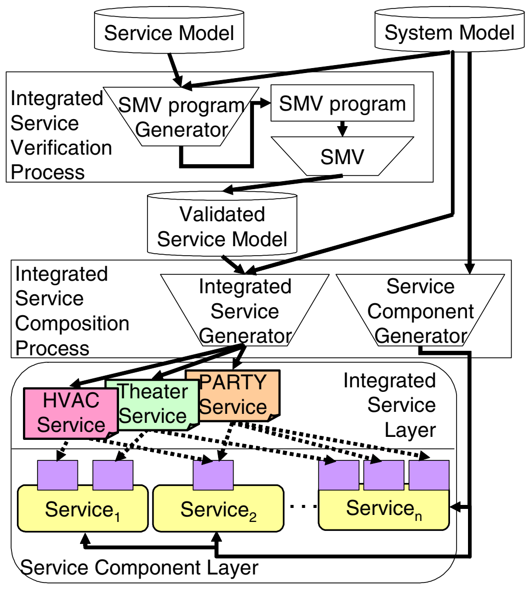


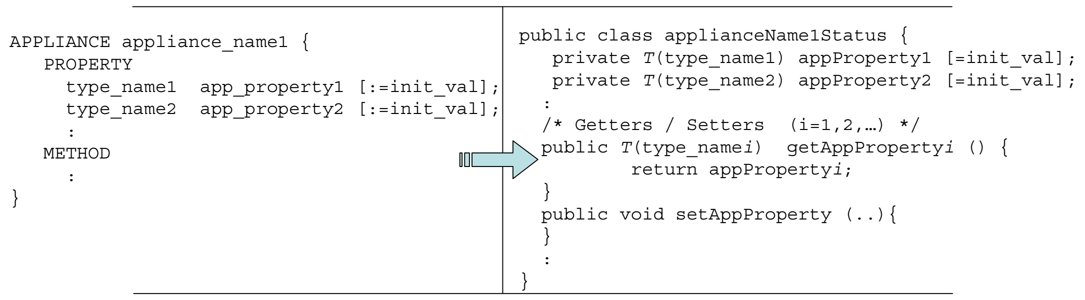
Figure 5. Model-Driven Development Process for Integrated HNS Services

3.1 Key Idea

Figure 5 illustrates a process model of the proposed MDD(Model-Driven Development) framework for integrated HNS services. The system model defines home environment and exhibited features of appliance in HNS. Service model shows the scenarios of integrated HNS services. These models are input to the MDD framework. Our framework consists of integrated service verification process and integrated service composition process. In verification process, SMV program generator transforms a service model and a system model to SMV program and SMV checks its program [11]. If behavioral anomalies of the models are discovered by model checking, the developer corrects the bugs and re-verifies them with SMV, and finally gets the validated service model.

Next process is an integrated service composition process. In the composition process, service component generator generates service components from the system model, integrated service generator generates integrate service implementations from the validated service model and the system model.

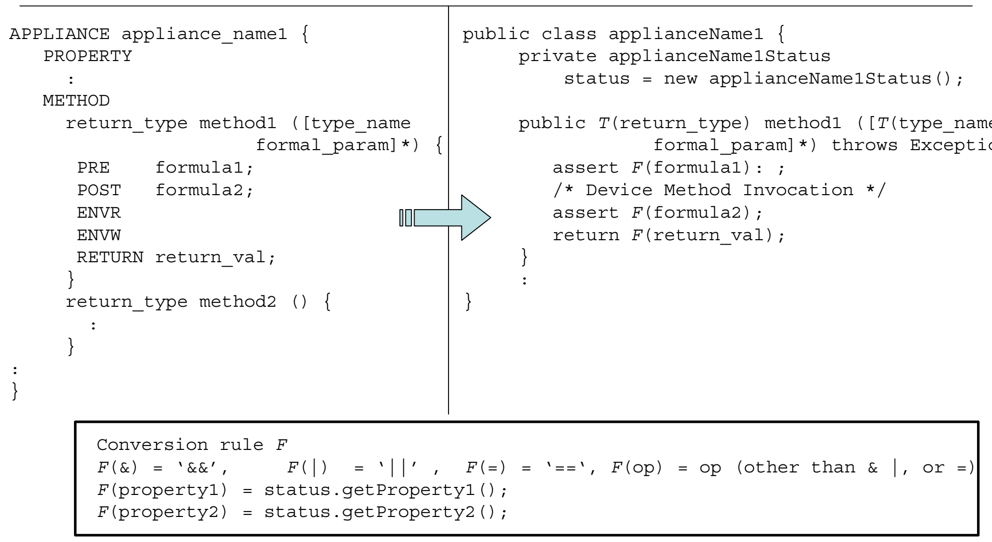
We use Java Web services for implementation of service components, and Perl script for composing services. In the following section we define transformation rules for integrated service composition process. As shown in Section 2.1, system model and service model are platform-independent and are defined as a set of arbitrary constructs. Implementation artifacts(called $ARTIFACTS$) such as service components and integrated services, are



```
APPLIANCE appliance_name1 {
   PROPERTY
     type_name1  app_property1 [:=init_val];
     type_name2  app_property2 [:=init_val];
     :
   METHOD
     :
}
```

```
public class applianceName1Status {
   private T(type_name1) appProperty1 [=init_val];
   private T(type_name2) appProperty2 [=init_val];
  :
  /* Getters / Setters  (i=1,2,…) */
  public T(type_namei)  getAppPropertyi () {
          return appPropertyi;
  }
  public void setAppProperty (..){
  }
  :
}
```

Figure 6. Transformation Rules from PROPERTY Section into a Status Java Bean



```
APPLIANCE appliance_name1 {
   PROPERTY
     :
   METHOD
     return_type method1 ([type_name
                      formal_param]*) {
      PRE    formula1;
      POST   formula2;
      ENVR
      ENVW
      RETURN return_val;
     }
     return_type method2 () {
       :
     }
:
}
```

```
public class applianceName1 {
     private applianceName1Status
         status = new applianceName1Status();

     public T(return_type) method1 ([T(type_name)
                 formal_param]*) throws Exception {
        assert F(formula1): ;
        /* Device Method Invocation */
        assert F(formula2);
        return F(return_val);
     }
     :
}
```

```
Conversion rule F
F(&) = '&&',     F(|)  = '||' ,  F(=) = '==', F(op) = op (other than & |, or =)
F(property1) = status.getProperty1();
F(property2) = status.getProperty2();
```

Figure 7. Transformation Rules from METHOD Section into an Appliance Class with Methods

generated from this PIM(Platform Independent Model). Moreover, if $ARTIFACTS$ is a set of arbitrary constructs in the implementation artifacts, the transformation to $ARTIFACTS$ from PIM is defined as a map M : $PIM- > ARTIFACTS$. Henceforth, each transformation rule which constitutes the map M is explained.

In Section 3.2, transformation rules to service components (Java Web services) from the system model are shown. In Section 3.3, transformation rules to integrated service (Perl script) from the validated service model and the system model are shown.

3.2 Transformation Rules from System Model to Service Component

Service component generator generates service component implementation with Java Web services, from system model. Table 1 shows transformation rules *T* for type definition of property used in HNS. Type transformation rules *T* transform three type definitions: *Boolean*, *int*, *enumeration* to three type definition in *int*. *Boolean* is transformed

Table 1. Property Type Transformation Rules

	HNS Description (system and service model)	Implementation Artifacts (Java Web Services)
Type Transformation *T*	TYPEDEF type_name1{true, false}	Int /* true=1, false=0 */
	TYPEDEF type_names{upper..lower}	int
	TYPEDEF type_name3{enumerating concrete elements}	Int /* ordered integer number from zero */

to {*true=1, false=0*}. In *enumeration* type, its enumerating concrete elements are transformed to ordered integer value from zero (for example, {*COOLING, FAN*} is {*0,1*}).

Figure 6 and Figure 7 are transformation rules for property and method of appliances, respectively. In a system model, an appliance consists of a set of properties and a set of methods. A set of properties are transformed to appliance status Java bean, and a set of methods are transformed to the methods of the appliance class to invoke the corresponding status Java bean. The status java bean have prop-

```
DEPLOYED_SYSTEM HNS_name;
SERVICE service_name1([type_name formal_param]*){
   # Local variable declaration
   VAR  type_name local_var1 [:=initial_value];
        type_name local_var2 [:=initial_value];
   :
   # Appliance declaration
   APPLIANCE appliance1, appliance2,..;

   CONTENT              # service content
    statement1;
    statement2;
    :
}
```

```
#!usr/bin/perl
use SOAP::Lite;
use strict;

#Service instantiation
my $appliance1Service = SOAP::Lite ->
service("http://anyserver/appliance1Service/services/
appliance1Service?wsdl");
my $appliance2Service = SOAP::Lite ->
service("http://anyserver/appliance2Service/services/
appliance2Service?wsdl");
:

my $formal_param = shift @ARGV; #service argument
$SIG{'INT'} = 'set_end_flag';#for pseudo function end()
my $end = 0;
:
sub set_end_flag {#for pseudo function end()
    $end = 1;
}
```

Figure 8. Transformation Rules for Instantiation of Integrated HNS Service Scenario

erty declaration and initialization denoted by the section of `APPLIANCE` and `PROPERTY` in the system model. And Getter/Setter methods for accessing the properties are declared.

In the appliance class, instantiation of the corresponding status Java bean and the method declaration defined by the `METHOD` in the `APPLIANCE` section are denoted. Argument and return type and value of the method are written, and `PRE/POST` attributes are inserted in the method as a set of pre-condition and post-condition of assertion. As you see in the Figure 7, the appliance class is transformed to the skeleton of appliance component from the models. Developer can implement the appliance component only coding *device-dependent* part in the method.

3.3 Transformation Rules from Service Model to Integrated Service

Integrated Service Generator generates integrated service implementation in Perl script from the validated service model and the system model. In Figure 8, instantiation part of the integrated service implementation is shown. In the Perl script for Web services integration requires to include SOAP::Lite module and instantiation of WSDL for each service component. Then, arguments of the integrated service (`formal_param`), and procedure for pseudo function `end()` are declared. These declarations express the section of `VAR` in the `SERVICE` and `APPLIANCE` section. `CONTENCT` section is transformed by statement transformation rules *S* (in Table 2).

4 Case Study

As a case study, we developed HVAC service. The detailed HVAC service is as follows.

Table 2. Statement Transformation Rules

	HNS Integration Service Description	Implementation Artifacts(Perl Script)
Statement Transformation *S*	Appliance1.method1([arg_list]*)	appliance1Service->method1([arg_list]*)
	exit()	exit
	end()	$end
	:=	=
	=	==
	|	||
	&	&&
	Other statement	same

HVAC Service : HVAC serves energy-saving air-conditioning service to keep a room at the set temperature. For the simplicity the discussion here, we focus on its cooling function. If the room is warmer than the set temperature, the HVAC service turns the air-conditioner to the cooling mode. To efficiently cool down the room, if the room temperature is warmer than the outside, the ventilator is also turned on to provide fresh outside air. In this case the ventilator will keep working until the room temperature reaches the outside temperature. If the room temperature is below the set temperature, on the other hand, HVAC turns the air-conditioner to the fan mode. This service requires four appliances: AirConditioner, Thermometer_inside, Thermometer_outside, and Ventilation.

A part of system model is shown in Figure 3. In Figure 4, service model of HVAC service is defined. Device itself is realized virtually as software functions.

Development environments are as follows.

- Apache Tomcat 5.5.17
- JDK 5.0 Update 7
- Apache Axis 1.4
- Active perl 5.8.8 (with SOAP::Lite and strict module)

```
import java.io.*;
public class AirConditioner{
  private AirConditionerStatus status = new AirConditionerStatus();

  public void ON() throws Exception{
     /*DEVICE_METHOD_INVOCATION*/
     assert status.getPower()==0 : status.getPower();
  }
  public void OFF() throws Exception{
     /*DEVICE_METHOD_INVOCATION*/
     assert status.getPower()==1 : status.getPower();
  }
  public void setTemperature(int temp) throws Exception{
     assert status.getPower()==0 : status.getPower();
     /*DEVICE_METHOD_INVOCATION*/
     assert status.getTempSetting()==temp :
status.getTempSetting();
  }
  public void setMode(int mode) throws Exception{
     assert status.getPower()==0 : status.getPower();
     /*DEVICE_METHOD_INVOCATION*/
     assert status.getModeSetting()==mode :
status.getModeSetting();
  }
}
```

Figure 9. AirConditionerClass

Figure 9 and Figure 10 are AirConditioner class and AirConditionerStatus Java bean generated by the service component generator, respectively. Interface of the AirConditioner class is exhibited as Web services. In this development, we coded only virtual appliance procedure in the generated program skeleton. Table 3 shows LOC of developed each artifact. *LOC of generated code* means size of the code generated automatically. *LOC of added code* means size of the code added by us to implement device-independent parts. Moreover, the whole of integrated service implementation (HVAC.pl) for HVAC service was generated automatically. We confirmed that these implementation artifacts perform HVAC service.

5 Discussion

As shown in Section 4, the proposed MDD framework realizes the following processes.

1. Platform-independent service and system models are verified to create a validated service model by SMV.

Table 3. LOC of Developed Appliance Components and Integrated Service

	Name of generated artifacts	LOC of generated code	LOC of added code
Appliance classes and status java beans	AirConditioner.java	19	8
	AirConditionerStatus.java	25	0
	Ventilation.java	11	4
	VentilationStatus.java	11	0
	ThermometerInside.java	15	6
	ThermometerInsideStatus.java	18	0
	ThermometerOutside.java	15	6
	ThermometerOutsideStatus.java	18	0
Integrated service script	HVAC.pl	36	0

```
import java.io.*;
public class AirConditionerStatus{

  private int power=1;/*tPower{ON=0,OFF=1}*/
  private int tempSetting=24;
  private int modeSetting=0;/*tAC_Mode{COOLING=0,FAN=1}*/

  /*Getter/Setter methods*/
  public int getPower(){
       return power;
  }
  public void setPower(int power){
       this.power = power;
  }
  public int getTempSetting(){
       return tempSetting;
  }
  public void setTempSetting(int tempSetting){
       this.tempSetting = tempSetting;
  }
  public int getModeSetting(){
       return modeSetting;
  }
  public void setModeSetting(int modeSetting){
       this.modeSetting = modeSetting;
  }
}
```

Figure 10. AirConditionerStatus Java Bean

2. Appliance component skeletons of Java Web service are generated from the system model.

3. The whole of integrated service implementation (Perl script) is generated from the validated service model and the system model.

Verification process and composition process enables developers to make more reliable and safe integrated HNS services. Program skeleton of the appliance component realizes separation of exhibited interface to network and device/middleware-dependent procedure. So, developers code only device/middleware-dependent parts. Moreover, in the program skeleton, *assertion* is inserted for evaluation of `PRE/POST` attribute in the exhibited method. These assertion statements enable the developers to test the appliance component program [5]. As a result, these development support capabilities in our MDD framework are expected enhance productivity and quality of integrated HNS services in various development environment such as multiplatform.

In conventional research, several MDDs for Web services are proposed [1], [16]. These researches realizes transformation from standardized modeling language such UML or proprietary models to Web services implementation. However, these researches lack separation of concerns between exhibited interfaces of appliance and device/middleware-dependent procedure, and verification the services.

In the domain of verification in HNS application, DLNA [3] uses *CTT*(Conformance Test Tool for networked appliance) to verify fixed integrated services thoroughly. However, new flexible services can not be verified and developers are not supported.

6 Conclusion

This paper presents a MDD framework for integrated HNS services. In the domain of HNS application, safety, reliability, portability and maintainability are important factor, because HNS applications are closely involving our daily life. So our framework enables developers to verify the services and generate implementation artifacts. Generated artifacts use our proposed application architecture which can use multiple HNS platform together, based on Web service. As a result, developers can create reliable and safe integrated services at low-cost.

We are planning to create more various generation rules corresponding to more practical HNS applications creation.

Acknowledgments

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