MODELLING OF VERTICAL HANDOVER FROM UNTRUSTED WLAN NETWORK TO LTE

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KEYWORDS

Vertical handover, 3GPP access network, LTE, modelling, simulation, untrusted WLAN.

ABSTRACT

Nowadays, operators offer telecommunication services at a very high level. For the support of the best quality of service it would be reasonable to implement a handover to another radio access network cell in the same territory, a so-called vertical handover (VHO), by transferring the user connection and IP session from the current access network to a new network. In this paper, we analyze vertical handovers from an untrusted WLAN network to an LTE network. This type of handover from an untrusted WLAN network is the most difficult because of the many nodes of an LTE network related to authorization and resource allocation. The paper includes a synthesis of the basic procedures for the session setup and LTE resource allocation. Unlike other papers, we represent a complicated VHO procedure as a sequence of at least 40 signalling messages from the discovery of a new network for the VHO to its full completion at the target LTE network. We also propose a vertical handover time estimation method for the said VHO procedure. We perform numerical experiments on realistic data.

INTRODUCTION

Modern wireless access networks can be characterized as heterogeneous and ubiquitous with overlapping and seamless mobile and IP–connectivity. Enhanced quality of service (QoS) for the delivery of multimedia services can be made through a handoff to the best network from the point of view of such criteria as increasing received signal strength (RSS), decreasing handover latency, increasing available bandwidth, optimal power consumption, satisfaction of user preferences with some decision schemes (Ahmed et al., 2014).

Handover process is categorized into vertical handover (VHO) and horizontal handover (HHO). Horizontal handover occurs in homogeneous network. This type of handover is well researched. A vertical handover occurs when user equipment (UE) switches between the cells of two different networks located on the same territory but which support different radio access technologies. During a VHO process, the UE can fetch a new physical connection and a new IP session. In (Abdoulaziz et al., 2012), the VHO time (or latency) is discussed as one of the main parts of a handover process because a mobile terminal may leave the WLAN area before the VHO to a 3GPP network will be completed. In (Yu et al. 2013) there is a case with lost or buffering packets due to a time out in the WLAN–3GPP VHO. Since VHO time has a clear impact on QoS and mobility, an analytical estimation of VHO time should be useful for reasonability analysis of VHO decision making in real time.

This paper is organized as follows: the "VHO standardizations and specifications" section is devoted to the analysis of current VHO standards and technical specifications. The "WLAN–LTE VHO procedure design" section includes information on a step–by–step time-dependent VHO procedure. The "Mathematical modelling of VHO procedures" section includes an analytical model of the discussed VHO procedure. A numerical example for initial realistic data is shown in the "Numerical experiment" section.

VHO STANDARDIZATIONS AND SPECIFICATIONS

One of the main technical specifications which considers VHO architecture, principles and scenarios is the (3GPP TS 23.402 2016). This standard has been designed for non-3GPP access network interconnection with an Evolved 3GPP Packet Switched (EPS) domain. This technical specification describes an IP–based protocol for evolved UMTS Terrestrial Radio Access Networks (E–UTRAN). EPS may provide the UE with assistance data and policies about available networks for VHO by establishing secure communication in the form of an IP tunnel between the UE and the EPS core. This means that the security aspects of a 3GPP access and non–3GPP (non–compliant access with 3GPP specification) need to be taken into consideration for the VHO procedure and VHO time estimation. Some security aspects of VHOs are described in (3GPP TS 33.222

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2016) where an authentication mechanism was proposed for the UE. This mechanism is appropriable for an HTTP client and server which can authenticate each other based on a shared key, generated during the bootstrapping procedure. The shared key can be obtained as a master key for the generation of transport layer security (TLS) session keys to protect initial signalling messages between the UE and the access network discovery and selection function (ANDSF). The ANDSF is a source of information about a network for VHOs. In (3GPP TS 33.402 2016), there are additional descriptions of an IPsec-based double-stack mobile IPv6 (DSMIPv6) protocol and security associations with the Internet Key Exchange version 2 (IKEv2). The IPsec security association is established between the UE and the 3GPP node which acts as a home agent (HA).

In the content of the VHO, the IEEE 802.21 procedure (IEEE Std 802.21–2008 2008) acts as a Media Independent Handover Function (MIHF). The MIHF provides abstracted services concerning VHO policy and signaling to higher layers (from Level 3 OSI and higher) with technology-specific protocol entities. The MIHF communicates with the lower layers (Level 2 OSI) as a logical part of the mobility-management protocol stack through technology-specific interfaces. Generally, the IEEE 802.21 MIH architecture and protocol are more abstracted than the 3GPP technical specification and no detailed procedure of a VHO between WLAN and 3GPP (LTE) networks is specified.

The efforts of the IETF are aimed at IP–mobility, authentication and security procedures concerning VHO. RFC 5996 (The Internet Engineering Task Force RFC 5996 2010) and RFC 4555 (The Internet Engineering Task Force RFC 4555 2006) contain specifications of an IKEv2 protocol that allows the IP addresses associated with IKEv2 and tunnel mode IPsec security associations to change. RFC 4793 (The Internet Engineering Task Force RFC 4793 2007) describes a certificate-based authentication method of the client host followed by Extensible Authentication Protocol (EAP) authentication of the user. One of the key specifications in the context of RFC 5555 (The Internet Engineering Task Force RFC 5555 2009) declares that the IPv6 protocol is not widely deployed. It is a reasonable option to extend MIPv6 capabilities to allow dual stack mobile nodes to request that their HA tunnel IPv4/IPv6 packets be addressed to their home addresses, as well as their IPv4/IPv6 care-of address (CaO). Extensions are defined for the binding update and binding acknowledgement. Finally, RFC 6611 (The Internet Engineering Task Force RFC 6611 2012) defines the MIPv6 bootstrapping procedures. It enables the assignment of home agents by utilizing the Dynamic Host Configuration Protocol (DHCP) v6 and the Authentication, Authorization, and Accounting (AAA) protocol.

Due to the design of the VHO time estimation method, it is important to form a WLAN–LTE VHO procedure that is associated with real network performance values. In the context of procedure design, the 3GPP interworking architecture for 3GPP and non–3GPP access networks is more preferable than IEEE 802.21 MIH. Our model fully complies with the technical specifications of 3GPP.

WLAN-LTE VHO PROCEDURE DESIGN

As shown above, one of the substantial elements in a 3GPP–based VHO is the ANDSF, which provides an inter–system mobility policy, network access discovery information with a list of prioritized networks for VHO as well as a WLAN selection policy and rules. The ANDSF is responsible for delivering information on discovered access networks in response to UE requests. For example, the ANDSF may list the prioritized networks for VHO in response to the UE request so that the 3GPP (LTE) has a maximal priority of 1, WLAN (Wi-Fi) has a priority of 2, while WLAN (WiMAX) has a priority of 3. There is a document (3GPP TS 23.002 2016) that specified the S2a interface for trusted non–3GPP IP access, and the S2c interface for untrusted non–3GPP access. Trusted and untrusted non-3GPP access networks support the IP protocol and use radio/wireless or fixed access technology whose specification and standardization is out of the scope of 3GPP. “Trusted” means full support of 3GPP–based authentication. For interaction between the UE and the ANDSF there is the S14 interface.

The discovery part of the procedure using the ANDSF was simulated in (Xenakis et al. 2016) but without a detailed description of VHO execution after decision making and with no general mathematical model for the establishment of a new connection. In (Triantafyllopoulou et al. 2012), a new network discovery algorithm was proposed for the VHO decision stage but with no mathematical modelling of the VHO procedure execution phase.

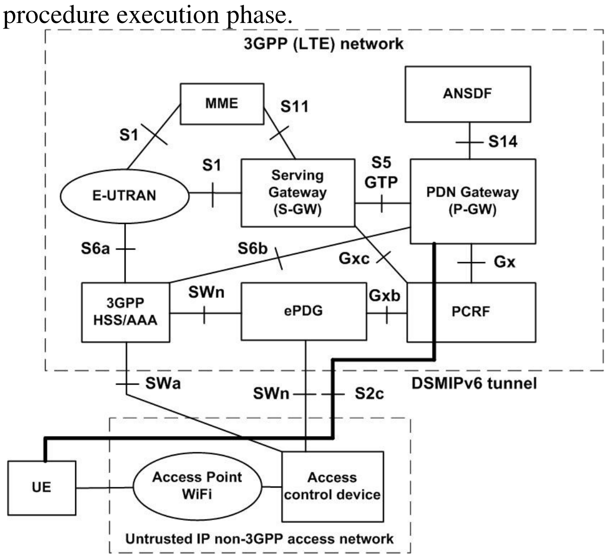

Figure 1: Architecture for WLAN – LTE VHO

For the following research, let’s suppose that the UE receives a list of prioritized networks for a VHO i.e. the decision making process has been finished and the results have been placed into a list. The VHO procedure will be based on host–based mobility, where the VHO is initiated by the UE (a mobile terminal) in accordance with (Boccardi et al. 2014) within a 5G device-centered network architecture. The architecture used for VHO time estimation is shown in Fig. 1. All interfaces in Fig. 1 are specified by 3GPP. The Access point and access control device belonging to the non-3GPP access network were described in (Gast 2005) and both support connection and information exchange between WLAN and 3GPP. A mathematical model of this architecture and VHO procedure will provide at least an upper bound for VHO time estimation.

On the side of the 3GPP network, there is an E-UTRAN subsystem and an EPS. The E-UTRAN in the context of this work supports a physical connection between the UE and 3GPP network. The home subscriber server (HSS) is combined with an AAA server and supports the registration, authentication and authorization of the UE in the 3GPP network. The Mobility Management Entity (MME) is responsible for Serving Gateway (S-GW) and Packet Data Network (PDN) Gateway (P-GW) selection, roaming, authentication, dedicated bearer establishment and the transfer of information between the MME and HSS/AAA.

The Evolved Packet Data Gateway (ePDG) can be used for the decapsulation and encapsulation of packets for IPSec tunnels, tunnel authentication and authorization, care–of–addresses (CoAs) for associating this mobile node with visited mobile networks including CoA for S2c. The S-GW is responsible for packet routing and forwarding, transport level packet marking in the uplink and the downlink. The P-GW provides PDN connectivity to the UE using non-3GPP access networks. The Home network Policy and Charging Rules Function (hPCRF) supports UE serving policy decision making, charging control of service data flow and the IP bearer resources.

The scheme of a step-by-step VHO procedure based on the 3GPP specifications can be divided into (#) phases. Phase A is presented in Fig. 2. Step (1) is the initial stage of the procedure. The UE sends a message via a non-trusted 3GPP IP access network with an ANDSF server host name. The ANDSF server name is public. Steps (2)–(3) include a special request–respond message with a pre–shared key before TLS tunnel establishment. Step (4) is a TLS finish message which is a part of the handshake procedure.

Step (5) is a request from the UE to the ANDSF to retrieve information on discovered networks Step (6) is the ANDSF's response with information on the available access networks, mobility rules and ePDG configuration information. The UE turns on a radio interface, measures access network characteristics (e.g. RSS) and selects a preferable access network (e.g. 3GPP LTE) for the VHO.

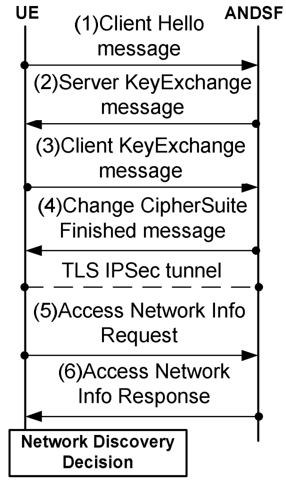

Figure 2: WLAN – LTE VHO Procedure Phase A

Phase B is presented in Fig. 3. Step (7) includes the UE state with the initial request for attachment to the 3GPP ePDG.

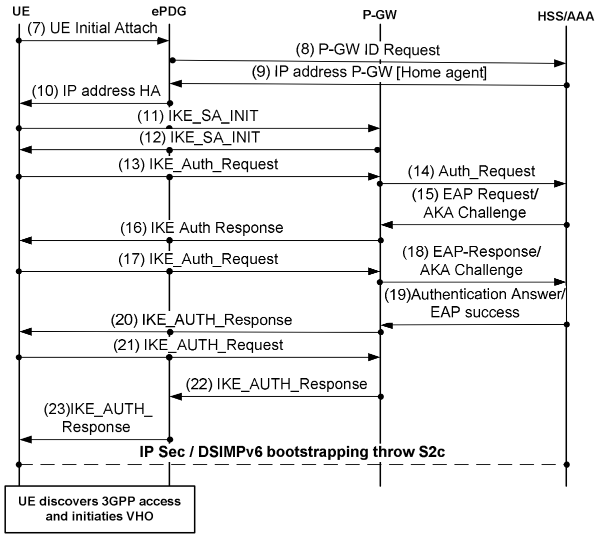

Figure 3: WLAN – LTE VHO Procedure Phase B

Step (7) includes the UE action of sending an Initial Attach message to the ePDG. Step (8) is where the ePDG sends the request from step (7) for P-GW identification to the 3GPP HSS/AAA. Step (9) includes the selection of the P-GW closest to the ePDG by the HSS/AAA; the IP address of the P-GW or the HA is sent by the HSS/AAA to the ePDG. Step (10) includes the further transmission of the IP address or HA to the UE by the ePDG. Steps (11) and (12) include the initiation of an IKEv2 exchange using a cryptographic algorithm and the successful result of this exchange.

Step (13) includes the authorization procedure to obtain an IPv6 network prefix and to protect DSMIPv6 signaling for future communication. Steps (14) and (15) are responsible for UE authentication in the 3GPP with an Authentication and Key (AKA) 3GPP protocol and DSMIPv6 with security support. Step (16) includes the transmission of security parameters to the UE for the

EAP procedure to restart the IKEv2. Step (17) is needed for the IKEv2 parameters to be checked by the UE and the generation of a UE response message as an EAP message for the P-GW and HSS/AAA. Steps (18) and (19) include the final part of the authorization procedure, where the HSS/AAA generates an Authentication Answer of EAP success. Step (20) is the translation of an EAP success message to the UE.

Step (21) includes the process of generating the Master Session Key (MSK) on the side of the UE and the generation of authentication parameters with the MSK. These parameters will be sent to the P-GW from the UE. Steps (22) and (23) describe the reception of the assigned IP address for the UE. After step (23), there is a secure IPsec tunnel for an S2c interface and the UE has authorization for VHO initialization via 3GPP.

Phase C is presented in Fig. 4. Steps (24) - (26) are the attachments/connections at the physical (L1) and channel (L2) levels to the eNode (LTE base station). Steps (27) - (30) are the sequential requests for a VHO IP–session establishment for the UE in the 3GPP network. Steps (31) - (33) are the responses containing a session grant and parameters. As a result, there is an establishment of a radio and access bearer.

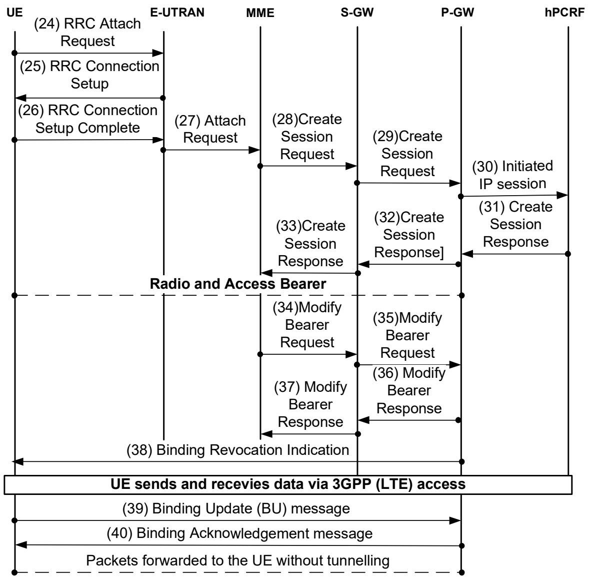

Figure 4: WLAN – LTE VHO Procedure Phase C

Steps (34) - (37) are needed to modify packet connection and then to tunnel the packets from the untrusted non-3GPP IP network to the 3GPP (LTE) access network and EPS, routing packets to the S-GW for the radio and access bearer. We must note that steps (36) and (38) could either occur simultaneously or after a specific time interval.

Step (38) is initialized by the P-GW approx. after a 1 ms expiration delay in accordance with the P-GW delay from (Nikaein and Krco, 2011). This step includes the initial message from the P–GW to the UE for the de-registration of the DSMIPv6 binding.

Steps (39)–(40) include the final messages for the de-registration of the UE DSMIPv6 binding. After step (40), the reception of packets by the UE without tunneling has been realized. Finally, the UE sends and receives data packets only through the eNode (LTE) and EPS system. Formally, the VHO is over and from this moment the tunnel is no longer needed.

MATHEMATICAL MODELLING OF VHO PROCEDURES

In this section we offer a method for VHO procedure time estimation. In the previous section, nine functional entities of VHO procedures were described: UE (I), ANDSF (II), ePDG (III), E-UTRAN (IV), MME (V), S-GW (VI), P-GW (VII), hPCRF (VIII) and HSS/AAA (IX) as well as the 40 signaling messages that are transmitted between them.

In this section we have built a mathematical model for analysing the sojourn time Δ from the first initiating message until the final message of VHO completion.

For preliminary performance measures, we used a well-known class of queueing networks for open, closed or mixed models with various service disciplines. The most noted paper, (Bassket, et al, 1975), on the BCMP method was presented by Baskett, Chandy, Muntz and Palacios. We will base our method on BCMP.

Let's use two subsets of network nodes: $M_1 = \{\mathrm{I}\}$ and M_2, which contains the other eight nodes II-IX. By Basharin-Kendall notation, the first node is of type $M \mid M \mid inf$, while the nodes in subset M_2 are of type $M \mid M \mid 1 \mid inf$ with the FCFS service discipline. External arrivals are Poisson with a rate of λ_0. The service rates on the nodes is μ_i, where $i \in (M_1 \cup M_2)$. The average sojourn time for a customer is equal to μ_1^{-1} in the first node and $(\mu_i - \lambda_i)^{-1}$ in the FCFS nodes, where λ_i is the total incoming intensity rate to the i th node.

During the VHO procedure, messages (1)–(40) move from one node to another as shown in Fig. 5, where the numbers on the arrows correspond to the index numbers of the signalling messages.

The steady state condition for the queueing network is:

$$\lambda_0 < \min\left(\frac{\mu_2}{3};\frac{\mu_3}{3};\frac{\mu_4}{2};\frac{\mu_5}{3};\frac{\mu_6}{4};\frac{\mu_7}{10};\mu_8;\frac{\mu_9}{3}\right) \quad (1)$$

Using the approach of (Raad, et al. 2013; Gaidamaka and Zaripova 2014; Samouylov, et al. 2016) the average sojourn time Δ_{ident} with identical customers can be estimated using formula (2):

$$\Delta_{ident} = 12\mu_1^{-1} + \frac{3}{\mu_2 - 3\lambda_0} + \frac{3}{\mu_3 - 3\lambda_0} + \frac{2}{\mu_4 - 2\lambda_0} + \\ + \frac{2}{\mu_5 - 3\lambda_0} + \frac{3}{\mu_6 - 4\lambda_0} + \frac{10}{\mu_7 - 10\lambda_0} + \frac{1}{\mu_8 - \lambda_0} + \\ + \frac{3}{\mu_9 - 3\lambda_0}. \qquad (2)$$

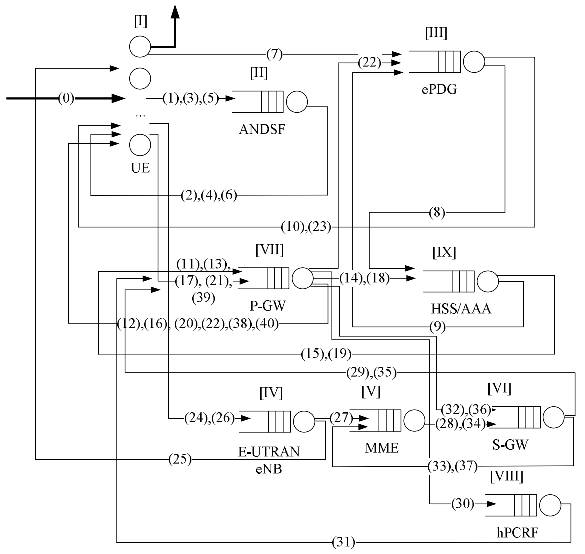

Figure 5: Nine-Node Open Queueing Network

The first addendum $12\mu_1^{-1}$ shows the total time at the first node within the VHO procedure, i.e. the 12 times that the signaling messages have gone through the UE. The second addendum $\frac{3}{\mu_2 - 3\lambda_0}$ corresponds to the total time interval on the second ANDSF node, the VHO procedure has gone through the ANDSF node 3 times.

We simplify our VHO procedure and forward messages (36) and (38) simultaneously from node (VII) P-GW. You can observe changes in the fifth and sixth addendums, where we estimated additional load from signaling messages (36) and (37).

Messages (24), (25) and (27) have different service time. For this case, the average sojourn time Δ can be estimated by formula (3) for heterogeneous customers.

$$\Delta = 10\mu_1^{-1} + T_{24} + T_{26} + \frac{3}{\mu_2 - 3\lambda_0} + \frac{3}{\mu_3 - 3\lambda_0} + \\ + \frac{2}{\mu_4 - 2\lambda_0} + \frac{1}{\mu_5 - 3\lambda_0} + T_{27} + \frac{3}{\mu_6 - 4\lambda_0} + \\ + \frac{10}{\mu_7 - 10\lambda_0} + \frac{1}{\mu_8 - \lambda_0} + \frac{3}{\mu_9 - 3\lambda_0}. \qquad (3)$$

NUMERICAL EXPERIMENT

The proposed mathematical model allows us to estimate the VHO time of the proposed method. To illustrate this estimation method, we used input data from (Nikaem and Krco 2011; Cardona, et al. 2013; Prados-Garzon et. al. 2015; Granlund et. al. 2015). The amount of transactions per second depends on the provider, network configuration and many other different parameters. We assume that a maximum of 10 % of subscribers are in need of a vertical handover on the same territory as the cell. Each request for a VHO generates the 40 signaling messages that have been described above. Average service time intervals for our preliminary analysis are shown in Table 1. The signaling messages service times differ from each other because of their functionality and different length.

Table 1: Average Service Time

Nodes	Average service time, μ_i^{-1}, ms	Ref.
I - UE	77.5 for (24) 28.5 for (26) 2 for other steps	(Nikaem and Krco, 2011)
II - ANDSF	70	(estimated as HSS/ AAA)
III - ePDG	2	(estimated as P-GW)
IV - eNB	4	(Cardona, et al., 2013)
V - MME	15 for (27) 1 for other steps	(Cardona, et al., 2013) (Prados-Garzon et. al, 2015)
VI - S-GW	2	(Nikaem and Krco, 2011)
VII - P-GW	2	(Nikaem and Krco, 2011)
VIII - hPCRF	70	(estimation as HSS / AAA)
IX - HSS / AAA	70	(Granlund et. al., 2015)

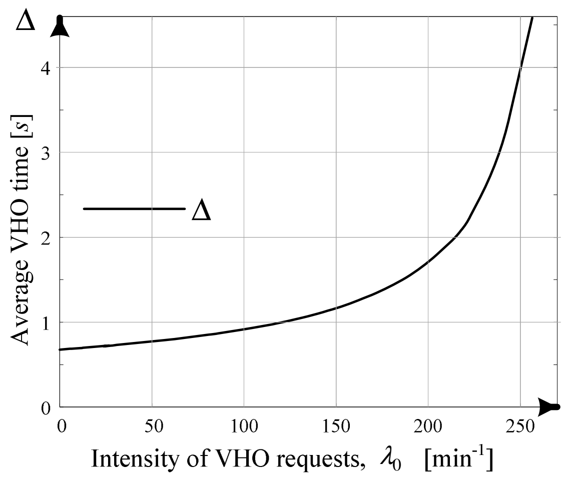

Figure 6: Average VHO Time

There is a dependence of the VHO time on the intensity of VHO requests. It should be noted that it is not necessary to use an ANDSF node when the VHO intensity λ_0 is equal to 0, since the total VHO time will be no more than 462 ms in the beginning. VHO time can be estimated by summing the average service times of the signalling messages. Increasing the intensity of VHO requests affects the average VHO time (see Fig. 6).

The ANDSF node could help select the optimal network for the handover. Therefore this estimation method is an upper bound for VHO time.

CONCLUSION

In this paper, a VHO time estimation method and a mathematical model for a non-trusted IP 3GPP access network to a 3GPP LTE was proposed. This procedure covers VHO phases from network discovery decision to the completion of the VHO procedure with physical and IP–connection re-establishment in the 3GPP network.

At the next stage of research, the scheme of a VHO from a 3GPP (LTE) network to WLAN will be discussed. Another issue at the next stage of research is the modelling of a probabilistic VHO procedure. In this future scheme, the UE has a choice of a given probability to initiate a VHO procedure to 3GPP LTE, to initiate a VHO procedure to WiMAX, or to remain in the current WLAN network.

The aim of future research is implementation of another analytical methods and models to vertical handover time estimation. The first method is for queueing network with given variation coefficients for service times. This method could be implemented for any service times distribution using Kramer and Langenbach-Beltz approximate formula for sojourn time estimation. The second method is for multiphase queuing system with background traffic. This approximate method divides incoming flow into foreground and background traffic, so we could consider several types of traffic.

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