ABSTRACT
The advances in technology to support complex communication services, such as the pervasiveness of mobile devices and the convergence of multimedia communication over digital networks, has resulted in a need for a new approach to model and realize communication services. The stovepipe approach used to develop today’s communication applications is no longer effective since it results in a lengthy and costly development cycle. In this paper we present an approach that allows a user (end-user or domain expert) to model and realize communication services using a model-driven approach. We describe a semi-formal communication logic which is the meta-model for creating instances of user communication services. To show the applicability of our approach we demonstrate how models are created and realized using our prototype and a scenario from the healthcare domain.

KEY WORDS
Modeling-driven development, Communication services, Meta-Model.

1. Introduction
The pervasiveness of communication technology facilitates the widespread use of communication-intensive applications. Improvements in network capacity and reliability, as well as the wide use of communication devices such as PDAs and cell phones provide developers with the ability to create more complex communication-intensive applications. These applications cover domains such as telemedicine, disaster management, and scientific collaboration. The communication services used in these applications include various combinations of: IP telephony, instant messaging, video conferencing, and other forms of multimedia data transfers. However, traditional stovepipe approaches to developing communication-intensive applications are cumbersome and costly with long development cycles. Today, all trends indicate that the pace of innovation of new communication-intensive and collaborative applications is expected to accelerate even faster.

In this paper, we define a user-level communication logic meta-model to support the model-driven development of communication-intensive applications. This meta-model defines the communication primitives, constraints and association policies between these primitives. Using the communication logic meta-model the communication needs of different applications can be modeled during requirements analysis and be realized in days rather than weeks or months. The rapid realization of the model is achieved by automatically transforming this model into an executable script language that is then interpreted. The modeling, transformation and realization of communication services are made possible by using the concepts outlined in the Communication Virtual Machine (CVM) [3]. Finally, we present a prototype which works on top of the Skype platform [11] to illustrate the realization process.

The paper is organized as follows. Section 2 provides background on model-driven development. Section 3 defines the semi-formal model for communication logic. Section 4 describes the architecture of the prototype used to realize a communication model. Section 5 describes how the prototype creates and realizes communication models. Section 6 discusses the related work and we conclude in Section ??.
spect to a particular problem solution. An artifact is therefore a subgraph of some model \( M \). A relationship \( R \) maps artifacts in one model \( M_i \) to artifacts in another model \( M_j \). \( R \) is therefore \( < A_i, A_j, \Sigma_R, \Lambda_R > \), where \( A_i, A_j \) are the artifacts in models \( M_i, M_j \), respectively; \( \Sigma_R \) are the labels in \( R \) assigned by \( \Lambda_R \). Halpern and Tarr [5] define meta-data as the set of annotations at both the model level, \( \Lambda_M \), and relationship level, \( \Lambda_R \). We use this definition of meta-data throughout the paper.

2.2 Model-Driven Development

Model-driven development (MDD) automates the transformation of models from one form to another [8]. The MDD process usually requires that there be a source model or a platform independent model (PIM), and a target model or platform specific model (PSM) [12]. The initial source model represents the concepts of a specific domain (\( M_{CS} \)), in our case user view of communication services, and the final target model contains the source code that interacts with the underlying communication infrastructure (\( M_{CI} \)).

To ensure the consistency of models during transformation the technique of meta-modeling is used [10]. We define the meta-models used to realize communication services based on the meta-data extracted from the communication logic models. Atkinson and Kühne [1] state that meta-modeling should consist of two orthogonal dimensions that support two forms of instantiation: linguistic - concerned with the language definition, and ontological - concerned with domain definition. We use both in defining the meta-models used in our approach. The ontological meta-modeling will be implemented using profiles and stereotypes provided in UML 2 [9].

3. Modeling Communication

As stated in Section 2.2 one of the essential properties of MDD is the automatic transformation between different models. Meta-models are essential to the transformation process and in this section we present an abstract model of communication that forms the basis of a meta-model. The meta-model also supports the notion of a user view, synonymous to a use case, and the global view synonymous to the application. We also use this meta-model to create a UML profile that is used in developing the graphical modeling environment.

3.1 Abstract Communication Model

We define a communication logic model (\( M_{CL} \)) as a four tuple consisting of a set of nodes (\( N_{CL} \)), edges (\( E_{CL} \)), an alphabet of model labels (\( \Sigma_{CL} \)) and an annotation mapping function (\( \Lambda_{CL} \)). We use sans serif font to denote literal labels. The communication logic model is recursively defined where the nodes are themselves models.

\[
\begin{align*}
N_{CL} & \in \{ M_P, M_C, M_I \} \\
E_{CL} & \in \{ < M_P, M_I >, < M_I, M_C > \} \\
\Sigma_{CL} & \in \{ \text{attributes}_{CL}, \text{transmission}, \text{isAttached} \} \\
\Lambda_{CL} & = \{ M_P \rightarrow \text{attributes}_{CL}, \\
& \quad M_C \rightarrow \text{attributes}_{CL}, \\
& \quad M_I \rightarrow \text{attributes}_{CL}, \\
& \quad < M_P, M_I > \rightarrow \text{isAttached}, \\
& \quad < M_I, M_C > \rightarrow \text{transmission} \}
\end{align*}
\]

- \( M_P \) represents a Participant model. Each \( M_P \) can only send or receive data via an interface model. A \( M_P \) may be associated with one or more interface models.
- \( M_I \) represents an Interface model. An \( M_I \) is associated with one and only one \( M_P \).
- \( M_C \) represents a Channel model. A \( M_C \) may be associated with one or more \( M_I \). A \( M_I \) may also be associated with one or more \( M_C \).
- \( \text{attributes}_{CL} \) represents a set of attributes including a unique identifier.
- \( \text{transmission} \in \{ \text{send, receive, bi-directional, disconnected} \} \)

A Participant model \( M_P \) is defined as follows:

\[
\begin{align*}
N_P & \in \{ \text{Participant}, M_{CL} \} \\
E_P & \in \{ \} \\
\Sigma_P & \in \{ \text{attributes}_P \} \\
\Lambda_P & = \{ \text{Participant} \rightarrow \text{attributes}_P, \\
& \quad M_{CL} \rightarrow \text{attributes}_P \}
\end{align*}
\]

- A \( \text{Participant} \) is a source or sink of data.
- \( \text{attributes}_P \) represents a set of attributes for Participants.

An Interface model \( M_I \) is defined as follows:

\[
\begin{align*}
N_I & \in \{ \text{Interface} \} \\
E_I & \in \{ \} \\
\Sigma_I & \in \{ \text{attributes}_I \} \\
\Lambda_I & = \{ \text{Interface} \rightarrow \text{attributes}_I \}
\end{align*}
\]

- An \( \text{Interface} \) represents either the actual device or a virtual device used by the participant to pass data to the channel.
- \( \text{attributes}_I \) represents a set of attributes for Interfaces.

A Channel model \( M_C \) is defined as follows:

\[
\begin{align*}
N_C & \in \{ \text{Channel}, M_D \} \\
E_C & \in \{ < \text{Channel}, M_D > \} \\
\Sigma_C & \in \{ \text{attributes}_C, \text{allows} \} \\
\Lambda_I & = \{ \text{Channel} \rightarrow \text{attributes}_C, \\
& \quad M_D \rightarrow \text{attributes}_C, \\
& \quad < \text{Channel}, M_D > \rightarrow \text{allows} \}
\end{align*}
\]

- A \( \text{Channel} \) is the conduit that allows data to pass between interfaces.
- \( M_D \) models the data transmitted through a channel.
- \( \text{attributes}_C \) represents a set of attributes for the Channel model.
A Data model $M_D$ is defined as follows:

- $N_D \in \{M_M, M_F\}$
- $E_D \in \{\}$
- $\Sigma_D \in \{attributes_D\}$
- $\Lambda_D = \{M_M \rightarrow attributes_D, M_F \rightarrow attributes_D\}$
  - $M_M$ represents a Medium model.
  - $M_F$ represents a Form model. A Form is a user defined type that allows the creation of complex data types.
  - $attributes_D$ is a set of attributes for the Data model.

A Form model $M_F$ is defined as follows:

- $N_F \in \{M_M, M_F\}$
- $E_F \in \{<M_F, M_M>, <M_F, M_F>\}$
- $\Sigma_D \in \{attributes_F, contains\}$
- $\Lambda_D = \{M_M \rightarrow attributes_F, M_F \rightarrow attributes_F,$
  $<M_F, M_M> \rightarrow contains,$
  $<M_F, M_F> \rightarrow contains\}$
  - $M_M$ represents a Medium model.
  - $M_F$ represents a Form model. A $M_F$ is defined as follows:
  - $(attributes_F, contains)$
- $attributes_F$ represents a set of attributes for Form.

A Medium model $M_M$ is defined as follows:

- $N_M \in \{Medium\}$
- $E_M \in \{\}$
- $\Sigma_D \in \{attributes_M\}$
- $\Lambda_D = \{Medium \rightarrow attributes_M\}$
  - $M_M$ represents a Medium model.
  - $M_M$ is a Medium model.
- $attributes_M$ represents a set of attributes for Medium.

### 3.2 Views of Communication

The semi-formal model defined in Section 3.1 represents the meta-model that can be used to generate a model for the complete structure of communication services provided to all the users for an application in some specified domain. An example of such an application would be a surgeon sharing patient data with the referring and attending doctors immediately after surgery. Since our aim is to model and realize communication services it is important to define different views of the communication logic model. Note that these views represent the aspects of communication in the use cases that define the application. For example, the surgeon and the doctors in the healthcare application each has a view of the communication. We use the notion of artifact introduced in Section 2.1 to define the view of a communication logic model.

A view of a communication logic model $M_{CL}$ is an artifact generated by applying constraints to $M_{CL}$. It can therefore be stated that different views of the model $M_{CL}$ are all subgraphs of $M_{CL}$. The constraints are applied to the edges, alphabet of model labels and the annotation mapping function. In this paper we consider two views: (1) *Global view* - the communication logic model $M_{CL}$, and (2) *User view* - an artifact, $A_{M_{CL}}$, is a communication model of one user’s perspective. We define the user view as:

1. Each participant model, $M_F$, is considered as a singleton.
2. There is a unique participant labeled as local.
3. All participants that can be reached from the local participant through exactly one channel are labeled as remote.
4. All channels in $A_{M_{CL}}$ are connected to the local participant through one interface.
5. Each participant is connected to a channel through an interface.
6. The only participants in $A_{M_{CL}}$ are labeled as local or remote.

The global view captures the requirements of a complete communication application. The user view captures communication requirements of one user’s perspective. The prototype presented in this paper realizes the user view communication logic model. A user view can be projected from the global view by using a breadth-first traversal. The algorithm is:

1. Label the participant $p$ as local representing the specified user.
2. Label all associated interface of $p$ as local interface.
3. Label all channel associated with labeled interface. If a labeled interface has no associated channel, unlabel it.
4. Find all unlabeled interfaces associated with labeled channels. Label them as remote interface.
5. Label all dependent participants of remote interfaces as remote.

In order to construct a global view of the communication from several user views we assume that: (1) participant, interface and channel in different user views have unique identifier, and (2) input include views of all participants in the communication logic model. The main steps in the algorithm to merge all user views are as follows:

1. Set $N_{global}$ as union of all users’ $N$.
2. Set $E_{global}$ as union of all users’ $E$.
3. Create new labels and mapping functions to remove duplicate information in user’s view.

### 3.3 UML Profile for Communication

In Section 3.1 we presented a semi-formal model for the communication logic that can be used to construct a global communication view consisting of a set of user communication views. The communication logic model is a metamodel and therefore can support the various transformations used during model-driven development. The abstract syntax and static semantics of this meta-model can therefore be used in tools to support the construction of valid
communication models. Given the fact that UML is a popular modeling language and UML artifacts can be imported into MDD development environments [14] we have created a UML 2 profile [9] for the user view of a communication model.

The UML 2 profile for the user view of a communication model is shown in Table 1. UML 2 profiles are specific kinds of packages that allows meta-models to be created for specialized domains. The UML profile in Table 1 consists of three kinds of artifacts: (1) stereotypes - define specific meta-classes, Column 1, (2) tagged values - define meta-attributes, i.e. attributes of the stereotype, Column 3, and (3) constraints - modeling guidelines i.e., restrictions on how the meta-model maybe used, Column 4. For example, in Row 1 the stereotype is <<Participant>> which is a base class, it contains the tagged value id of type string String and it may only contain variables of the class whose stereotype is <<Interface>>.

<table>
<thead>
<tr>
<th>Stereotype</th>
<th>Base Class</th>
<th>Tagged Values</th>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;&lt;Participant&gt;&gt;</td>
<td>Class</td>
<td>id: String</td>
<td>May only be associated with instances of Interface. id is unique.</td>
</tr>
<tr>
<td>&lt;&lt;Interface&gt;&gt;</td>
<td>Class</td>
<td>id: String</td>
<td>May be associated with at most one instance of Participant. id is unique.</td>
</tr>
<tr>
<td>&lt;&lt;Channel&gt;&gt;</td>
<td>Class</td>
<td>id: String</td>
<td>May only be associated with instances of Interface and Data. id is unique.</td>
</tr>
<tr>
<td>&lt;&lt;Data&gt;&gt;</td>
<td>Class</td>
<td>id: String</td>
<td></td>
</tr>
<tr>
<td>&lt;&lt;Local&gt;&gt;</td>
<td>Participant</td>
<td></td>
<td>There is only one instance of Local.</td>
</tr>
<tr>
<td>&lt;&lt;Remote&gt;&gt;</td>
<td>Participant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;&lt;Device&gt;&gt;</td>
<td>Interface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;&lt;Medium&gt;&gt;</td>
<td>Data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;&lt;Form&gt;&gt;</td>
<td>Data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;&lt;isAttached&gt;&gt;</td>
<td>Association</td>
<td></td>
<td>Instances of Participant are associated with instances of Interface</td>
</tr>
<tr>
<td>&lt;&lt;callows&gt;&gt;</td>
<td>Association</td>
<td></td>
<td>Instances of Channel are composed of instances of Data.</td>
</tr>
<tr>
<td>&lt;&lt;contains&gt;&gt;</td>
<td>Association</td>
<td></td>
<td>Instances of Form are composed of instances of Medium.</td>
</tr>
<tr>
<td>&lt;&lt;connectTo&gt;&gt;</td>
<td>Association</td>
<td></td>
<td>Instances of Interface are associated with instances of Channel.</td>
</tr>
</tbody>
</table>

Table 1. UML Profile for the user’s view of a communication model

4. Architecture of Prototype

The prototype developed to model and realize user-level communication services is based on the layered architecture of the Communication Virtual Machine (CVM) [3]. The CVM enables the realization of models created using the Communication Modeling Language (CML) [2]. The CVM consists of the following layers: (1) user communication interface (UCI), allows users to declaratively specify their communication needs and requirements (in CML), (2) synthesis engine (SE), generates an executable script from a CML model and negotiate the model with other participants in the communication, (3) user-centric communication middleware (UCM), executes the communication control script to manage and coordinate the delivery of communication services, and (4) network communication broker (NCB), which interfaces with the underlying networks to implement the communication services.

CML is a language generated from the user view of communication logic model. It is used to define a communication schema as well as a communication instance. A communication schema, or simply schema, defines the allowed configurations and data transfers. A schema is synonymous to a class in the object-oriented paradigm and an instance to an object. There are two equivalent variants of CML: the XML-based (X-CML) and the graphical (G-CML). Figure 1 shows a simplified version of the X-CML in EBNF form. The G-CML is used to create graphical communication models for both communication schemas and instances. The details of the CVM and CML can be found in [3] and [2], respectively.

Figure 1. EBNF representation of X-CML.

1. userSchema := local connection { connection
2. connection := mediaAttached connection
   remote (remote)
3. local := person isAttached device
4. remote := device isAttached person
5. mediaAttached := {medium} { form
6. device := device deviceCapability (deviceCapability)
7. form := (form) { medium } | form
8. person := personName, personID, personRole
9. device := deviceId
10. medium := builtinType, mediumURL
    suggestedApplication, action
11. deviceCapability := builtinType
12. form := suggestedApplication, action
13. action := "send" | "doNotSend" | "startApplication"
5. Realizing Communication Services

In this section we describe how models are created and realized using the implementation of the prototype presented in Section 4. A common scenario from the healthcare domain is used to illustrate how a developer can easily create an application that provides communication services to a doctor on-demand.

Scenario: After heart surgery Dr. Monteiro (the cardiologist) contacts Dr. Sanchez (family doctor) and Dr. Lopez (a heart specialist) to update them on a patient’s condition. During communication with doctors Dr. Sanchez and Dr. Lopez, Dr. Monteiro sends them the post-surgery echocardiogram (echo) of the patient’s heart and a text summary of the patient’s current condition.

5.1 Model Creation

Communication models are created and validated in the UCI. The Communication Modeling Environment, shown in the upper left hand corner of the UCI, see Figure 2, is composed of (1) the graphical diagram editor used to create and validate the graphical models, and (2) the G-CML to X-CML transformer which converts the graphical model in G-CML to a text representation of the model in X-CML. The graphical diagram editor in the prototype was developed using a combination of the Graphical Modeling Framework (GMF) [15], the Eclipse Modeling Framework (EMF) [14] and the Graphical Editing Framework [13]. A summary of the steps used to create the graphical diagram editor are as follows:

1. Create a UML class diagram for the G-CML metamodel using a refined version of the UML profile in Table 1.
2. Use the class diagram in Step (1) to generate the Ecore model in EMF.
3. Through a series of transformations, the G-CML editor is generated from EMF [15]
4. The graphical diagram editor can now be used to create the model and output its XML representation.

The G-CML to X-CML transformer converts the XML representation of the G-CML model ($G-CML_{XML}$) generated by the graphical diagram editor into the equivalent X-CML representation. The G-CML model may be a schema or an instance of the required communication. An outline of the algorithm used to convert $G-CML_{XML}$ to X-CML is as follows:

1. Parse the $G-CML_{XML}$.
2. For each “connection” shape ($c_g$) in the parse tree of $G-CML_{XML}$
   
   (a) create the new “connection” element ($c_x$) in X-CML using the XML schema [2]
   (b) Retrieve the shapes ($S_g$) directly linked to $c_g$
   (c) For each $s \in S_g$
      
      i. create a new element in X-CML ($s_x$)
      ii. add $s_x$ as a child of $c_x$, where $s_x$ maybe a “device”, “medium”, or “form”

3. For each shape $s_g$ in the parse tree of $G-CML_{XML}$ where $s_g$ is a “person” or “isAttached”

   (a) create the corresponding X-CML element for $s_g$

The EBNF grammar shown in Figure 1 represents the XML schema that is used to construct the X-CML representation of the communication model.

5.2 Model Realization

Realizing a communication model requires two major steps, these are (1) checking the communication model to ensure it is a valid instance, and (2) translating the X-CML model into a communication control script containing calls to the underlying platform (Skype). The first step is performed by the Schema Transformation Environment in the UCI. In order to realize a communication model the Schema Transformation Environment loads either a schema or instance from the repository (or the Communication Modeling Environment) and checks if all the required attributes have values. This checking is done by a single traversal of the X-CML parse tree. If there are any required attribute values missing, usually true in the case of a schema, the user is requested to enter the missing values. For example, if the communication model is a schema for a two-party call then the user will be requested to enter the callee id of the remote participant.
Translating the X-CML model into a communication control script is done in the Synthesis Engine, as stated in Section 4. The following algorithm outlines how the X-CML is converted into a communication control script and executed for the initiation of communication.

1. Parse X-CML and traverse parse tree
2. For each connection $c_i$,
   
   (a) Identify the required media types associated with $c_i$
   
   (b) Establish a connection with the remote user(s) using a default type (e.g., audio)
   
   (c) If other media types are required then negotiate for each type. For example, if a video connection is required then listen for the remote video status. If the video is available then invoke the local video stream

Before a communication instance is realized the Skype application should be running and the caller logged in. Note that all participants in the communication should have Skype accounts.

6. Related Work

Our survey of the literature shows that although there has been much investigation done in domain specific modeling, there is currently no formal modeling techniques for modeling user-level communication services. Widespread modeling techniques currently used in software engineering and data modeling, like UML [9], are too generic and lack the formalism required for domain modeling, such as the modeling of user-level communication services. Greenfield et al. argue that although UML 2.0 is a useful modeling language, it is not an appropriate language for MDD [4]. Modeling and realizing communication aspects of applications for specific domains is still in its infancy.

Meanwhile, the software engineering community has been working on software frameworks for IP-based telecommunication (JAIN SIP [6], and Java Media Framework [7]). However, these communication services are usually tightly coupled with user applications. By applying the MDD [1] concepts, such as a visual modeling environment, meta-models, and model transformations, we decouple communication services from the application logic, hence providing a more effective way of modelling communication logic.

Deng et al. [3] introduced the Communication Virtual Machine (CVM) that provides the conceptual idea for the rapid realization of communication services that uses a layered architecture. However, there is no discussion on the theoretical foundations to support the automatic transformation of models between different layers of CVM. Clarke et al. [2] defined a simple and declarative Communication
Modeling Language (CML) for modeling user-level communication services. However, CML lacks a formal meta-model, which is the basis for any attempt at complete automation [12]. The meta-model in this paper provides a more complete and consistent approach to generating valid G-CML models and supports the automatic transformation between G-CML and X-CML. Using this meta-model, and the control script meta-model we can further automate the realization process.

7. Conclusion

In this paper we presented a semi-formal meta-model for user-level communication services and a prototype that realizes the communication aspects of an application using a model-driven approach. The prototype accesses the services of the underlying networks by using the Skype platform. Currently the realization process focuses on a user’s view of the communication, that is the communication for an individual scenario. Our future work is to extend the construction and realization of the communication model, to include a global view. We also plan to investigate what network services can be provided by other open platform communication tools.

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References