



Mobile Edge Service for Intersystem Handover

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Abstract

Multi-access Edge Computing (MEC) appears to be an integrating technology for radio access networks to enhance the access capacity, optimize network performance and improve quality of experience for end users. MEC distributes cloud capabilities for storage and computing in the radio access network, close to the end users. As far as the development of advanced Application Programming Interfaces is a key area, we propose a new mobile edge service that enables 3rd party control on intersystem handover. The proposed service enables authorized applications to initiate intersystem handover following specific policy. The service is described by information flows illustrating the basic functionality, data models that provide mediation functions, and handover state models considering some implementation issues.

Keywords: component; Multi-access Edge Computing; open access; vertical handover; Application Programming Interfaces

1. Introduction

The ubiquitous penetration of smart devices and the thriving range of new and diverse services increasingly tend to place a serious strain on cellular systems due to expectations for exciting Quality of Experience (QoE). Nevertheless the improvements in system capacity and average data speeds, the requirements for low latency and high bandwidth increase and the coexistence of today wireless networks is the best solution. In heterogeneous environment, users will be able to enjoy bandwidth hungry applications through diverse radio access technologies [1], [2]. Radio access technology selection is crucial and

must be designed intelligently to avoid resource wastage. The traditional approach of radio access technology selection is network-centric and the decision is primarily focused on the channel conditions. However, 5G is expected to be more user-centric, delegating more radio resource management functions to third party applications created to maximize both network performance and user QoE [3]-[6].

A promising technology that may address the application requirements for high bandwidth and low latency is Multi-access Edge Computing (MEC). MEC creates highly distributed environment that brings cloud computing capabilities into radio access network (RAN). The proximity to end users allows fast reaction of dynamic changes in radio conditions. Currently, European Telecommunications Standard Institute (ETSI) defines

MEC infrastructure services, radio network information service, location service, and bandwidth management service. MEC services open radio access network functionalities for MEC and 3rd party applications. Applications access mobile edge services through application programming interfaces (APIs). In order to facilitate interoperability, ETSI defines REST (REpresentational State Transfer) APIs based upon a generic set of design principles and patterns [7].

The efficiency of MEC services is a very focus of ongoing research and standardization activities, as far as there are challenges to cope with. One of the key research areas is the development of advanced APIs that will enable 3rd parties to acquire and simply and efficiently manage resources on MEC platforms, including also the corresponding data models [8]. The enhanced form of the APIs should be providing network and RAN related information to the application, thus making it network-aware. So, the emerging applications, and respective variety of APIs and data models, are object of discussion and consideration at the MEC responsible body of ETSI.

In this paper, we propose an approach to design a new mobile edge service that exposes functions for radio resource management, in particular functionality for intersystem handover control. The approach is illustrated with typical use case and includes definition of data model, representing RESTful resources, API definition, and models representing the handover state as seen by 3rd party application, the serving RAN and target RAN.

The paper is structured as follows. Section II presents the related works and outlines the research motivation. A description of the proposed mobile edge service is provided in Section III, where a



use case of application-initiated intersystem handover is presented. In Section IV, the data model, which provides a description of information elements enabling open access to intersystem handover control, and API definition are presented. As a proof of the concept, handover state models are proposed in Section V, which are formally described and verified. The conclusion summarizes the authors' contribution.

2. Related Work and Research Motivation

To provide seamless roaming and service continuity there is a need to combine various wireless access technologies and define reliable intersystem handover strategies. Related works on intersystem handover are focused on performance optimization [9], [10] and algorithms for handover decision [11], [12], [13].

MEC can play an important role in providing low latency communication in robust infrastructure as a single common anchor point to sit in both the control and data planes for maintaining reachability (i.e. location management) information of User equipments (UEs), performing handover signaling (i.e. location update), and tunneling data packets [14]. Extensions of existing MEC APIs for bandwidth management and radio network information service are proposed in [15] and [16]. In [17], the author proposes mechanisms for improving handover decision-making that may be implemented in MEC environment. MEC-based architecture to support service continuity in a multi-access heterogeneous network is proposed in [18] and the aim is to maximize the QoE and fairness for mobile users. In [19], a MEC-based architecture for decision making processes of the transport network control, such as handover and traffic offloading, is proposed. A method and device for determining a bearer by a MEC in the handover process is proposed in [20].

The current research is aimed at further developing the MEC potential for RAN performance improving. The idea is to trigger intersystem handover based on 3rd party criteria such as UE location, quality of service (QoS) experienced by the UE, required data speeds, and the average number of session drops. With the existing 3GPP standards, the necessary data management and control functionality to provide network discovery and selection assistance data as per operators' policy is defined for Access Network Discovery and Selection Function (ANDSF) [21]. The purpose of ANDSF is to assist UE to discover non-3GPP access networks that can be used for data communications in addition to 3GPP access network. ANDSF provides the information, but the real bearer selection is done by UE and it also initiates the procedure. Delegation of the decision for intersystem handover to 3rd party enables applying application-specific logic for connectivity management. Policies for connectivity management may be based on specific geographic area, experienced QoS, average number of session drops in a predefined time period, and the required data speeds. Information about UE location, call drops and data speeds may be received from mobile edge services Radio Network Information Service (RNIS) [22] and Location Service [23]. RNIS provides authorized applications with low level real-time radio and network information related to users and cells. The mobile edge application can subscribe for:

- up-to-date radio network information regarding radio network conditions;
- measurement information related to the user plane based on 3GPP specifications;
- information and changes in information about UEs connected to the radio node(s) associated with the mobile edge host, their UE context and the related radio access bearers.

A mobile edge application that uses the proposed mobile edge service needs to subscribe for receiving notifications about Radio Access Bearer establishment, modification and release.

The application-initiated intersystem handover may be aimed at better usage of available network resources. The data rates a user received for multimedia applications affect the real speed the user can utilize which depends on how close or how far she is away from the base station. A use case illustrating the benefits of the proposed functionality is in heterogeneous access network environment. A user with UE featuring multi-radio access technology capabilities may be at the edge of LTE (Long Term Evolution) coverage where the available data speeds are not sufficient for exciting QoE. In case, an alternative HRPD (High Rate Packet Data) coverage is available, the ongoing multimedia session of a bandwidth intensive application may be switched to the HRPD base station which provides high data speeds at this location, as shown in Figure 1.

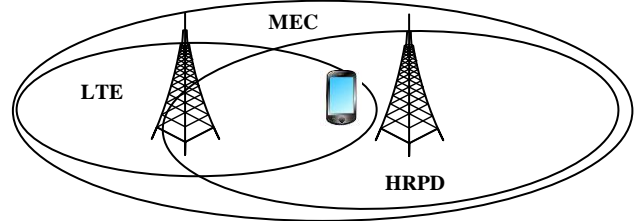


Figure 1 UE in heterogeneous multi-access network environment

Another use case illustrating the benefits of the proposed functionality is as follows. Being a 3GPP subscriber, a user possesses a VoIP (Voice over Internet Protocol) capable, i.e. multimedia UE. She prefers to use Wireless Local Area Network (WLAN) when making her multimedia calls, because most of the time she communicates happens to be at places where WLAN coverage is available. Still, being mobile, it happens to leave the WLAN coverage while communicating, and therefore it's better for her all ongoing sessions to be kept intact, or the eventual interruption to be as unnoticeable as possible. Alice achieves that by obtaining a WLAN card for her UE, and thus, switching the 3GPP and WLAN accesses, whenever it's necessary, assures the session continuity.

With the proposed APIs, the final choice of bearer and initiation of bearer change procedure are delegated to the business logic of 3rd party MEC application. Further, the open access to intersystem handover control enables creation and deployment of innovative applications. The benefits of open access to network functionality in the core network are studied in [24].

3. Service Description

The proposed mobile edge service exposes functionality for vertical handover control. It may be used by authorized mobile edge applications to:

- receive information about UE capabilities, and
- initiate intersystem handover following an application-specific policy.

Figure 2 illustrates the flow for application-initiated handover from LTE to HRPD.

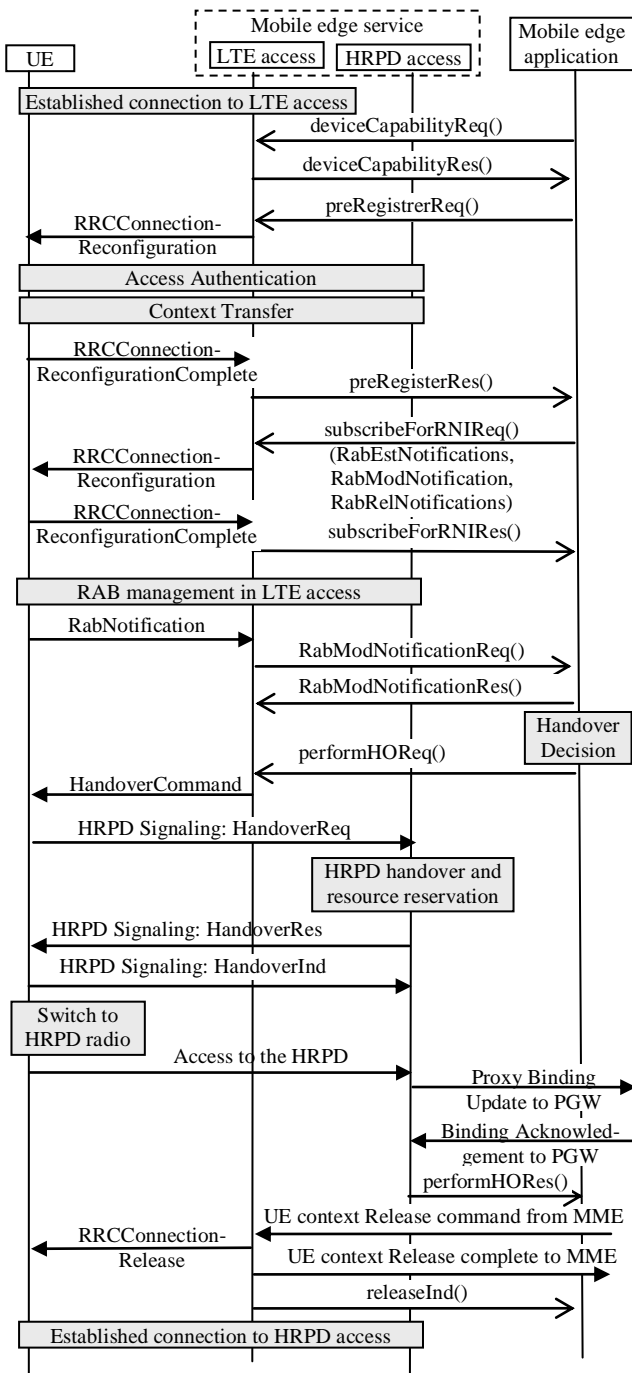


Figure 2 Application-initiated vertical handover

The mobile edge application accesses resources via APIs in mobile edge host. Let us assume that the mobile edge host enables edge computing within LTE and HRPD access networks. First, the application retrieves the UE capabilities regarding other radio accesses and systems it can support, and relevant details such as single/dual radio receiver, dual receiver, and frequency. Next, the application may decide to request pre-registration of the UE in the target access network.

The optimized handover defined between LTE and HRPD networks is performed in two phases: the pre-registration phase where the target access and specific core network entity for the specific access are prepared ahead of time anticipating a possible handover; and the handover preparation and execution phase, where the actual access network change occurs [21].

So, having information about UE supported access networks, the mobile edge application initiates pre-registration procedure which lets the UE attach to the HRPD system in advance of a handover.

The LTE network instructs the UE to perform pre-registration to the HRPD access by RRC Connection Reconfiguration procedure. The UE performs access authentication and authorization for the HRPD access. The mobile edge application is notified about UE pre-registration within HRPD access and it subscribes with the RNIS for events related to RAB management established for the UE. In case of RAB modification or release, the RNIS notifies the mobile edge application. Thereafter based on network selection criteria and connectivity management policy, the mobile edge application makes a decision to handover to the HRPD access. The application indicates to UE to initiate the handover procedure i.e. to switch over to the target HRPD network. The UE then initiates HRPD specific handover signaling to prepare the target network while continue maintaining the current connection, and sending and receiving data over LTE radio. Once the target preparation is complete the UE is notified and it releases the LTE resources and switches over to HRPD radio. Once the initial HRPD radio entry is completed, the UE performs the HRPD specific access procedure and path switching is initiated. The mobile edge application is notified about result of the intersystem handover.

4. Data Model and API Definition

The resource structure provides applications with data mediation functions, which is a meaningful way for addressing resources. The AccessNetworks resource is a placeholder for one or more access network types available for the UE. The available access network types are represented by 3GPPAccessNetworkType, 3GPP2AccessNetworkType, WiMaxAccessNetworkType and WLANAccessNetworkType resources. Each of these resources acts as a placeholder for one or more access networks of the respective type. Each available access network is represented by a resource, e.g. a 3GPPAccessNetwork resource contains information about a 3GPP access network available for the UE. The 3GPP2AccessNetwork specific resources are 3GPP2 1x and HRPD. The 1x resource is a container for one or more 3GPP2 1x RAT access networks, where a particular 3GPP 1x RAT access network is described by the System Identification code, Network Identification code and Base Station Identification code. The HRPD resource is a container for one or more 3GPP2 HRPD access networks, where a particular HRPD access network is described by Sector Identification and Netmask code, as shown in Figure 3. The 3GPPAccessNetwork specific resources are the PLMN code and Cell Global Identity.

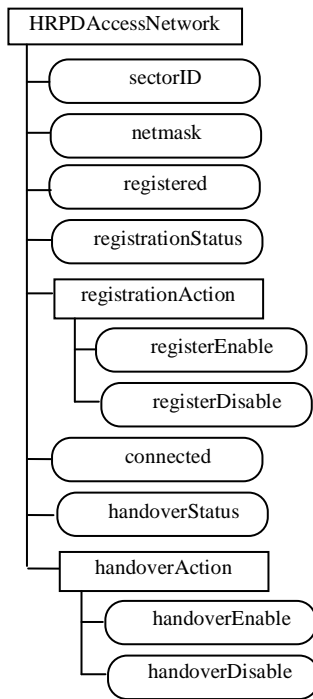


Figure 3 Resources for HRPD access network

Common attributes for all access networks available for the UE are registered, registrationStatus, connected, handoverStatus. Common resources for all access networks are registrationAction, and handoverAction. Table 1 explains the attribute semantics.

Table 1: Common Resource Attribute

Attribute name	Access	Description
sectorID	RO	Indicates a Sector Identification code for the particular HRPD location.
netMask	RO	Indicates a Netmask code for the particular HRPD location.
registered	RO	Indicates whether the UE is registered in the HRPD network or not.
registrationAction-Status	RO	Indicates the status of the registration action (including a progress indicator, a final state and a reminder of the requested action).
registerEnable	RW	The action that allows to enable registration to HRPD.
registerDisable	RW	The action that allows to disable registration to HRPD.
connected	RO	Indicates whether the UE is connected to the access network or not.
handoverStatus	RO	Indicates the status of the handover.
handoverEnable	RW	The action that allows to enable handover to HRPD.
registerDisable	RW	The action that allows to disable handover to HRPD

Following the ETSI way of resources addressing, all resource URIs of the proposed mobile edge service Application-driven handover (ADHO) have the following root: {apiRoot}/apiAdho/v1, where apiRoot and apiAdho are discovered using service registry. The content format of JSON is supported.

Table 2 provides an overview of the defined resources and applicable HTTP methods.

Table 2 Resources And Applicable HTTP Methods

Resource name	Resource URI	HTTP method
AccessNetworks	/AccessNetworks	GET
3GPPAccess NetworkType	/AccessNetworks/3GPPAccess NetworkType	GET

3GPPAccess Network	/AccessNetworks/3GPPAccessNetworkType/3GPPAccessNetwork
3GPP2Access NetworkType	/AccessNetworks/3GPP2AccessNetworkType
3GPP2Access Network	/AccessNetworks/3GPP2AccessNetworkType/3GPPAccessNetwork
Registration Action	/AccessNetworks/{ AccessNetworkType}/{ AccessNetwork}/Connect
HandoverAction	/AccessNetworks/{ AccessNetworkType}/{ AccessNetwork}/Connect

Figure 4 shows a successful application-driven pre-registration in a HRPD network.

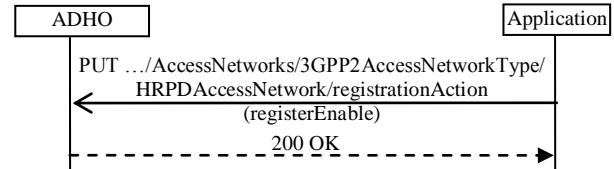


Figure 4 Successful application-driven pre-registration in a HRPD network

Figure 5 shows an unsuccessful application-driven pre-registration in a HRPD network. Other possible responses indicating unsuccessful application-driven pre-registration may be 401 Unauthorized (the application did not submit credentials), and 404 Not Found (the application provided an URI that cannot be mapped to a valid resource URI).

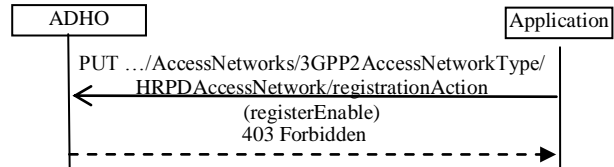


Figure 5 Unsuccessful application-driven pre-registration into a HRPD network

Figure 6 shows a successful application-driven handover to a HRPD network.

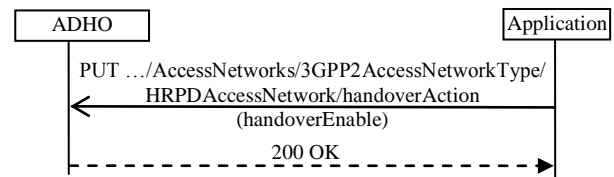


Figure 6 Successful application-driven handover to a HRPD network

Figure 7 shows an unsuccessful application-driven handover to a HRPD network.

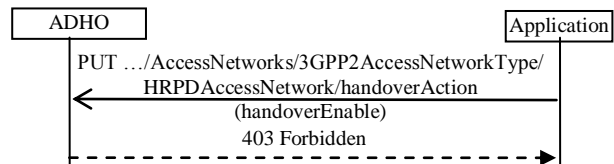


Figure 7 Unsuccessful application-driven handover to a HRPD network

Figure 8 shows a successful application-driven release of a 3GPP network.

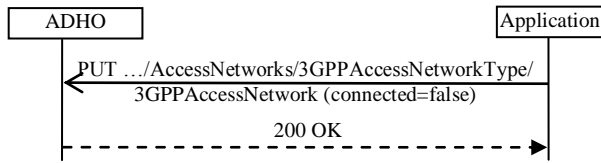


Figure 8 Successful disconnection from a 3GPP access network

5. Handover State Models

As a proof of the concept, models representing the handover state as seen by the mobile edge application, serving and target networks are designed. The three models have to be synchronized, i.e. to expose equivalent behavior.

Figure 9 shows the mobile edge application view on the handover state.

In ConnectedToServing state, the UE is connected to the serving 3GPP access network. The mobile edge application may send a request to receive a cell level Radio Access Bearer (RAB) information from the LTE cell and HRPD cell that are associated with the requested mobile edge application instance. The response contains information on users in the cells such as the identifiers of the cells, the identifiers associated to UEs in the cells and information on their RABs, consisting of the QoS information. The mobile edge application may subscribe for receiving RAB modification related information for a particular user. After being notified about RAB modification or release, the mobile edge application initiates timeouted hysteresis in order to assure that change in data speed is stable (e.g. the data speed is low). In LowDataSpeeds state, the mobile edge application may decide to initiate a UE pre-registration into the target HRPD access network when the timer expires. In RegisteringInTarget state, UE performs registration in the target HRPD access network. After successful registration, the mobile edge application initiates handover to the HRPD access network which includes pre-registration. The application initiated pre-registration may be skipped if the UE is already registered in the target network. In RegisteredInTarget state, the UE is successfully registered in the target access network. In HandoverToTarget, the UE performs a handover procedure to the target access network. In ConnectedToTarget state, the UE successfully has performed handover to the target HRPD access network.

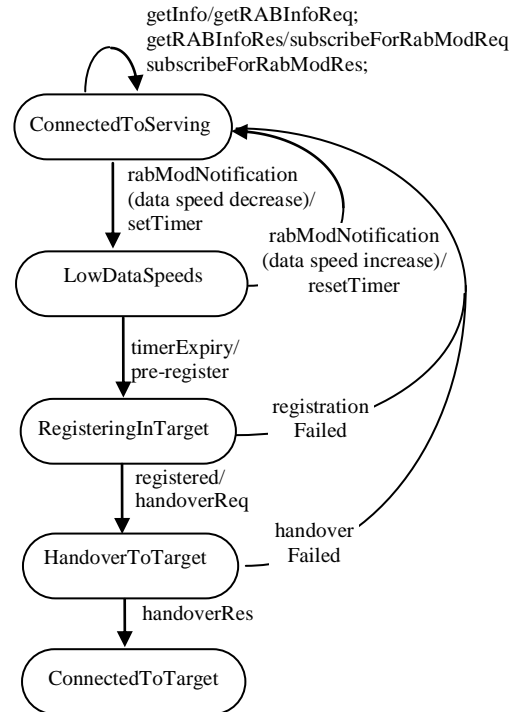


Figure 9 Application view on the handover state

Figure 10 shows the handover state model as seen by the serving LTE access network.

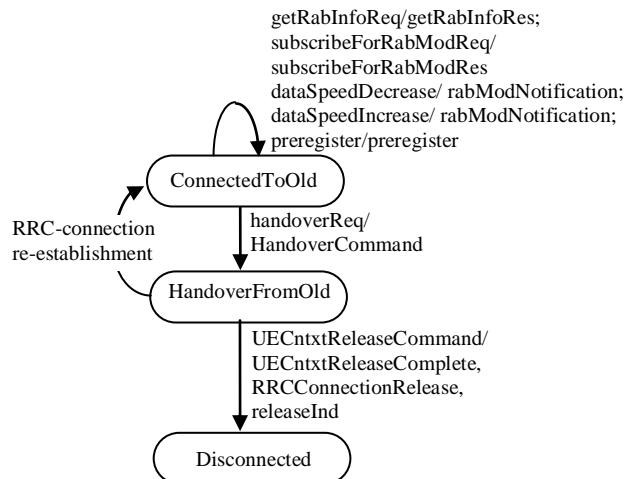


Figure 10 Handover state model as seen by the serving access network

In ConnectedToOld state, the UE is connected to the serving access network. Being in that state, the serving access network may provide actual radio network information to the mobile edge application, and may send notifications about RAB modifications in case of active subscription. The serving network relays the application request for pre-registration in the target network to the UE. In HandoverFromOld state, the UE performs handover procedure to the target access network as a result of receiving MobilityFromEUTRACommand [21]. When a UE context release command is received from the core network, the RRC connection is released, the mobile edge application is notified and the state becomes Disconnected.

Figure 11 shows the handover state model as seen by the target access network. In Disconnected state, the UE is not connected to the target access network. In Registering state, UE performs registration procedure. In Registered state, the UE is registered to the target access network. In ResourceReservation state, the target

access network reserves radio resources for the UE. In PathSwitch state, the path is switched to the target access network. In ConnectedToNew state, the UE is connected to the target access network, and the mobile edge application is notified about the handover result.

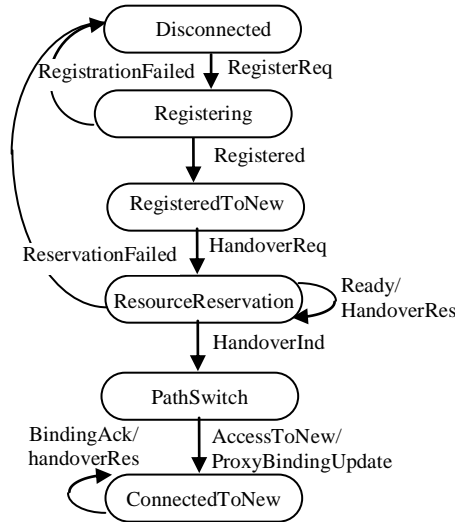


Fig.11 Handover state model as seen by the target access network

Let us present the state machines as Labeled Transition Systems (LTS) [25].

Definition 1: A Labeled Transition System (LTS) is a quadruple $(S, Act, \rightarrow, s_0)$, where S is countable set of states, Act is a countable set of elementary actions, $\rightarrow \subseteq S \times Act \times S$ is a set of transitions, and $s_0 \in S$ is the set of initial states.

By $TApp = (SApp, ActApp, \rightarrow App, s_0App)$ it is denoted an LTS representing the mobile edge application view on the handover state, where:

$$- SApp = \text{ConnectedToServing} (s_1^A), \text{LowDataSpeeds} (s_2^A), \\ \text{RegisteringInTarget} (s_3^A), \text{HandoverToTarget} (s_4^A), \\ \text{ConnectedToTarget} (s_5^A);$$

$$- ActApp = \text{getInfo} (t_1^A), \text{getRabInfoRes} (t_2^A), \\ \text{subscriberForRabModRes} (t_3^A), \text{dataSpeedDecrease} (t_4^A), \\ \text{dataSpeedDecrease} (t_5^A), \text{timerExpiry} (t_6^A), \text{registered} (t_7^A), \\ \text{registrationFailed} (t_8^A), \text{handoverRes} (t_9^A), \text{handoverFailed} \\ (t_{10}^A);$$

$$- \rightarrow App = (s_1^A t_1^A s_1^A), (s_1^A t_2^A s_1^A), (s_1^A t_3^A s_1^A), \\ (s_1^A t_4^A s_2^A), (s_2^A t_5^A s_1^A), (s_2^A t_6^A s_3^A), (s_3^A t_7^A s_4^A), \\ (s_3^A t_8^A s_1^A), (s_4^A t_9^A s_5^A), (s_4^A t_{10}^A s_1^A);$$

$$- s_0App = \{\text{ConnectedToServing}\}.$$

Short notations for states and actions are given in brackets.

By $ToldAN = (SoldAN, ActoldAN, \rightarrow oldAN, s_0oldAN)$ it is denoted an LTS representing the serving access network view on the handover state, where:

$$- SoldAN = \text{ConnectedToOld} (s_1^O), \text{HandoverFromOld} (s_2^O), \\ \text{Disconnected} (s_3^O);$$

$$- ActoldAN = \text{getRabInfoReq} (t_1^O), \\ \text{subscriberForRabModReq} (t_2^O), \text{dataSpeedDecrease} (t_3^O), \\ \text{dataSpeedIncrease} (t_4^O), \text{preregister} (t_5^O), \text{handoverReq} (t_6^O), \\ \text{RRCConnectionReestablishment} (t_7^O), \\ \text{UECntxtReleaseCommand} (t_8^O);$$

$$- \rightarrow oldAN = (s_1^O t_1^O s_1^O), (s_1^O t_2^O s_1^O), (s_1^O t_3^O s_1^O), \\ (s_1^O t_4^O s_1^O), (s_1^O t_5^O s_1^O), (s_1^O t_6^O s_2^O), (s_2^O t_7^O s_1^O), \\ (s_2^O t_8^O s_3^O);$$

$$- s_0oldAN = \{\text{ConnectedToOld}\}.$$

By $TnewAN = (SnewAN, ActnewAN, \rightarrow newAN, s_0newAN)$ it is denoted an LTS representing the target access network view on the handover state, where:

$$- SnewAN = \text{Disconnected} (s_1^N), \text{Registering} (s_2^N), \\ \text{RegisteredToNew} (s_3^N), \text{ResourceReservation} (s_4^N), \\ \text{PathSwitch} (s_5^N), \text{ConnectedToNew} (s_6^N);$$

$$- ActnewAN = \text{RegisterReq} (t_1^N), \text{Registered} (t_2^N), \\ \text{RegistrationFailed} (t_3^N), \text{HandoverReq} (t_4^N), \text{Ready} (t_5^N), \\ \text{HandoverInd} (t_6^N), \text{ReservationFailed} (t_7^N), \text{AccessToNew} \\ (t_8^N), \text{BindingAck} (t_9^N)$$

$$- \rightarrow newAN = (s_1^N t_1^N s_2^N), (s_2^N t_3^N s_1^N), (s_2^N t_2^N s_3^N), \\ (s_3^N t_4^N s_4^N), (s_4^N t_5^N s_4^N), (s_4^N t_7^N s_1^N), (s_4^N t_6^N s_5^N), \\ (s_5^N t_8^N s_6^N), (s_6^N t_9^N s_6^N);$$

$$- s_0newAN = \{\text{Disconnected}\}.$$

Having a formal description of the models representing handover status as seen by the mobile edge application, the serving access network, and the target access network, we can prove that these models are synchronized i.e. they expose equivalent behavior.

Intuitively, in terms of observed behavior, two LTSs are equivalent if one LTS displays a final result and the other LTS displays the same result. The idea of equivalence is formalized by the concept of bisimilarity [26]. In practice, strong bisimilarity puts strong conditions for equivalence which are not always necessary. In weak bisimilarity, internal transitions can be ignored.

Proposition: $TApp$, $ToldAN$ and $TnewAN$ are weakly bisimilar.

Proof: To prove the bisimilarity between any two labeled transition systems, it has to be proved that there exists a bisimilar relation between their states. Let us denote by $UAON$ a relation between states of $TApp$, $ToldAN$ and $TnewAN$ where

$$UAON = \{ (\text{ConnectedToServing}, \text{ConnectedToOld}, \\ \text{Disconnected}), \\ (\text{HandoverToTarget}, \text{HandoverFromOld}, \\ \text{ResourceReservation}),$$

(ConnectedToTarget, Disconnected, ConnectedToNew)}.

Then the following relation exists for UAON for the events related to intersystem handover:

1. The mobile edge application queries about radio network information and subscribers for RAB modification events related to a particular UE: for $(s_1^A t_1^A s_1^A), (s_1^A t_2^A s_1^A), (s_1^A t_3^A s_1^A) \exists (s_1^O t_1^O s_1^O), (s_1^O t_2^O s_1^O)$.
2. The mobile edge application receives notification about RAB modification (data speeds decrease), but before the expiry of the hysteresis timeout, the data speeds increase and the application is notified: for $(s_1^A t_4^A s_2^A), (s_2^A t_5^A s_1^A) \exists (s_1^O t_3^O s_1^O), (s_1^O t_4^O s_1^O)$.
3. The data speeds decrease, the hysteresis timeout expires, and the mobile edge application initiates UE (successful) registration and handover to the target access network: for $(s_1^A t_4^A s_2^A), (s_2^A t_6^A s_3^A), (s_3^A t_7^A s_4^A) \exists (s_1^O t_5^O s_1^O) \cap \{(s_1^N t_1^N s_2^N), (s_2^N t_2^N s_3^N), (s_3^N t_4^N s_4^N)\}$.
4. The data speeds decrease, the hysteresis timeout expires, and the mobile edge application initiates UE (unsuccessful) registration to the target access network: for $(s_1^A t_4^A s_2^A), (s_2^A t_6^A s_3^A), (s_3^A t_8^A s_1^A) \exists (s_1^O t_5^O s_1^O) \cap \{(s_1^N t_1^N s_2^N), (s_2^N t_3^N s_1^N)\}$.
5. In case of successful application-initiated handover to the target access network: for $(s_4^A t_9^A s_5^A) \exists (s_1^O t_6^O s_2^O), (s_2^O t_8^O s_3^O) \cap \{(s_4^N t_5^N s_4^N), (s_4^N t_6^N s_5^N), (s_5^N t_8^N s_6^N), (s_6^N t_9^N s_6^N)\}$.
6. In case of unsuccessful application-initiated handover to the target access network: for $(s_4^A t_{10}^A s_1^A) \exists (s_1^O t_6^O s_2^O), (s_2^O t_7^O s_1^O) \cap \{(s_4^N t_7^N s_1^N)\}$.
7. Therefore TApp, ToldAN and TnewAN are weakly bisimilar. ■

The synchronized behaviour of the models allows to prove in a mathematically formalized manner that the approach is consistently implementable. Mathematical formalism for equivalence of behaviour is used to generate model-based test situations in order to demonstrate compliance of a system's implementation with its specification.

6. Conclusion

Multi-access Edge Computing appears to be an integrating technology for recent radio access technologies to enhance the access capacity and QoE for end users.

In this paper, we present a new mobile edge service which opens the radio resource management for 3rd party applications, deployed in MEC environment. The service allows an authorized mobile edge application to apply specific handover policy based on device location, received QoS, required data speeds and the

average number of session drops. With existing radio resource management mechanisms in different radio access networks, it is the network or the device that initiates handover. With the proposed functionality, an authorized application may first initiate a device pre-registration into the target access network and then based on measurements it may initiate intersystem handover.

Deployment of RESTful API for intersystem handover control enables applications aimed at efficient usage of limited radio resources and optimization of radio resource management. For 3rd party application developers it is an opportunity to create new attractive applications, and for network operators it is a new source of revenue generation due to the reduction of data delivery cost.

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