Reasoning on Service Interaction in Mobile Networks

Ivaylo I. Atanasov and Evelina N. Pencheva

Abstract— The paper presents a formal approach to detection of interaction between CAMEL-based services. CAMEL stands for Customized Application for Mobile network Enhanced Logic and it is a way for mobile operators to offer customized services that may be unique or differentiated from similar services offered by competitors. The more services operate in the network, the greater chance that they will interfere with each other. CAMEL basic call control models and mobility management models are described by means of the formalism of description logic. Services are modeled by refinement which transforms the knowledge base. A standard inference mechanism is used to reason about service interaction.

Keywords— Call control, CAMEL, Description logic, Inference algorithm, Mobility management control, Satisfiability.

I. INTRODUCTION

THE service interaction problem arises with the introduction of Intelligent network where the number of customized services and features increases. Service interaction occurs as an unexpected behavior due to conflict between service requirements or to the failure to meet service requirements by combined execution of multiple service logic instances. These interactions are called logical interactions.

Common practice of the telecom operators is to avoid any kind of service interaction. The combinations of services that might cause troubles are forbidden in the design of service control model, so that certain interactions cannot occur. However, restrictions on usage of certain services reduce the flexibility in service creation. Further, the service interactions can never be completely avoided as there are almost always interactions that slip through the networks. Another approach to solve the service interaction problem is by resolution. When a conflict between services occurs in the network, it has to be resolved. The intelligent agents technology provides a way of resolving service interactions by negotiations [1]. The agent approach is flexible, but it depends on how services are represented. It is difficult to express the intention or meaning of the service. Context dependent expectations of service behavior are difficult to express in any models [2].

Significant research efforts were made into service interaction detection. Before introducing a new service, one has to investigate whether the introduction of the service will invalidate one or more requirements of another service or whether its own requirements will not be satisfied.

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Formal methods and tools provide precise and unambiguous descriptions of services, and help to have a door understanding of the informal requirements of the services [3, 4, 5]. Formal model based solutions apply formal reasoning to detect service interaction. The formal models use finite state machines [6, 7, 8, 9], temporal logic [10, 11, 12, 13], process algebra [14, 15, 16, 17], and Petri nets [18, 19, 20, 21]. The applicability of approach depends on the expression of the expected service's behavior and its implementation in the network.

On the one hand, the interactions within given model can be found after conducting complete analysis which is possible only if the approach is formalized. On the other hand, the exponential increment of models' size with respect to size of the problems might become an issue. Having a reasonable set of services can lead to models to explode in number of their states and each state will need further exploration.

Our approach is based on the elaboration of different models of mobile communication system behavior which helps to describe service specification and to analyze interaction. The approach is applicable to CAMEL-based services.

CAMEL stands for Customized Application for Mobile network Enhanced Logic and it is Intelligent Network for mobile networks. CAMEL is considered as one of the three types of service provisioning platforms in managed Internet Protocol based multimedia networks [22, 23].

To accomplish the goal of flexible addition of behaviorally quite different service, CAMEL defines different models related to call control, mobility management control, data session control and messaging control [24]. We illustrate the capabilities for detection of service interaction for call related services triggered by mobility management events. The same approach may also be applied to signaling connections that are not call related such as Short Message Service or Internet Protocol (IP) connectivity.

The paper is structured as follows. In Section II, we briefly discuss previous works that are connected with our approach to service interaction detection. Section III starts with an introduction to description logic and then discusses its usage for formal definition of CAMEL models. An approach to service definition and an algorithm for inference of service interaction are presented in Section IV and Section V. We conclude the paper with evaluation of service interaction detection complexity.

II. Related Work

A number of authors had suggested that service interaction detection is a satisfiability problem. Starting point of our research was the work of C. Areces, W. Bouma and M. Rijke [25]. The authors use a formal model to specify services by means of description logic. Their formal definition of a basic telephone system and suplementary services is based on the basic call processing. Properties of services are formally proved and interactions are detected by means of standard reasoning tasks from description logic.

The authors present a formal language FI to define concepts related to possible communication terminal states, network states and subscriber actions. For example, $ringing_v$ $ringback_u$ and $engaged_u$ are subscriber states representing ringing terminal with receiver onhook, the receiver is off and emits a ring back tone, and a connection with another party respectively, while $calling_{uv}$ and $path_{uv}$ are internal states of the network, representing the terminal at v is ringing with u waiting for v to accept the call, and u and v can communicate respectively. First-order logic is used to define terminologies and assertions, and also to reason about them. For example, the following statements connect the observable states of the terminal with ones representing network states

$$calling_{uv} \sqsubseteq ringing_v \sqcap ringback_u \quad u \neq v$$

$$path_{uv} \sqsubseteq engaged_u \sqcap engaged_v.$$

There are statements specifying how a user and the network can change states.

The approach proposes a “good logic” to reason about services and the interaction problem, but its view of the network is simplified on purpose. In reality, we can not manage the network as if it is a single network element with a single copy of basic call process for each call. The call may originate from an exchange and terminate in another one, or even may connect subscribers in different networks. There is no notion of terminal mobility.

To provide more realistic model of the network, reflecting the distributed nature of the call control, a more detailed representation of the basic call process is needed. The CAMEL splits the basic call process into two parts, called originating basic call state model (O_BCSM) and terminating basic call state model (T_BCSM) [24]. The models describe procedures for initiating and receiving call respectively. In both models, detection points are defined, at which the service logic can be triggered. In addition to basic call state models, CAMEL introduces three models that allow service logic to control procedures related to mobility management, data session establishment and messaging [24].

Our approach is based on CAMEL call control and mobility management models to describe the behavior of mobile communication system (MCS) in the context of call-related service. The approach possesses more expressive power as it distinguishes between call processing for the originating party and terminating party, and considers mobility management also. Following the same approach, it is also possible to express service interactions for data communications and for sending and receiving short messages.

III. Description Logic of CAMEL Services

A. Basics of Description Logic

Description logic is knowledge representation formalism representing the knowledge of an application domain [26]. A knowledge representation system based on description logic provides facilities to set up knowledge bases, to reason about their content, and to manipulate them. Fig. 1 shows the architecture of such a system [27]. The knowledge base consists of terminology box (TBox) and the assertion box (ABox). The TBox stores a set of universally quantified assertions stating general properties of concepts and roles. The ABox comprises assertions on individual objects. The basic syntactic building blocks are atomic concepts (unary predicates), atomic roles (binary predicates), and individuals (constants). In addition to atomic concepts and roles, description logic systems allow their users to build complex descriptions of concepts and roles. Each description logic system is characterized by the language for building descriptions. The description language has a model-theoretic semantics. It is used to describe statements in the TBox and in the ABox which can be identified with formulae in first-order logic or, in some cases, a slight extension of it. A description logic system is also characterized by the inference mechanisms provided for reasoning on the knowledge base expressed in the system.

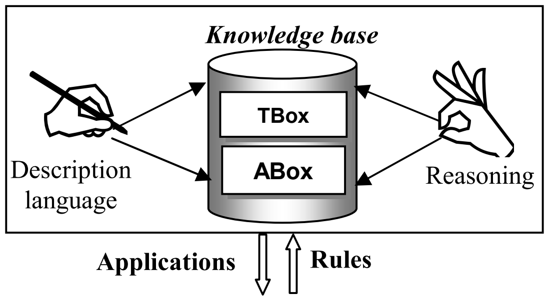

Fig.1 Architecture of knowledge representation system based on description logic

The applications interact with the knowledge base by queries and modifications, i.e. by adding and retracting concepts, roles, and assertions. The rules form a restricted mechanism to add assertions. Thus, rules extend the logical core formalism, which can still be interpreted logically.

Having a domain Δ with fixed names of the concepts and the roles, and given constants form a triplet $\langle C, R, A \rangle$ thus that one can define the set of the concepts C, terminologies T and assertions A (i.e. allowed formulae in TBox and ABox respectively) as follows:

$$\begin{aligned} BC &\coloneqq \top \mid C \mid \neg BC \mid BC \sqcap BC \\ C &\coloneqq BC \mid \forall R.BC \mid \exists R.BC \\ T &\coloneqq BC \sqsubseteq C \mid BC \equiv C \end{aligned}$$

A ≔ a:C | (a,b):R

where in C is any basic concept C, in R is any basic relation R, and in A are constants a, b. The pair $\langle T, A\rangle$ is *knowledge base* where $T \subseteq$ T and $A \subseteq$ A.

Interpretations of description logics are I = $(\Delta^I, \cdot^I)$ where Δ^I is non-empty set and $\cdot^I$ is mapping of subsets of Δ^I onto the concept names, relations over Δ^I onto role names, and elements of Δ^I onto constants. The interpretations are extended over C as follows:

$(\top)^I = \Delta^I$
$(\bot)^I = \varnothing$
$(C \sqcap D)^I = C^I \cap D^I$
$(\neg C)^I = \Delta^I \setminus C^I$
$(\forall R.C)^I = \{ a \in \Delta^I \mid \forall b\ ((a,b) \in R^I \rightarrow b \in C^I) \}$
$(\exists R.C)^I = \{ a \in \Delta^I \mid \exists b\ ((a,b) \in R^I \wedge b \in C^I) \}$

In fact, $\exists R.C$ means the whole subset of elements of Δ that are in relation R with the element C. The duality of operator ∀ can be expressed in terms of operator ∃, as $\forall R.C = \neg\exists R.\neg C$.

The definition of *satisfaction* is intuitive as a relation between interpretations and terminologies or assertions. Thus ⊨ is relation between I and all formulae supported by I:

$I \vDash C \sqsubseteq D$ iff $C^I \subseteq D^I$
$I \vDash C \doteq D$ iff $C^I = D^I$
$I \vDash$ a:C iff $a^I \in C^I$
$I \vDash$ (a,b):R iff $(a^I, b^I) \in R^I$

So, for a subset $K \subseteq$ T ∪ A one may state that $I \vDash K$ iff $I \vDash \varphi$: $\forall \varphi \in K$. In general, *consequence* is if having a knowledge base ⟨T, A⟩ and formula φ such that φ∈T ∪A then φ *follows from* ⟨T, A⟩ i.e. ⟨T, A⟩⊨φ iff ∀I: I⊨⟨T,A⟩ ⇒ I⊨φ where ⇒ notes implication. One of the main reasoning tasks in description logics is to check if given formula follows from given knowledge base.

B. CAMEL Models

CAMEL provides models describing the process for initiating calls (O_BCSM) and the process of receiving ones (T_BCSM) [19]. Both models can trigger CAMEL service logic. Both O_BSCM and T_BCSM are represented as state-transition diagrams that describe the call processing states and transitions between them. The states are named *points in call* and the transitions are caused by events such as call initiation, call answer, or disconnect. An event can have an associated detection point at which service logic can be invoked if predefined criteria are met. The CAMEL T_BCSM is shown in Fig.2.

The CAMEL Attach-detach model is defined to enable service logic to control the mobility management in the packet switched domain. This model tracks the mobility management procedures and allows the service logic to intervene in them. Fig.3 shows the CAMEL Attach-detach model.

Although there is no explicitly defined model, the CAMEL specifications [24] define a mechanism for service logic notification about events concerning mobility management in the circuit-switched domain. The service logic may be triggered on events related to location update, attach and detach procedures.

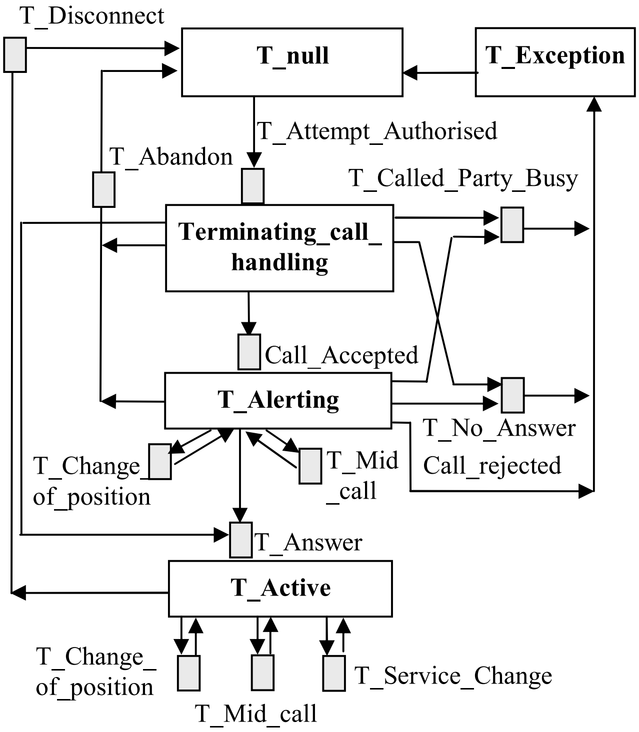

Fig. 2 CAMEL Terminating BCSM

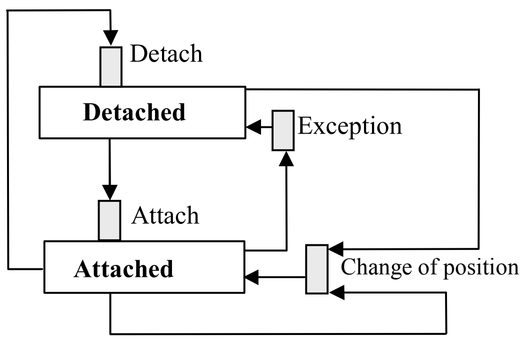

Fig. 3 CAMEL Attach-detach model

C. Description of CAMEL Models

Our approach to definition of atomic concepts is to represent each call state and mobility management state in models as a separate concept. We also define the subscriber state as idle which means that the subscriber is not involved in a call, or not idle. Table I shows the call states at the terminating party, the mobility management states and the mobile station states.

Each transition in the models is defined as a role since if it has an encountered detection point, the call processing or mobility management will be suspended and the control will be handed over the service logic. The roles and their meaning are shown in Table II.

Table I. Atomic concepts related to call and mobility management state, and mobile station state

Concepts	*Description*
T_Null	There is no incoming call. In case of incoming call, terminating CAMEL subscription information is analyzed.
T_Call_Handling	Routing address and call type are interpreted. The next route or terminating access is selected.
T_Alerting	Waiting for the call to be answered by terminating party.
T_Active	Connection is established between originating and terminating party. Call supervision is provided.
T_Exception	Default handling of the exception condition is being provided in the terminating party.
Attached	The mobile station is attached to the network.
Detached	The mobile station is detached from the network.
Idle	The mobile station is not involved in a call.

Our terminology box contains statements that express the relationship between the calls states, mobility management states and subscriber states as shown in Table III.

There are also expressions representing the changes in models and statements specifying the relationship between the events that cause the call processing and mobility management as shown in Table IV.

Let denote by SUBS the set of all subscribers. By TBCSM we denote the states s_i in the T_BSCM model, and by MM the states s_j in the Attach-detach model. The assertion box contains one statement presenting the initial state for each subscriber:

s_0: $\sqcap_{u\in SUBS}$ (Detached).

To express the fact that the call at the terminating party may be in exactly one state at any moment we use the statement:

$\top\sqsubseteq\neg(\sqcup_{s1,s2\in TBCSM,\ s1\neq s2}(s1\sqcap s2))\sqcap(\sqcup_{s\in TBCSM}\ s)$

The state of call changes by means of actions defined as action functions. An action function $Func_{TBCSM}$ for given state corresponds to the possible transitions in the TBCSM. For example, the expression:

$Func_{TBCSM}$(T_Call_Handling)={T_Called_Party_Busy}$\cup$ {T_No_Answer}$\cup${T_Answer}$\cup${Call_Accepted}$\cup$ {T_Abandon}

means that all transitions starting at the T_Call_Handling state may be triggered by one of the following events: the called party is busy or not reachable, the called party does not answer at all, the called party answers or accepts the call, or an indication that the calling party abandons the call.

Table II. Atomic roles related to call and mobility management transitions

Roles	*Description*
T_Att_Auth	Indication that the terminating CAMEL subscription information is analyzed.
T_Busy	Indication that a busy or not reachable event is received, or call establishment failure event is determined.
Call_Accepted	Indication that the terminating party is alerted.
T_Answer	The call is accepted and answered by the terminating party.
T_No_Answer	Indication that an application timer associated with the T_No_Answer detection point expires.
T_Abandon	A disconnect indication is received from the originating party during the call establishment procedure.
T_Disconnect	A disconnect indication is received from the terminating party or from the originating party.
Detach	The mobile station performs detach procedure.
Attach	The mobile station performs attach procedure.
ChangeOfPosition	Indication that the mobile station has changed position.
T_Mid_Call	Indication that a service is received from the terminating party.
T_Service_Change	Indication that the mobile station has changed the bearer service.
Exception	The signaling connection fails.

The fact that each state may be changed only by means of certain actions is represented by the following statement:

for all $s\in$TBCSM, and all $R\notin Func_{TBCSM}$ (s), $s\sqsubseteq\forall R.s$.

The same is applied to the Attach-detach model where the action function $Func_{MM}$ for given state corresponds to the possible transitions in the Attach-detach model. For example, the activation functions $Func_{MM}$(Detached)={Attach}, $Func_{MM}$(ChangeOfPosition)={Detach}, and $Func_{MM}$(Attach)= {Detached} describe all possible changes of the detached state. Then having the statement

for all $s\in$MMs, and all $R\notin Func_{MM}(s)$, $s\sqsubseteq\forall R.s$

we can derive

$Detached_C\sqsubseteq\forall T\_Call\_Handling_{AB}.Detached_C$.

Table III. TBox representing relationships between states

Statement	*Description*
Detached≡¬Attached	The detached state is the opposite of the attached state.
T_Active⊑¬Idle	If a connection between the originating party and terminating party is established then the terminating party is not idle.
Attached⊑T_Null⊔ T_Call_Handling⊔ T_Alerting⊔T_Active	If the mobile station of the terminating party is attached then there may be no incoming call, or an incoming call may be routed, or the call may wait to be answered by terminating party, or a connection may be established.
Detached⊑(T_Null⊔T_Call_Handling) ⊓¬T_Alerting⊓¬T_Active	If the mobile station of the terminating party is detached then there may be no incoming call, or an incoming call may be routed, and the terminating party can not be alerted, and a connection can not be established.

Table IV. TBox representing changes in T_BCSM and Attach-Detach model

Statement	*Description*
Detached⊑∃Attach.Attached⊓Idle	If the mobile station is detached from the network, it may perform an attach procedure resulting in the attached state and idle state.
T_Null⊑∃T_Att_Auth.T_Call_Handling	If there is no incoming call, then the terminating CAMEL subscription information may be analyzed leading to terminating call handling.
T_Call_Handling⊓(Detached⊔¬Idle)⊑ ∃T_Busy.T_Exception	If an incoming call is routed and the mobile station of the terminating party is detached or not idle, then a busy indication may be received and an exception situation will occur.
T_Call_Handling⊓Idle⊑ ∃T_Answer.T_Active⊔ ∃T_No_Answer.T_Exception⊔ ∃Call_Accepted.T_Alerting⊔ ∃T_Abandon.T_Null	If an incoming call is routed and the terminating party is idle, then the subscriber may answer resulting in the active state, or the subscriber may not answer leading to default handling, or the call may be accepted resulting in the alerting state, or an indication that the calling party abandons the call may be received leading to the state of no incoming call.
T_Alerting⊓Detached⊑ ∃T_Busy.T_Exception	Waiting for the call to be answered, if the mobile station of the terminating party is detached then a busy indication may be received.
T_Alerting⊓Idle⊑ ∃T_Answer.T_Active⊔ ∃T_Busy.T_Exception⊔ ∃T_No_Answer.T_Exception⊔ ∃T_Abandon.T_Null⊔ ∃T_Mid_Call.T_Alerting⊔ ∃T_ChangeOfPosition.T_Alerting	Waiting for the call to be answered, if the mobile station is idle, then the terminating party may answer resulting in the active state, or the terminating party may reject the call leading to an exception situation, or the terminating party may not answer leading to an exception situation, or an indication that the originating party abandoned the call may be received resulting in the state of no incoming call, or the terminating party may change the position and remain in the same state.
T_Active⊑∃T_Mid_Call.T_Active⊔∃T_ Service_Change.T_Active⊔ ∃T_ChangeOfPosition.T_Active⊔ ∃T_Disconnect.T_Null	If a connection between the originating party and terminating party is established then one of the following events may take place: an indication that a service is received from the terminating party, or the terminating party changes the bearer service or its position, or a disconnect indication is received resulting in the state of no incoming call.
T_Exception⊑T_Null	The default handling will result in the state of no incoming call.
Attached⊑∃Detach.Detached	If the mobile station is attached to the network, it may perform detach procedure.
Detached⊑∃ChangeOfPosition.Attached	The mobile station may detach from the old serving node and attach to a new one.
Attached⊑∃ChangeOfPosition.Attached	The mobile station may perform an intra serving node location area update.

$Attached \sqsubseteq \exists Exception.Detached$	The mobile station may lose the signaling connection.

IV. SERVICE MODELS

A. An Approach to Definition of Services

Services are modeled by *refinement*. The definition of refinement is formalized as refinement operation δ_F, for given service F, which operation transforms given knowledge base K into another knowledge base $\delta_F(K)$. The last is augmented by a set of *activation concepts* which generally are $A_F \subseteq \{ F_u \mid u \in SUB \}$. So, let $N \subseteq A_F$ then K and F *interact on activation* N if $\delta_F(K) \cup \{ \top \sqsubseteq F_u \mid F_u \in N \} \cup \{ \top \sqsubseteq \neg F_u \mid F_u \in A_F \setminus N \} \models \neg\top$. Let one has different services i.e. F_a, F_b : a≠b. Then $\delta_{Fb}(\delta_{Fa}(K)) \equiv F_a \circ F_b$ and the services under consideration are such that $F_a \circ F_b \equiv F_b \circ F_a$. We use contexts C[φ] to define refinements in the knowledge base, where φ is a subformula of any formula ψ.

B. Definition of Location Changed Alerting Service

The Location Changed Alerting (LCA) service notifies by incoming call a subscriber who has entered a given area. The service may be useful for parents that want to monitor the location of their children. It is activated when the subscriber performs a mobility management procedure related to change of position. This means that the Attach-detach model and T_BCSM are applied. The service is activated at the ChangeOfPosition detection point and a network initiated call takes place. The refinement for the LCA service is defined by the statements shown in Table V.

C. Definition of Do Not Disturb Service

The Do Not Disturb (DND) service allows a subscriber not to be disturbed by incoming calls. The refinement for the DND service is defined by the statements shown in Table VI.

Table V. TBox modified by Location Changed Alerting Service

Statement	*Description*
$C_1[\neg LCA_b \sqcap Attached_b] \sqsubseteq \exists ChangeOfPosition_b.C_2[Attached_b]$	If the LCA_b service is not activated for the subscriber *b* then the mobile station of *b* may change its position keeping attached to the same serving node.
$C_1[LCA_b \sqcap Attached_b] \sqsubseteq \exists ChangeOfPosition_b.C_2[Attached_b] \sqcap \exists T\_Att\_Auth_b.C_3[T\_Call\_Handling_b]$	If the LCA_b service is activated for the subscriber *b* then the mobile station of *b* may change its position keeping attached to the same serving node and a network initiated call to *b* will take place.
$C_4[\neg LCA_b \sqcap Detached_b] \sqsubseteq \exists ChangeOfPosition_b.C_5[Attached_b]$	If the LCA_b service is not activated for the subscriber *b* then the mobile station of *b* may detach from the old serving node and attach to the new serving node.
$C_4[LCA_b \sqcap Detached_b] \sqsubseteq \exists ChangeOfPosition_b.C_5[Attached_b] \sqcap \exists T\_Att\_Auth_b.C_6[T\_Call\_Handling_b]$	If the LCA_b service is activated for the subscriber *b* then the mobile station of *b* may detach from the old serving node and attach to the new serving node and a network initiated call to *b* will take place.

Table VI. TBox modified by Do Not Disturb Service

Statement	*Description*
$C_1[\neg DND_b \sqcap Idle_b \sqcap T\_Null_b] \sqsubseteq \exists T\_Att\_Auth_b.C_2[T\_Call\_Handling_b]$	If the DND_b service is not activated for the subscriber *b* and *b* is idle and the originating party initiates an incoming call to *b* then the terminating attempt may be authorized and the terminating party is informed of the incoming call
$C_1[DND_b \sqcap Idle_b \sqcap T\_Null_b] \sqsubseteq \exists T\_Busy_b.C_2[T\_Exception_b]$	If the DND_b service is activated for the subscriber *b* and *b* is idle then an exception condition may be encountered.
$DND_b \sqsubseteq \neg T\_Call\_Handling_b$	If the DND_b service is activated for the subscriber *b* then the terminating party can not be informed of the incoming call.

V. SERVICE INTERACTION REASONING ALGORITHM

A. Tableau Method

A knowledge representation system based on description logics is able to perform specific kinds of reasoning. For example, it is important to find out whether a newly defined concept makes sense or it is contradictory. From a logical point of view, a concept makes sense if there is some interpretation that satisfies the axioms of *T* (that is, a model of *T*) such that the concept denotes a nonempty set in that interpretation. A concept with this property is said to be *satisfiable* with respect to *T* and *unsatisfiable* otherwise.

Description logic as that for representation of mobile communication system behavior with negation and disjunction can be handled by so-called *tableau-based algorithms.* Instead of directly testing subsumption of concept descriptions, tableau-based algorithms use negation to reduce subsumption to (un)satisfiability of concept descriptions: $C \sqsubseteq D$ if $\neg C \sqcup D$ is unsatisfiable.

We use a tableau method [25] to detect service interaction.

The tableau $t \stackrel{\text{def}}{=} \{ \langle b \mid p\text{: } C \rangle \}$ is a set of prefixed formulae where the prefix of given formula is consisted of a binary string $b := \varepsilon \mid (1|0)^{+}$ and a string of alternating names $p := n(Rm)^{+}$, and C is concept. Here ε is the empty string, n and m are names of individuals, R stands for the names of roles, and $()^{+}$ denotes one or more occurrences. Strict or relaxed prefix σ_1 of given string σ_2 can be defined by total ($\sigma_1 \prec \sigma_2$) or partial ($\sigma_1 \preccurlyeq \sigma_2$) order. Then b_M is called maximal for b in t if $b \in t \wedge b_M \in t \wedge b_M \prec b \wedge (\neg \exists b_I \in t\text{: } b_M \prec b_I \wedge b_I \prec b)$.

Table VII. Tableau Method

AND: $\dfrac{\langle b \mid p : C \sqcap D \rangle}{\langle b \mid p : C \rangle \quad \langle b \mid p : D \rangle}$	
OR: $\dfrac{\langle b \mid p : C \sqcup D \rangle}{\langle b_M 0 \mid p : C \rangle \quad \langle b_M 1 \mid p : D \rangle}$	b_M maximal for b
SOME: $\dfrac{\langle b \mid p : \exists R.C \rangle}{\langle b \mid pRn : C \rangle}$	pRn new (unless pR exists in the branch)
ALL: $\dfrac{\langle b \mid p : \forall R.C \rangle}{\langle b \mid pRn : C \rangle}$	pRn present in b
KB: $\dfrac{\vdots}{\langle b \mid p : \neg C \sqcup D \rangle}$	with p present in b and $C \sqsubseteq D \in T$

B. Reasoning about LCA and DND Interaction

The tableau algorithm for reasoning about interactions between LCA and DND services activated for the subscriber B proceeds as follows:

1. Applying AND to the start formula $\langle \varepsilon \mid s_0\text{: } \sqcap_{u \in SUB}$ Detached$\rangle$ gives

1.1 $\langle \varepsilon \mid s_0\text{: Detached}_B \rangle$

2. Applying KB to rule $\text{Detached}_B \sqsubseteq \exists \text{Attach}_B.\text{Attached}_B \sqcap \text{Idle}_B$ produces $\langle \varepsilon \mid s_0\text{: } \neg \text{Detached}_B \sqcup (\exists \text{Attach}_B.\text{Attached}_B \sqcap \text{Idle}_B) \rangle$. Applying OR gives two branches:

2.1 $\langle 0 \mid s_0\text{: } \neg \text{Detached}_B \rangle$ which is closed.

2.2 $\langle 1 \mid s_0\text{: } \exists \text{Attach}_B.\text{Attached}_B \sqcap \text{Idle}_A \rangle$. Applying AND gives

2.2.1 $\langle 1 \mid s_0\text{: Idle}_B \rangle$

2.2.2 $\langle 1 \mid s_0\text{: } \exists \text{Attach}_B.\text{Attached}_B \rangle$ to which applying SOME produces $\langle 1 \mid s_0 \text{ Attach}_B \text{ } s_1\text{: Attached}_B \rangle$

3. We derive $\langle 1 \mid s_0 \text{ Attach}_B \text{ } s_1\text{: } \exists \text{ChangeOfPosition}_B.\text{Attached}_B \rangle$ to which applying SOME produces $\langle 1 \mid s_0 \text{ Attach}_B \text{ } s_1\text{: Attached}_B \text{ } s_2 \text{ ChangeOfPosition}_B \text{ } s_3\text{: Attached}_B \rangle$

4. We derive $\langle 1 \mid s_0 \text{ Attach}_B \text{ } s_1\text{: Attached}_B \text{ } s_2 \text{ ChangeOfPosition}_B \text{ } s_3\text{: T\_Null} \sqcup \text{T\_Call\_Handling} \sqcup \text{T\_Alerting} \sqcup \text{T\_Active} \rangle$. Then applying OR produces:

4.1 $\langle 10 \mid s_0 \text{ Attach}_B \text{ } s_1\text{: Attached}_B \text{ } s_2 \text{ ChangeOfPosition}_B \text{ } s_3\text{: T\_Null} \rangle$ to which we apply further intermediate derivation $\langle 10 \mid s_0 \text{ Attach}_B \text{ } s_1\text{: Attached}_B \text{ } s_2 \text{ ChangeOfPosition}_B \text{ } s_3\text{: } \exists \text{T\_Att\_Auth.T\_Call\_Handling} \rangle$ and applying SOME results in $\langle 10 \mid s_0 \text{ Attach}_B \text{ } s_1\text{: Attached}_B \text{ } s_2 \text{ ChangeOfPosition}_B \text{ } s_3 \text{ T\_Att\_Auth}_B \text{ } s_3\text{: T\_Call\_Handling} \rangle$ which is closed because of $\text{DND}_B \equiv \neg \text{T\_Call\_Handling}_B$.

4.2 $\langle 11 \mid s_0 \text{ Attach}_B \text{ } s_1\text{: Attached}_B \text{ } s_2 \text{ ChangeOfPosition}_B \text{ } s_3\text{: T\_Call\_Handling} \sqcup \text{T\_Active} \rangle$ to which we apply OR results in

4.2.1 $\langle 110 \mid s_0 \text{ Attach}_B \text{ } s_1\text{: Attached}_B \text{ } s_2 \text{ ChangeOfPosition}_B \text{ } s_3\text{: T\_Call\_Handling} \rangle$ which is closed

4.2.2 $\langle 110 \mid s_0 \text{ Attach}_B \text{ } s_1\text{: Attached}_B \text{ } s_2 \text{ ChangeOfPosition}_B \text{ } s_3\text{: T\_Active} \rangle$ which is closed because of 2.2.1.

The result is a closed tableau which means that $\delta_{DND}(\delta_{LCA}(\text{MCS}))$ interacts on activation $\{\text{LCA}_B\} \cup \{\text{DND}_B\}$. It is important to mention that the service interaction can be detected automatically since the programmability of the algorithm.

VI. Conclusion

CAMEL allows service control on mobility management and communication management procedures in mobile networks. Our approach suggests a formal method for detection of interactions between call-related and call-unrelated services. We formalize some of the ideas introduced in [25] and develop more detailed representations that exploit standardized CAMEL models. Using description logic, we formally represent the behavior of mobile communication system in different scenarios such as call setup and release both at originating party and terminating party, attach to and detach from the network, and location update. The same formalism is used for specification of services. The service interaction detection is presented as standard reasoning task.

We argue that our approach provides a good expressive tool for reasoning about service interaction and complete decision method. The approach is also appropriate for formal specification of CAMEL models related to data communication control and messaging control which expand the range of services that may be explored.

By using the well-known results for description logics we may conclude that complexity of service interaction as satisfiability problem is ExpTime-complete.

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Ivaylo Atanasov received his M.S. degree in electronics from Technical University of Sofia, Sofia, Bulgaria, and PhD degree in communication networks. His current position is Associate Professor at Faculty of Telecommunications, Technical University of Sofia. His main research focus is set on open service platforms for next generation networks.

Evelina Pencheva received her M.S. degree in mathematics from University of Sofia "St. Kliment Ohridski, Sofia, Bulgaria and PhD degree in communication networks from Technical University of Sofia. Her current position is Professor at Faculty of Telecommunications, Technical University of Sofia. Her scientific interests include next generation mobile applications and middleware platforms.