Multi-access edge service for application-initiated offload

Evelina Pencheva, Denitsa Kireva, Ivaylo Atanasov

The growth in services for smart devices, such as video, music, social networking, gaming and other interactive applications, that become ubiquitously penetrated, sets requirements for high bandwidth and low latency, which the traditional centralized network architecture cannot face due to heavy burdens on the backhaul links and long delays. Multi-access Edge Computing (MEC) is an edge paradigm which deploys cloud services in the radio access network. The vicinity to the end users allows timely reaction to dynamic changes in radio conditions. Offloading is a promising technique for reducing the amount of data being carried on the cellular bands to alternative wireless ones. With existing solutions, it is the user who initiates offloading. In this paper, we propose a new mobile edge service that allows mobile edge applications to initiate offloading. The offloading trigger may be congestion in the radio access network, quality of service experienced by the user, user location, etc. The service is described by use cases, a data model and application programming interfaces. The data model represents the resources as a tree structure, provides applications with data-mediation functions as far as it is a meaningful way for addressing resources. As a proof of concept, models representing the offloading state as seen by the application, serving and target access networks are proposed and formally verified.

Keywords – Edge computing, Proximity-based service, Application programing interfaces, Finite state machines

Услуга за множествен достъп за приложения, иницииращи разтоварване (Евелина Пенчева, Деница Кирева, Ивайло Атанасов). *Нарастването на броя на услугите за интелигентни устройства като видео, музика, социални мрежи, игри и други интерактивни приложения, които се разгръщат повсеместно, поставя изисквания за широка честотна лента и ниска латентност, които традиционната централизирана мрежова архитектура не може да предложи поради натоварването на връзките в опорната мрежа и големите закъснения. Multi-access Edge Computing (MEC) е парадигма за края на мрежата, която разгръща облачните услуги в мрежата за радиовръзка. Близостта до крайните потребители позволява своевременна реакция при динамични промени в радиоусловията. Разтоварването е обещаваща техника за намаляване на количеството данни, пренасяни от клетъчните радиомрежи към алтернативни безжични такива. При съществуващите решения потребителят започва разтоварването. В тази статия предлагаме нова услуга в мрежата за радиодостъп, която позволява на мобилните приложения да инициират разтоварване. Причина за разтоварването може да бъде претоварване в мрежата за радиодостъп, качеството на обслужване, предоставено от потребителя, местоположението му и т.н. Услугата е описана посредством случаи на използване, модел на данни и приложни програмни интерфейси. Моделът за данни представя ресурсите като дървовидна структура и предоставя на приложенията с функции за медиация на данни, доколкото това е начин за адресиране на ресурсите. Като доказателство на концепцията са предложени и формално проверени модели, представящи състоянието на разтоварване, от гледна точка на приложението, обслужващата и целевата мрежа за достъп.*

Introduction

The ubiquitous penetration of smart devices with embedded capabilities for multi-radio technologies operation and the exposure of attractive applications like video, streaming, gaming, social networking etc. become a challenge for traditional telecom operators which have deployed centralized architectures. These architectures feature long latency and heavy load on the backhaul links. Therefore, new architectures that bring the network function control close to the edge of the mobile network are needed.

Multi-access Edge Computing (MEC) is a relatively new paradigm that brings cloud capabilities into the radio access network [1]. The vicinity to the end users enables applications with low latency and high bandwidth requirements, which may be provided with real time radio network information and location awareness [2].

MEC may be useful in migrating cellular data traffic to supplementary networks using different communication technologies such as Wireless Access Network (WLAN) and thus mitigating the radio access network overloading [3], [4].

To provide seamless roaming and service continuity there is a need to combine various wireless access technologies and provide reliable intersystem handover strategies [5]. Related works on intersystem handover are focused on performance optimization [6], [7], [8] and algorithms for handover decision [9], [10], [11].

With the current solutions, it is the User Equipment (UE) that initiates offloading. The network provides access network discovery and selection information which reflects the telecom operator preferences for access prioritization, but the final choice is delegated to the user.

In this paper, we propose a new mobile edge service which allows mobile edge applications to initiate offloading based on application specific policies. The triggers for application-initiated offloading may be real-time information about access network congestion, user location, quality of service experienced by the user, requested data speeds, call drops, and even information about available user credit.

Following the adopted RESTful style for definition of mobile edge service interfaces, we model resources as tree structure which provides great flexibility of addressing resources and creation of new resources. We also discuss actual interface definition by providing HTTP methods that may be used for resource manipulation. To prove our concept, we describe the offloading state models which represent the application's, serving and target access networks' views, and show that these models expose equivalent behavior.

The paper is structured as follows. Next section provides an informative description of the new mobile edge computing service, illustrating the service functionality by a use case. Then a data model that provides data-mediation functions is described and some examples of mobile edge service interfaces are provided. Before the conclusion, the offloading models as seen by the application, serving cellular access network, and target WLAN, are described and formally verified. The conclusion summarizes the author contribution.

Informative service description

The proposed mobile edge service for WLAN offloading allows applications running at the edge of the network to control mobile data offloading i.e. to trigger usage of WLAN technology for delivering data targeted originally for cellular network.

There are several different technologies that fall into the WLAN category. An existing industry standard is IEEE 802.11b operating in the 2.4 GHz ISM band. A new entrant for this same band is Bluetooth. New technologies such as IEEE 802.11a and ETSI BRAN Hiperlan2 are being developed for 5GHz bands. It is recognized that WLANs are, and will continue to be deployed by independent (i.e. non 3GPP) operators and that these WLANs may or may not be interworked with a 3GPP system. Further, these WLANs may overlap with WLANs that are interworked with 3GPP systems, and they may also overlap each other. These situations create multiple permutations of coverage areas and service states which will need to be carefully understood and managed.

Mobility is a mechanism of switching between 3GPP (e.g. LTE) and non-3GPP (e.g, WLAN) networks. For a subscriber, the motivation to switch the used communication channel from LTE to WLAN during connection is to get access to wider bandwidth and probably in lower cost or free. For mobile network operators it would help to reduce the load on the LTE network by offloading the subscriber to WLAN network. The network operator may not be able to charge for WLAN network usage as much as for LTE network, but they may be able to get some gain from load balancing and still keep some portions of the money from the mobile user by directing to switch to the WLAN network serviced by the mobile network operator (not free WLAN).

With existing standards, it is the user that may initiate WLAN offloading [12]. It is the network that provides information about access network discovery and selection, and thus controls offloading between 3GPP and non-3GPP access networks. The purposes of access network discovery and selection function is to assist UE to discover access networks in their vicinity and to provide policies to prioritize and manage connections to available networks, but the final decision on the choice of access network is up to the user. The UE periodically performs WLAN scanning and when a WLAN network is found, an offloading procedure is initiated where the user is prompted to select what network technology to be used.

The research novelty is that with the proposed approach, it is an authorized mobile edge application that may initiate WLAN offloading based on specific application defined policy. For example, the application may trigger WLAN offloading in case of radio access network congestion or based on user location. Another reason may be quality of service (QoS) experienced by the user or requested uplink and/or downlink data speeds. An authorized mobile edge application may use MEC Location API to receive information about UE location, or Open Mobile Alliance (OMA) diagnostics and trap monitoring mechanism to acquire information about available access networks and QoS experienced by the UE [13]. The application may be hosted by network operator or by 3rd party. The benefit for deployment the application driven offload functionality as a MEC service is more timely reaction on dynamic changes in radio network conditions. Moving the WLAN offloading trigger logic to 3rd party application enables creation and deployment of attractive applications that implement different offloading policies.

There are two methods for mobility: network initiated, and UE initiated. The proposed approach for application driven WLAN offloading is based on network initiated mobility.

There exist several 3GPP-WLAN interworking scenarios. The goal of WLAN offloading scenario is to provide seamless service continuity between the access technologies. Seamless service continuity means minimizing aspects such as data loss and break time during the switch between access technologies.

Use case: Being a 3GPP subscriber, Alice possesses a VoIP capable, i.e. multimedia, terminal device. She prefers to use 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 equipment, and thus, switching the 3GPP and WLAN accesses, whenever it's necessary, assures the session continuity.

Fig.1 shows the overall procedure for the case where UE starts communication from LTE and a mobile edge application initiates a switch to WLAN (trusted non-3GPP).

The case assumes that UE is connected to LTE before the switch (handover) and not connected in WLAN. If UE is already connected both to LTE and WLAN before this handover, it will skip the steps related to WLAN registration and directly jump to L3 configuration.

The UE has established tunnel for user data to the core network. Following specific policy the application may initiate WLAN offloading. In order to provide seamless service continuity, this results in inter-system handover from 3GPP serving access network to trusted target WLAN. The serving access network initiates RRC (Radio Resource Control) connection reconfiguration procedure.

The UE in turn initiates WLAN registration which includes EAP (Extensible Authentication Protocol) authentication and WLAN tunnel establishment. L3 Configuration procedure is aimed at acquiring of IPv4 address and/or IPv6 prefix for autoconfiguration. Being configured, the UE may switch to WLAN access. The core network initiates bearer deactivation procedure followed by RRC connection release, which includes the release of the established radio bearers as well as all radio resources. The mobile edge application is notified about the successful offloading to the target WLAN.

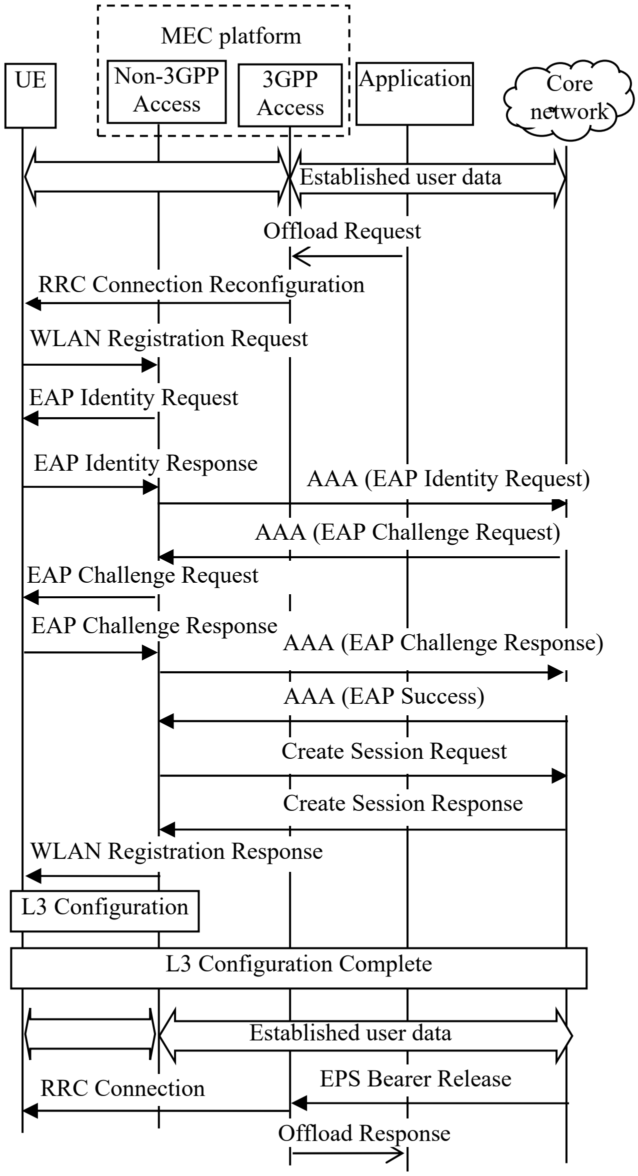

Fig.1. Mobile edge application initiated handover from 3GPP access to trusted WLAN.

Data model

REST is an architectural style for distributed systems which features loose coupling of components and stateless interactions. In REST, a distributed application is composed of resources. A resource can be addressing using HTTP Uniform Resource Identifier

(URI). It has a particular state and may be manipulated by four basic interactions: CREATE, READ, UPDATE and DELETE. The REST operations can be mapped onto HTTP methods: CREATE is mapped onto POST, READ onto GET, UPDATE onto PUT, and DELETE onto DELETE.

The data model of the proposed mobile edge service represents the resources as a tree structure. This provides applications with data-mediation functions and it is a meaningful way for addressing resources. The tree structure of resources is illustrated in Fig.2.

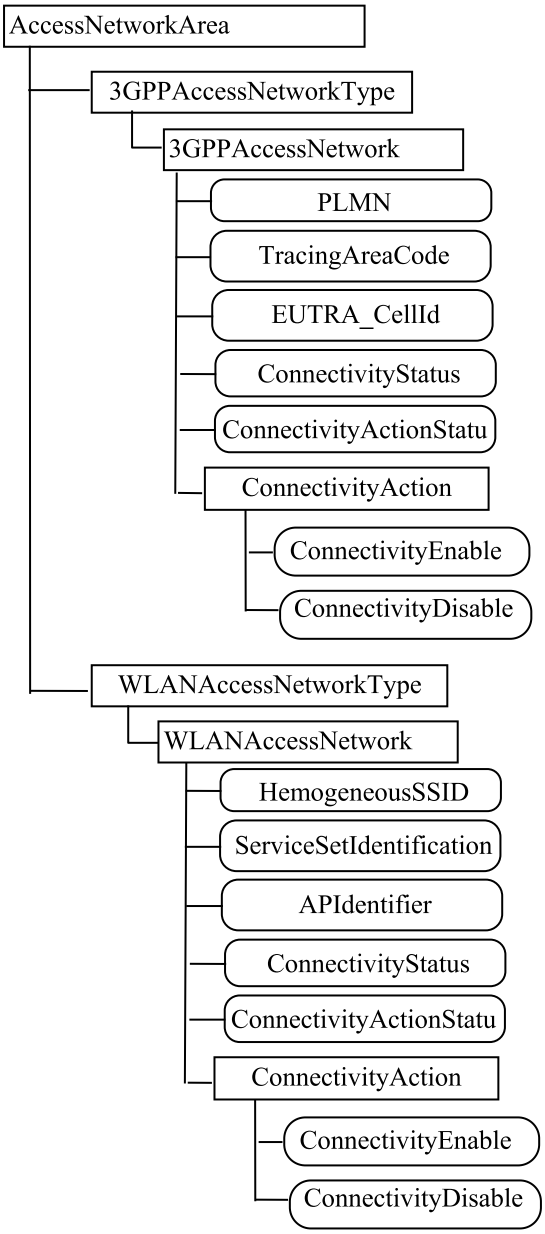

Fig.2 Resources representing access network area.

The AccessNetworkArea resource is a placeholder for one or more access network types available for the UE. For the purpose of interworking between 3GPP access networks and WLAN access networks it is assumed that the available access network types are represented by 3GPPAccessNetworkType and WLANAccessNetworkType resources. The tree structure may be extended in case of offloading to other access networks like 3GPP2 and WiMAX. Each of 3GPPAccessNetworkType and WLANAccessNetworkType 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 WLANAccessNetwork resource contains information about a WLAN access network available for the UE. The type of 3GPP access network may be E-UTRAN (LTE and LTE Advanced), GERAN (radio access network of GSM/GPRS) and UTRAN (radio access networks of UMTS-based technology).

Each 3GPP access network has attributes that describe the public land mobile network (PLMN) code and cell global identity. Each WLAN access network has attributes that describe the wireless network name. An extended service set (ESS) is one or more interconnected basic service sets (BSSs) and their associated LANs. Each BSS consists of a single access point (AP) together with all wireless client devices creating a local or enterprise 802.11 wireless LAN (WLAN). The Extended Service Set Identification (ESSID) is one of two types of Service Set Identification (SSID). In an ad hoc wireless network with no access points, the Basic Service Set Identification (BSSID) is used. In an infrastructure wireless network that includes an access point, the ESSID is used, but may still be referred to as SSID.

Common attributes for all access networks are ConnectivityStatus and ConnectivityActionStatus. The ConnectivityStatus attribute shows the UE connectivity status with respect to the particular access network (if it is true, then UE is connected, if false – the UE is disconnected). The ConnectivityActionStatus attributes show the status of the connectivity action (including a progress indicator, a final state and a reminder of the requested action). The ConnectivityAction resource contains sub-resources indicating the handover action which to allow and disable connectivity. The connectivityEnable attribute initiates handover to the target access network and the connectivityDisable attribute initiates the release of radio resources in the serving access network. The execution of an action is triggered by the UPDATE of the corresponding action type.

Following the ETSI way of resources addressing, all resource URIs of the proposed mobile edge service have the following root:
{apiRoot}/apiWlanOffload/v1,
where apiRoot and apiWlanOffload are discovered

using service registry. The JSON content format is supported.

Table 1 provides an overview of the defined resources and applicable HTTP methods.

Table 1

Resources and applicable HTTP методs

Resource name	Resource URI	HTTP method
AccessNet-workArea	/AccessNetworkArea	GET
3GPPAccess NetworkType	/AccessNetworkArea/ 3GPPAccessNetworkType	GET
3GPPAccess Network	/AccessNetworkArea/ 3GPPAccessNetworkType/ 3GPPAccessNetwork	POST, GET, PUT, DELETE
WLANAccess NetworkType	/AccessNetworkArea/WLAN AccessNetworkType	GET
WLANAccess Network	/AccessNetworkArea/WLAN AccessNetworkType/ 3GPPAccessNetwork	POST, GET, PUT, DELETE
WLANAccess NetworkType	/AccessNetworkArea/WLAN AccessNetworkType	GET, PUT, DELETE
Connectivity Action	/AccessNetworkArea/ {AccessNetworkType}/ {AccessNetwork}/ ConnectivityAction	GET, PUT

Fig.3 shows a successful application-initiated offloading.

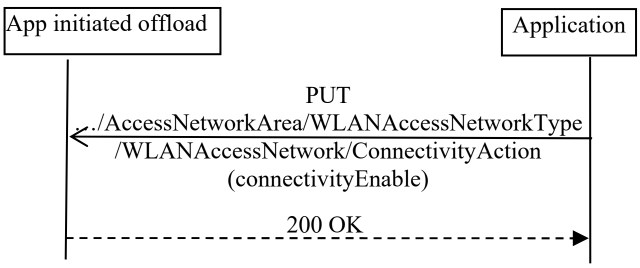

Fig.3 Successful application-initiated offloading to WLAN.

Fig.4 shows an unsuccessful application-initiated offloading. Other possible responses indicating unsuccessful application-initiated offloading 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).

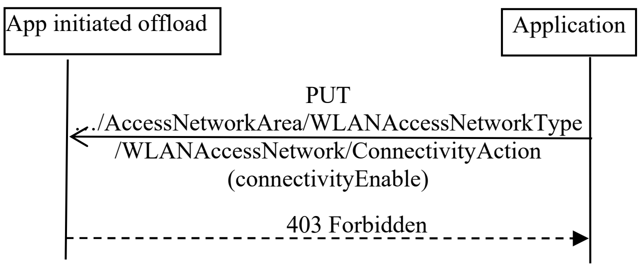

Fig.4 Unsuccessful application- initiated offloading to WLAN.

Offloading state models

As a proof of the concept, we design models representing the application, serving 3GPP access network and target WLAN. These models for a given UE have to be synchronized i.e. to expose equivalent behavior.

Fig.5 shows the mobile edge application view on the offloading state. In ConnectedTo3gpp state, the UE is connected to the serving 3GPP access network. Following a predefined policy, the Application may decide to initiate a UE offloading to the target WLAN. In ConnectedToWlan state, the UE successfully has performed the WLAN offload.

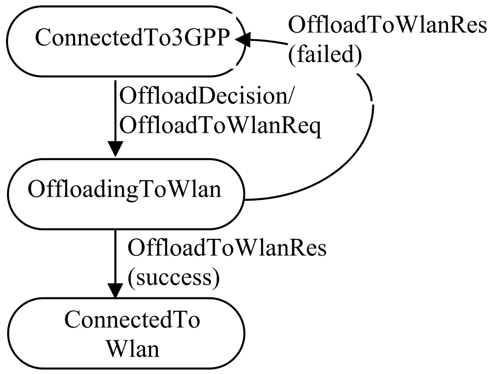

Fig.5 Application view on the offloading state.

Fig.6 shows the offloading state model as seen by the serving 3GPP access network. In 3gppConnected state, the UE is connected to the serving 3GPP access network. In HandoverToWlan state, the UE performs handover procedure to the target WLAN. In 3gppDisconnected state, the UE is disconnected from the 3GPP access network.

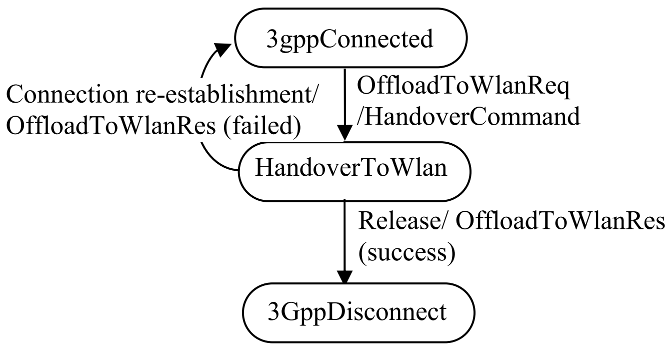

Fig.6 Offloading state model as seen by the serving 3GPP access network.

Fig.7 shows the offloading state model as seen by the target WLAN. In WlanDisconnected state, the UE is not connected to the target WLAN. In Registering state, UE performs registration procedure, including authentication and session establishment. In Registered state, the UE is registered to the target WLAN. In L3Configuration state, the UE acquires IP address.

In WlanConnected state, the UE is connected to the target WLAN.

Let us present the state machines as Labelled Transition Systems (LTS).

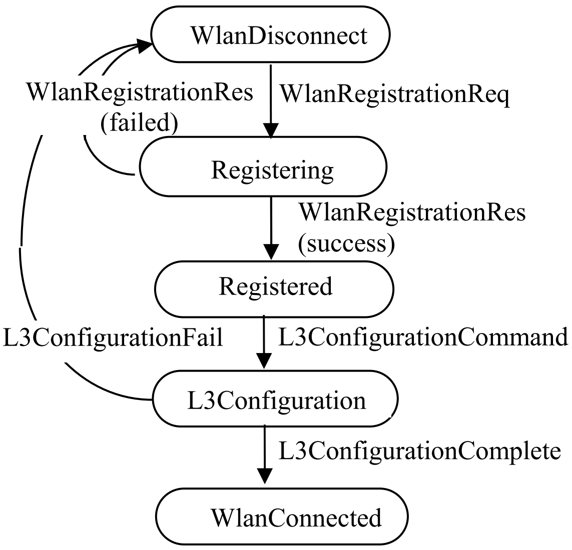

Fig.7 Offloading state model as seen by the target WLAN.

Definition 1: A *Labelled 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 $T_{App} = (S_{App}, Act_{App}, \rightarrow_{App}, s_0^{App})$ it is denoted an LTS representing the Application view on the offloading state, where:

- S_{App} = ConnectedTo3GPP (s_1^A), OffloadingToWlan (s_2^A),ConnectedToWLAN (s_3^A);
- Act_{App} = OffloadDecision (t_1^A), OffloadToWlan(success) (t_2^A), OffloadToWlan(failed) (t_3^A);
- $\rightarrow_{App} = (s_1^A\ t_2^A\ s_2^A), (s_2^A\ t_3^A\ s_1^A), (s_2^A\ t_2^A\ s_3^A)$;
- s_0^{App} = {Connected}.

Short notations for states and actions are given in brackets.

By $T_{3GPP} = (S_{3GPP}, Act_{3GPP}, \rightarrow_{3GPP}, s_0^{3GPP})$ it is denoted an LTS representing the serving 3GPP access network view on the offloading state, where:

- S_{3GPP} = 3gppConnected (s_1^O), HandoverToWlan (s_2^O), 3gppDisconnected (s_3^O);
- Act_{3GPP} = OffloadToWlanReq (t_1^O), Release (t_2^O), ConnectionReestablishment (t_3^O);
- $\rightarrow_{3GPP} = (s_1^O\ t_1^O\ s_2^O), (s_2^O\ t_3^O\ s_1^O), (s_2^O\ t_2^O\ s_3^O)$;
- s_0^{3GPP} = {3gppConnected}.

By $T_{WLAN} = (S_{WLAN}, Act_{WLAN}, \rightarrow_{WLAN}, s_0^{WLAN})$ it is denoted an LTS representing the target WLAN view on the offloadfing state, where:

- S_{WLAN} = WlanDisconnected (s_1^N), Registering (s_2^N), Registered (s_3^N), L3Configuration (s_4^N), WlanConnected (s_5^N);
- Act_{WLAN} = WlanRegisterationReq (t_1^N), WlanRegisterationRes(success) (t_2^N), WlanRegisteration-Res(failed) (t_3^N), L3ConfigurationCommand (t_4^N), L3ConfigurationComplete (t_5^N), L3ConfigurationFail (t_6^N);
- $\rightarrow_{WLAN} = (s_1^N\ t_1^N\ s_2^N), (s_2^N\ t_3^N\ s_1^N), (s_2^N\ t_2^N\ s_3^N), (s_3^N\ t_4^N\ s_4^N), (s_4^N\ t_6^N\ s_1^N), (s_4^N\ t_5^N\ s_5^N)$;
- s_0^{WLAN} = {WlanDisconected}.

The mathematical concept of weak bisimulation is used to prove that the three models expose equivalent behaviour.

Intuitively, in terms of observed behaviour, 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 [14]. In practice, strong bisimilarity puts strong conditions for equivalence which are not always necessary. In weak bisimilarity, internal transitions can be ignored.

Proposition: T_{App}, T_{3GPP} and T_{WLAN} are weakly bisimilar.

Proof: To prove the bisimilarity between any two labelled transition systems, it has to be proven that there exists a bisimilar relation between their states. Let us denote by U_{AON} a relation between sates of T_{App}, T_{3GPP} and T_{WLAN} where
U_{AON}={(ConnectedTo3GPP, 3gppConnected, WlanDisconnected),
(OffloadingToWlan, HandoverToWlan, Registering,
(ConnectedToWLAN, 3gppDisconnected, WLANConnected)}.

It is necessary to identify sequences of transition for the following states: from s_1^A, s_1^O, s_1^N to s_2^A, s_2^O, s_2^N; from s_2^A, s_2^O, s_2^N to s_3^A, s_3^O, s_5^N; and from s_2^A, s_2^O, s_2^N to s_1^A, s_1^O, s_1^N.

Then the following U_{AON} relation exists for the events related to WLAN offloading:

1. In case of application-initiated offload to target WLAN: for $(s_1^A\ t_2^A\ s_2^A)$ $\exists$ $(s_1^O\ t_1^O\ s_2^O)$ $\sqcap$ $(s_1^N\ t_1^N\ s_2^N)$.
2. In case of successful application-initiated offloading to target WLAN: for $(s_2^A\ t_2^A\ s_3^A)$ $\exists$ $(s_1^O\ t_1^O\ s_1^O)$

$\sqcap \{(s_2^O\ t_2^O\ s_3^O), (s_3^N\ t_4^N\ s_4^N), (s_4^N\ t_5^N\ s_5^N)\}$.

3. In case of unsuccessful application-initiated offloading to target WLAN: for $(s_2^A\ t_3^A\ s_1^A)\ \exists\ (s_2^O\ t_3^O\ s_1^O)\ \sqcap\ \{(s_2^N\ t_3^N\ s_1^N)\ \sqcup\ (s_2^N\ t_2^N\ s_3^N), (s_3^N\ t_4^N\ s_4^N), (s_4^N\ t_6^N\ s_1^N)\}$.

Therefore T_{App}, T_{3GPPN} and T_{WLAN} are weakly bisimilar.

Conclusion

Multi-access Edge Computing appears to be an integrating technology for cellular and wireless technology as it may face the requirements for low latency, massive connectivity, and high reliability of a large number of applications.

In this paper, we present a new mobile edge service which provides open access to offloading functions in the radio access network. The service allows an authorized application to apply specific offloading policy based on terminal location, experienced QoS, requested data speeds, and the average number of call drops. With existing radio resource management mechanisms in different radio access networks it is the network or the device that initiates handover. The novelty of the research is the delegating the offloading control to third party applications. With the proposed functionality, an authorized application may first initiate a device preregistration into the target access network and then based on measurements may initiate change of used radio access bearer.

Deployment of RESTful API for WLAN offloading 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 costs.

Acknowledgements

The research is conducted under the grant of project DH07/10-2016, funded by National Science Fund, Ministry of Education and Science, Bulgaria.

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Received on: 07.01.2018