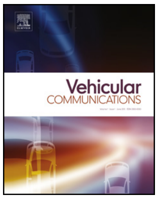
Vehicular Communications 16 (2019) 15–44

Contents lists available at ScienceDirect

Vehicular Communications

www.elsevier.com/locate/vehcom



Mobility management on 5G Vehicular Cloud Computing systems

Emmanouil Skondras [a], Angelos Michalas [b], Dimitrios D. Vergados [a],*

[a] *Department of Informatics, University of Piraeus, Piraeus, Greece*
[b] *Department of Informatics Engineering, Technological Education Institute of Western Macedonia, Kastoria, Greece*

ARTICLE INFO

Article history:
Received 7 September 2018
Received in revised form 11 December 2018
Accepted 13 January 2019
Available online 15 February 2019

Keywords:
Vertical Handover (VHO)
Network selection
Vehicular Cloud Computing (VCC)
Software Defined Networks (SDN)
Mobile Edge Computing (MEC)
Fifth generation networks (5G)

ABSTRACT

Fifth generation (5G) Vehicular Cloud Computing (VCC) systems use heterogeneous network access technologies to fulfill the requirements of modern services. Multiple services with different Quality of Service (QoS) constraints could be available in each vehicle, while at the same time, user requirements and provider policies must be addressed. Therefore, the design of efficient Vertical Handover (VHO) management schemes for 5G-VCC infrastructures is needed. In this paper, a novel VHO management scheme for 5G-VCC systems is proposed. Whenever the user satisfaction grade becomes less than a predefined threshold, VHO is initiated and network selection is performed, considering the velocity of the vehicle, network characteristic criteria such as throughput, delay, jitter and packet loss, as well as provider policy criteria such as service reliability, security and price. The proposed scheme uses linguistic values for VHO criteria attributes represented by Interval Valued Pentagonal Fuzzy Numbers (IVPFNs) to express the information using membership intervals. The VHO scheme is applied to a 5G-VCC system which includes 3GPP Long Term Evolution (LTE) and IEEE 802.16 Worldwide Interoperability for Microwave Access (WiMAX) Macrocells and Femtocells, as well as IEEE 802.11p Wireless Access for Vehicular Environment (WAVE) Road Side Units (RSUs). Performance evaluation shows that the suggested method ensures the Always Best Connection (ABC) principle, while at the same time outperforms existing VHO management schemes.

1. Introduction

It is widely agreed that Cloud Computing (CC) [1] and Software Defined Networking (SDN) [2–4] are the key enabling technologies for the fifth generation (5G) [5] networks. In addition, Vehicular Cloud Computing (VCC) which combines the operating principles of both Vehicular Networks and Cloud computing has emerged widely, inducing the evolution of the 5G approach. In a typical VCC system, vehicles are equipped with On-Board Units (OBUs) with computational, storage and communication resources. Vehicles communicate with each other as well as with Road Side Units (RSUs). Also, each RSU interacts with a Cloud infrastructure which offers a variety of modern services with strict Quality of Service (QoS) requirements. Vehicles such as cars, motorcycles, buses and trains provide a wide variety of cloud services to their passengers. Each vehicle could serve many passengers with different services and various requirements.

To support the communication needs of vehicular users, dense deployments of 5G networks are applied, called also Ultra Dense Networks (UDN) [6]. UDNs aim at the support of high data rates produced by an increased number of vehicular users. Accordingly, a large number of small cells, such as Femtocells, is deployed inside the network coverage area in order to increase the overall capacity of the access network [7][8]. In addition, heterogeneous network access technologies, such as 3GPP Long Term Evolution Advanced (LTE-A) [9] or IEEE 802.16 Worldwide Interoperability for Microwave Access (WiMAX) [10] Macrocells and Femtocells as well as IEEE 802.11p Wireless Access for Vehicular Environment (WAVE) [11] RSUs, are used for the interaction between the vehicles and the Cloud infrastructure.

The 5G architecture could be improved by applying the operating principles of Mobile Edge Computing (MEC) [12–17], resulting to the creation of a Fog infrastructure at the edge of the network. Specifically, LTE and WiMAX Base Stations (BSs), as well as WAVE RSUs are equipped with additional computational and storage resources and thus they are called micro-datacenter BSs (md-BSs) and micro-datacenter RSUs (md-RSUs), respectively. Vehicular services are provided directly from the access network. Thus, the

---

* Corresponding author.
E-mail addresses: skondras@unipi.gr (E. Skondras), amichalas@kastoria.teiwm.gr (A. Michalas), vergados@unipi.gr (D.D. Vergados).

https://doi.org/10.1016/j.vehcom.2019.01.001

durability and the response latency of the services are improved, compared with the traditional centralized cloud server approach.

Vehicular users should always obtain connectivity to the most appropriate network access technology, according to the requirements of their services, as well as the operators' policies. This situation could be considered as a Multiple Attribute Decision Making (MADM) problem, due to the high number of parameters that must be considered, including Signal to Noise plus Interference Ratio (SINR), throughput, delay, jitter, packet loss ratio, network reliability and price. Therefore, the design of efficient MADM Vertical Handover (VHO) [18] management schemes is required, to provide service continuity and ensure Quality of Service (QoS). Furthermore, network operators use Anything as a Service (ANYaaS) [19] in order to deploy and orchestrate network management algorithms and services using a Cloud infrastructure. Specifically, the Mobility Management as a Service (MMaaS) [20] [21] subcategory of ANYaaS, could be applied to accomplish VHO operations by the Cloud infrastructure. MMaaS allows the creation of a Mobility Instance (MI) for each vehicular user, which could be considered as a mobility management service that interacts with the user and manipulates his mobility. In this way, the user equipment resources will have decreased workload and consume reduced energy.

This paper describes a novel VHO management scheme for 5G-VCC systems. During the entire vehicle movement its velocity is monitored and is characterized as Normal, Medium or High. Whenever the user satisfaction grade becomes less than a predefined threshold, network selection is executed, while the mobility state of each vehicle is considered to select the set of possible alternative networks. Specifically, if the vehicle velocity is Normal, the vehicle considers all the available networks as alternatives, including both Macrocells and Femtocells. If the vehicle velocity is Medium, the vehicle skips some Femtocells along its trajectory, to reduce the handover rate. Finally, if the vehicle velocity is High, only Macrocells are considered as alternatives. Thereafter, the vehicle handovers to the most appropriate network, considering network characteristic criteria such as throughput, delay, jitter and packet loss, as well as provider policy criteria such as service reliability, security and price.

The proposed approach includes the following characteristics:

- Considers the velocity of each vehicle, to avoid unnecessary handovers to Femtocells, since a vehicle moving with high velocity will remain for a limited time inside their range.
- VHO is initiated considering not only the Signal to Noise plus Interference (SINR) but also the user satisfaction, since users with good SINR may not be satisfied from the QoS of their current networks.
- Allows complex relationships using a network model of dependencies, including network QoS and policy characteristics, by applying the Pentagonal Fuzzy ANP (PF-ANP) method.
- Imprecise information of performance selection criteria for different application types and users' SLAs is expressed using linguistic values and interval valued fuzzy numbers.
- Network selection is performed by considering contradictory selection criteria to promote the provision of high quality services, while at the same time satisfies different types of vehicles SLAs. This is achieved through a fuzzy version of TOPSIS, the Pentagonal interval-valued Fuzzy TOPSIS (PFT), introduced in this study. PFT also supports the case of having multiple services of different QoS constraints running simultaneously on a terminal, achieving the fulfillment of multiple criteria per user.
- VHO management services including VHO initiation and network selection are performed at the Cloud or at the network edge to reduce the processing load at the vehicle.

The remainder of the paper is as follows: In section 2 the related research literature is revised, while section 3 presents the methods followed in our study including the Pentagonal Fuzzy Analytic Network Process (PF-ANP), the Mamdani Pentagonal Fuzzy Inference System (MPFIS) and the Pentagonal Fuzzy TOPSIS (PFT). Section 4 describes the proposed scheme while section 5 presents the simulation setup and the evaluation results. Finally, section 6 concludes the discussed work.

2. Related work

Several VHO management algorithms for heterogeneous access network environments have been proposed in the literature, defining methods for both VHO initiation and network selection manipulation. VHO initiation methods decide when a VHO must be performed, while network selection methods decide the new access network that the user should be connected to, so that the continuity of his services is ensured.

In general, during the VHO initiation, the value of a network parameter (or a set of parameters) is monitored. If the monitored value drops below a threshold, then VHO should be performed. Several parameters have been proposed in the research literature to be considered for the VHO initiation.

The Received Signal Strength (RSS) is the most common parameter. Several studies [22–25] propose RSS-based VHO initiation methods, since the RSS parameter is easy to be measured, while at the same time it is directly relevant to the service quality.

Signal to Noise plus Interference (SINR) based VHO initiation methods [26][27] have also been proposed. Such methods usually succeed better results than the simple RSS based methods, since they consider the signal interference and noise levels along with the signal strength, resulting to an improved estimation of the quality of the received signal.

Additionally, several schemes consider the network load, as well as QoS aware criteria such as throughput, delay and packet loss, as main VHO initiation parameters. Indicatively, in [28] the authors propose a VHO initiation scheme for LTE networks, which include both Macrocells and Femtocells. A load-aware algorithm is described, which determines two handover thresholds, namely the γ_{th}^{M} and the γ_{th}^{F}, for Macrocells and Femtocells, respectively. Both thresholds are evaluated, considering the Reference Signal Received Power (RSRP) threshold defined in LTE [9], as well as network load information. Accordingly, when the RSRP drops below the corresponding γ_{th} threshold, a Time-to-Trigger (TTT) timer is activated, which is initialized to a certain value T, considering parameters such as the cell transmission power, the distances between the available cells, the path loss, the carrier frequency, the network traffic load and the user velocity. During the countdown, if the RSRP returns above the corresponding γ_{th} threshold, the timer is deactivated. Otherwise, when the timer becomes equal to zero, the handover is initiated and the user is transferred to the network with the highest RSRP.

In [29] a handover initiation mechanism is proposed, considering the scenario where both WiFi and WiMAX networks coexist. A network loads aware algorithm distributes the traffic load to WiFi and WiMAX networks considering the available bandwidth of each network. Each user has a set of services with strict QoS constraints. If the observed QoS drops below a threshold, a handover policy instructs the users to perform handover.

Several studies concentrate on the network selection part of the VHO management procedure. Current network selection schemes proposed in the literature employ MADM, fuzzy logic, neural networks and utility functions. MADM methods select the best alternative among candidate networks given a set of criteria with different importance weights. Specifically, MADM algorithms are able to evaluate criteria of different value ranges, sometimes even contradictory, using multi-criteria analysis. Widely used methods include Analytic hierarchy process (AHP) [30] and Analytic network process (ANP) [31], Technique for order preference by similarity to ideal solution (TOPSIS) [30][32], Simple additive weighting (SAW) [30], Multiplicative exponent weighting (MEW) [30], Gray relational analysis (GRA) [30], Distance to ideal alternative (DIA) [30] and Weighted Product Method (WPM) [33].

Some network selection schemes make use of utility/cost functions to provide performance metrics for different types of criteria. In [34] two utility functions are used for network selection, one for the user and one for the network. The user utility function considers user related parameters such as the user preferences, his moving velocity and his monetary budget. Accordingly, the network utility function considers network related parameters, such as the network load, the price and the network QoS which is estimated using the TOPSIS method. In [35] a set of utility functions is used to quantify selection criteria including the RSS, battery power, average throughput, network delay, monetary cost and application type. The relative weights of criteria are calculated according to the AHP method. Consequently, the candidate networks are ranked using the WPM method. In [36] the concepts of fuzzy logic, neural network and utility functions are combined to perform network selection. The proposed method makes use of a fuzzy neural network which obtains network, user and terminal related input criteria and evaluates the performance of each access network. Attributes of criteria are defined through utility functions and processed through the fuzzification, interference and defuzzification layers of the neural network.

Generally, there is a rate of uncertainty in characterizing network performance measurements as well as rates of influence of performance metrics. Therefore, Fuzzy MADM (FMADM) methods have received the interest of many researchers in decision theory. In particular, several FMADM network selection methods are suggested utilizing linguistic variables, triangular fuzzy numbers, trapezoidal fuzzy numbers etc., to model network attributes and their respective weights. Such methods include the Fuzzy AHP–TOPSIS (FAT) [37], the Fuzzy AHP–SAW (FAS) [37], the Fuzzy AHP Mew (FAM) [37], as well as the Fuzzy AHP–ELECTRE (FAE) [38].

In [22] a two-phase VHO management algorithm is proposed. Initially, the RSS-based handover initiation mechanism is applied. Then, during the second phase, a triangular fuzzy MADM algorithm that considers parameters such as the RSS, the delay, the network load and the battery utilization is used. Additionally, in [23] a VHO management method is proposed, while a heterogeneous network environment that is consisted of LTE and WiMAX networks is considered. Firstly, the simple RSS based method is used for the network initiation. Thereafter, a triangular fuzzy version of the TOPSIS method is proposed for the network selection. Network parameters such as the offered data rate and the delay are considered during the network selection process.

Several studies are introduced for the aim of supporting VHO management in vehicular environments.

In [39] a VHO management scheme for vehicular networks is proposed. The authors define two network interface types, namely the IEEE 802.11p network access technology which is considered as the primary interface, while the 3GPP LTE is considered as the secondary. By default, a vehicle is connected to the primary interface. Initially, a QoS aware VHO initiation algorithm is applied, which instructs the vehicle to perform handover to the secondary interface in case the observed packet loss of the provided services exceeds a maximum acceptable threshold. Thereafter, a timer is activated specifying the time interval that the user remains connected to secondary interface. When the timer expires and the estimated packet loss ratio of the primary interface is lower than the maximum acceptable threshold, the vehicle performs handover back to the primary interface.

Some velocity-aware VHO management schemes consider the users mobility state as a key factor for the VHO initiation phase. The authors of [40] statistically analyze the mobility state of a user considering Femtocells density, as well as user's handover count measured in a sliding time window, to characterize user's mobility as Low, Medium or High. The authors evaluate the accuracy of their method considering a network topology with several small cells and variable user velocities. Simulation results showed that the mobility state estimation is enhanced when more Femtocells are deployed. The proposed method could be used for the design of mobility aware VHO management schemes. Indicatively, in [41], the Velocity Aware Handover (VAH) VHO management scheme is proposed. The authors define two network tiers, namely the tier-1 consisted by Macrocells and the tier-2 consisted by Femtocells. Four vertical handover strategies are considered, including the Best Connected (BC), the Femto Skipping (FS), the Femto Disregard (FD) and the Macro Skipping (MS). The BC strategy is applied to static users and users with Low mobility, while both Macrocells and Femtocells are considered as alternatives. The user connects to a Macrocell if $P_1 \cdot B_1 \cdot R_1^{-\eta} > P_2 \cdot B_2 \cdot R_2^{-\eta}$ is satisfied, or to the nearest Femtocell if $P_1 \cdot B_1 \cdot R_1^{-\eta} < P_2 \cdot B_2 \cdot R_2^{-\eta}$ is satisfied, where P is the transmission power, B is the bias factor, R is the user distance and η is the pathloss exponent for each tier. The FS strategy considers users with Medium mobility and the Femtocells alternatives are skipped to reduce the handover rate, when $P_1 \cdot B_1 \cdot R_1^{-\eta} < P_2 \cdot B_2 \cdot R_2^{-\eta}$. In the FD strategy, which is applied to users with High mobility, the user always skips the available Femtocells and connects only to the available Macrocells. Finally, in the MS strategy, for users with extremely High mobility, the user skips the entire Femtocells as well as some of the Macrocells.

3. Preliminaries

The proposed VHO management scheme uses Interval Valued Pentagonal Fuzzy Numbers (IVPFN) for the representation of both VHO Initiation and Network Selection criteria values. IVPFNs are created using the Equalized Universe Method (EUM), which provides a well-defined way for the distribution of the IVPFNs inside a predefined domain. Additionally, the Pentagonal Fuzzy Analytic Network Process (PF-ANP) is used for the estimation of the criteria weights for both VHO Initiation and Network Selection.

During the VHO Initiation, the Mamdani Pentagonal Fuzzy Inference System (MPFIS) decides when a VHO must be initiated. Additionally, during the Network Selection, the Pentagonal Fuzzy TOPSIS (PFT) selects the most appropriate network according to vehicle's velocity, vehicular user service constraints and SLA.

In the following section, each one of the aforementioned methods is analyzed, while the design of the proposed VHO management scheme is presented in Section 4.

3.1. The Interval-Valued Pentagonal Fuzzy Numbers (IVPFN)

The concept of fuzzy logic was introduced in [42] and is used to make a decision from indeterminate and approximate information. A fuzzy number is represented by a set of real values representing an uncertain quantity and a convex normalized continuous function which estimates the degree of membership for each value in the subset. Triangular, trapezoidal or pentagonal fuzzy numbers are frequently used to represent uncertain information. A pentagonal fuzzy number can be defined as a vector $x = (x_1, x_2, x_3, x_4, x_5, v_{\hat{A}}, v_{\hat{A}1}, v_{\hat{A}2})$ with membership function:

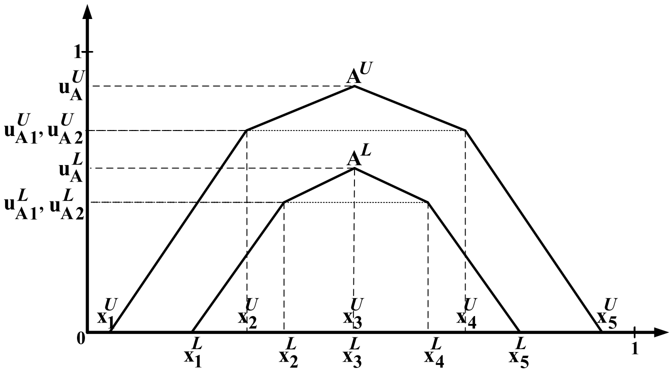


Fig. 1. The interval-valued pentagonal fuzzy numbers.

$$\mu(x) = \begin{cases} v_{\hat{A}1} \cdot \frac{x-x_1}{x_2-x_1}, & \text{if } x_1 \leqslant x < x_2; \\ v_{\hat{A}} - (v_{\hat{A}} - v_{\hat{A}1}) \cdot \frac{x-x_2}{x_3-x_2}, & \text{if } x_2 \leqslant x < x_3; \\ v_{\hat{A}}, & \text{if } x = x_3; \\ v_{\hat{A}} - (v_{\hat{A}} - v_{\hat{A}2}) \cdot \frac{x-x_3}{x_4-x_3}, & \text{if } x_3 < x \leqslant x_4; \\ v_{\hat{A}2} \cdot \frac{x-x_5}{x_4-x_5}, & \text{if } x_4 < x \leqslant x_5; \\ 0, & \text{otherwise}, \end{cases} \tag{1}$$

where $x_1 \leqslant x_2 \leqslant x_3 \leqslant x_4 \leqslant x_5$ and $v_{\hat{A}}, v_{\hat{A}1}, v_{\hat{A}2} \in [0, 1]$.

An Interval-valued fuzzy number (IVFN) introduced in [43] is defined as $A = [A^L, A^U]$ consisting of the lower A^L and the upper A^U fuzzy numbers. IVFNs replace the crisp membership values by intervals in $[0, 1]$. They were proposed due to the fact that fuzzy information can be better expressed by intervals than by single values. Also, IVFNs are useful in multiple criteria decision making (MCDM) problems and particularly in cases where attribute values are in the form of linguistic expressions [44][45]. Particularly, in [46] an extension of the fuzzy TOPSIS method using interval-valued triangular fuzzy numbers is proposed. Moreover, in [44] a decision making method is proposed, using weighted geometric aggregation operators on attribute values expressed in the form of interval-valued trapezoidal fuzzy numbers. According to the definition in [46] an IVFS A is defined as follows:

$$A = \{(x, [\mu_A^L(x), \mu_A^U(x)])\} \tag{2}$$

$$\mu_A^L(x), \mu_A^U(x) : X \to [0, 1] \forall x \in X, \mu_A^L(x) < \mu_A^U(x) \tag{3}$$

$$\hat{\mu}_A(x) = [\mu_A^L(x), \mu_A^U(x)] \tag{4}$$

$$A = \{(x, \hat{\mu}_A(x))\}, x \in (-\infty, \infty) \tag{5}$$

The interval-valued pentagonal fuzzy number is the most general IVFN case (Fig. 1) defined as: $A = [A^L, A^U] = [(x_1^L, x_2^L, x_3^L, x_4^L, x_5^L, v_A^L, v_{A1}^L, v_{A2}^L), (x_1^U, x_2^U, x_3^U, x_4^U, x_5^U, v_A^U, v_{A1}^U, v_{A2}^U))]$ where: $A^L \subset A^U$, $0 \leqslant x_1^L \leqslant x_2^L \leqslant x_3^L \leqslant x_4^L \leqslant x_5^L \leqslant 1$, $0 \leqslant x_1^U \leqslant x_2^U \leqslant x_3^U \leqslant x_4^U \leqslant x_5^U \leqslant 1$, $v_A^L \leqslant v_A^U$, $v_{A1}^L \leqslant v_{A2}^L \leqslant v_A^L$, $v_{A1}^U \leqslant v_{A2}^U \leqslant v_A^U$ and $v_A^L, v_{A1}^L, v_{A2}^L, v_A^U, v_{A1}^U, v_{A2}^U \in [0, 1]$. The operational rules of the interval-valued pentagonal fuzzy numbers are defined in [47].

3.2. The Equalized Universe Method (EUM)

The Equalized Universe Method (EUM) [48] [49] creates IVFNs with their centroids equally spaced along a predefined domain of values. Specifically, the values of the ith IVPFN are calculated using formula (6), where U_{min} and U_{max} are the minimum and maximum value of the domain and c represents the number of the IVPFNs created. Also, the v_{A1}^L, v_{A1}^U, v_{A2}^L and v_{A2}^U are defined by the user.

$$IVPFN_i = \begin{cases} x_{i,1}^U = x_{i,2}^U - \frac{U_{max}-U_{min}}{4\cdot(c-1)}, x_{i,1}^L = x_{i,1}^U \cdot (v_{A1}^L / v_{A1}^U) \\ x_{i,2}^U = x_{i,3}^U - \frac{U_{max}-U_{min}}{2\cdot(c-1)}, x_{i,2}^L = x_{i,2}^U \cdot (v_{A1}^L / v_{A1}^U) \\ x_{i,3}^{U,L} = U_{min} + \frac{U_{max}-U_{min}}{c-1} \cdot (i-1) \\ x_{i,4}^U = x_{i,3}^U + \frac{U_{max}-U_{min}}{2\cdot(c-1)}, x_{i,4}^L = x_{i,4}^U \cdot (v_{A2}^L / v_{A2}^U) \\ x_{i,5}^U = x_{i,4}^U + \frac{U_{max}-U_{min}}{4\cdot(c-1)}, x_{i,5}^L = x_{i,5}^U \cdot (v_{A2}^L / v_{A2}^U) \end{cases} \tag{6}$$

3.3. The Pentagonal Fuzzy Analytic Network Process (PF-ANP)

The Pentagonal Fuzzy Analytic Network Process (PF-ANP) method is the IVPFN version of the typical ANP [50] method, used for the calculation of the criteria weights. PF-ANP allows complex relationships within and among clusters of selection criteria using a network model of dependencies. A decision problem that is analyzed with the PF-ANP can be represented as a network of nodes. Each node represents a component (or cluster) of the system while arcs denote interactions between them. Interactions and feedbacks within clusters are called inner dependencies, while interactions and feedbacks between clusters are called outer dependencies. Indicatively, we could consider one cluster with network characteristics criteria such as throughput, delay, jitter and packet loss, as well as one cluster with operator policy criteria such as service reliability, security and price. In this situation, the PF-ANP will consider two clusters. The PF-ANP is composed of five major steps of selection criteria:

- *Model construction and problem structuring* During this step the problem is analyzed and decomposed into a rational system, consisting of a network of nodes.

- *Pairwise comparison matrices and priority vectors* Initially the fuzzy pairwise comparison matrix $\tilde{A}$ is derived for each cluster using the linguistic terms presented in Table 1, which are calculated using the EUM method and correspond to the nine-point importance scale introduced in [50]. The standard form of the $\tilde{A}$ matrix is expressed as follows:

$$\tilde{A} = \begin{bmatrix} 1 & \dots & \tilde{a}_{1j} & \dots & \tilde{a}_{1n} \\ \vdots & & \vdots & & \vdots \\ 1/\tilde{a}_{1i} & \dots & 1 & \dots & \tilde{a}_{in} \\ \vdots & & \vdots & & \vdots \\ 1/\tilde{a}_{1n} & \dots & 1/\tilde{a}_{jn} & \dots & 1 \end{bmatrix} \tag{7}$$

while n denotes the number of the cluster elements.

Subsequently, the geometric mean $r_{\tilde{A}_i}$ of each row i in $\tilde{A}$ is calculated according to formula (8), where $\otimes$ denotes the multiplication operator of two fuzzy numbers as defined in [51].

$$r_{\tilde{A}_i} = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \dots \otimes \tilde{a}_{in})^{\frac{1}{n}} \tag{8}$$

Following, the priority vector $\tilde{\Omega}_i$ of each cluster element is constructed as follows:

$$\tilde{\Omega}_i = [\ \tilde{\omega}_1 \quad \tilde{\omega}_2 \quad \dots \quad \tilde{\omega}_n\ ] \tag{9}$$

where each $\tilde{\omega}_i = [(\omega_1^U, \omega_2^U, \omega_3^U, \omega_4^U, \omega_5^U, v_i^U, v_{i1}^U, v_{i2}^U); (\omega_1^L, \omega_2^L, \omega_3^L, \omega_4^L, \omega_5^L, v_i^L, v_{i1}^L, v_{i2}^L)]$ is calculated using formula (10). The $\oplus$ indicates the addition operator of two fuzzy numbers as defined in [51].

$$\tilde{\omega}_i = r_{\tilde{A}_i} / (r_{\tilde{A}_1} \oplus r_{\tilde{A}_2} \oplus \dots \oplus r_{\tilde{A}_i} \oplus \dots \oplus r_{\tilde{A}_n}) \tag{10}$$

Table 1
The linguistic terms that used for criteria pairwise comparisons.

Linguistic term	Interval-valued pentagonal fuzzy number
Equally Important (EI)	[(0.043, 0.062, 0.1, 0.137, 0.156, 0.8, 0.6, 0.6), (0.025, 0.05, 0.1, 0.15, 0.175, 1.0, 0.8, 0.8)]
More than Equally Important (MEI)	[(0.143, 0.162, 0.2, 0.237, 0.256, 0.8, 0.6, 0.6), (0.125, 0.15, 0.2, 0.25, 0.275, 1.0, 0.8, 0.8)]
Moderately More Important (MMI)	[(0.243, 0.262, 0.3, 0.337, 0.356, 0.8, 0.6, 0.6), (0.225, 0.25, 0.3, 0.35, 0.375, 1.0, 0.8, 0.8)]
More than Moderately More Important (MMMI)	[(0.343, 0.362, 0.4, 0.437, 0.456, 0.8, 0.6, 0.6), (0.325, 0.35, 0.4, 0.45, 0.475, 1.0, 0.8, 0.8)]
Strongly More Important (SMI)	[(0.443, 0.462, 0.5, 0.537, 0.556, 0.8, 0.6, 0.6), (0.425, 0.45, 0.5, 0.55, 0.575, 1.0, 0.8, 0.8)]
More than Strongly More Important (MSMI)	[(0.543, 0.562, 0.6, 0.637, 0.656, 0.8, 0.6, 0.6), (0.525, 0.55, 0.6, 0.65, 0.675, 1.0, 0.8, 0.8)]
Very Strongly More Important (VSMI)	[(0.643, 0.662, 0.7, 0.737, 0.756, 0.8, 0.6, 0.6), (0.625, 0.65, 0.7, 0.75, 0.775, 1.0, 0.8, 0.8)]
More than Very Strongly More Important (MVSMI)	[(0.743, 0.762, 0.8, 0.837, 0.856, 0.8, 0.6, 0.6), (0.725, 0.75, 0.8, 0.85, 0.875, 1.0, 0.8, 0.8)]
Extremely More Important (EMI)	[(0.843, 0.862, 0.9, 0.937, 0.956, 0.8, 0.6, 0.6), (0.825, 0.85, 0.9, 0.95, 0.975, 1.0, 0.8, 0.8)]

- *Construction of the supermatrix* In this step, the fuzzy supermatrix $\tilde{W}$ of the PF-ANP model is constructed representing the inner and outer dependencies of the PF-ANP network. This is a partitioned matrix, with each matrix segment representing the relationship between two clusters of the network. To construct the supermatrix, the local priority vectors $\tilde{\Omega}$ are grouped and placed in the appropriate positions in the supermatrix based on the flow of influence from one cluster to another. For example if we assume a network of q clusters, where each cluster C_k, $k = [1, 2, \ldots, q]$ has n_k elements, denoted as $e_{k1}, e_{k2}, \ldots, e_{kn_k}$, then the supermatrix is expressed as:

$$\tilde{W} = \begin{array}{cc|ccccc|} & & C_1 & \dots & C_k & \dots & C_q \\ & & e_{11}\dots e_{1n_1} & \dots & e_{k1}\dots e_{kn_k} & \dots & e_{q1}\dots e_{qn_q} \\ C_1 & \begin{matrix} e_{11} \\ \vdots \\ e_{1n_1} \end{matrix} & \tilde{W}_{11} & \dots & \tilde{W}_{1j} & \dots & \tilde{W}_{1q} \\ \vdots & & \vdots & \vdots & \vdots & \vdots & \vdots \\ C_k & \begin{matrix} e_{k1} \\ \vdots \\ e_{kn_k} \end{matrix} & \tilde{W}_{k1} & \dots & \tilde{W}_{kj} & \dots & \tilde{W}_{kq} \\ \vdots & & \vdots & \vdots & \vdots & \vdots & \vdots \\ C_q & \begin{matrix} e_{q1} \\ \vdots \\ e_{qn_q} \end{matrix} & \tilde{W}_{q1} & \dots & \tilde{W}_{qj} & \dots & \tilde{W}_{qq} \end{array} \tag{11}$$

- *Construction of the weighted supermatrix* During this step, the supermatrix is transformed to a stochastic one, the Weighted Supermatrix $\tilde{W}'$ using formula (12).

$$\tilde{W}'_{k,j} = \tilde{W}_{k,j}/q \tag{12}$$

- *Calculation of the limited supermatrix* In this step, initially the deffuzified Weighted Supermatrix W is estimated by applying the Weighted Average method using formula (13). The parameters v and d represent the height and the centroid of each $\tilde{W}'_{k,j}$ pentagon respectively. Subsequently, W is raised to limiting powers until all the entries converge. In this way the overall priorities are calculated, and thus the cumulative influence of each element on every other interacting element is obtained [52]. At this point, all the columns of the produced Limited Supermatrix, are the same and their values show the global priority of each element of the network.

$$W_{k,j} = \frac{v^U \cdot d^U + v^L \cdot d^L}{d^U + d^L} \tag{13}$$

3.4. The Mamdani Pentagonal Fuzzy Inference System (MPFIS)

Fuzzy Inference (FI) [53–55] involves the mapping of a given input to an output using fuzzy logic. In particular, the Mamdani Pentagonal Fuzzy Inference System (MPFIS) considers two inputs ($Input_1$ and $Input_2$) to estimate the value of the $Output$. Both $Input_1$ and $Input_2$ obtain normalized values within the range [0, 1]. Also, the MF_{Input_1}, MF_{Input_2}, MF_{Output} membership functions (MF) are defined, indicating the linguistic terms and the corresponding Interval Valued Pentagonal Fuzzy Numbers (IVPFN) for the fuzzy representation of the $Input_1$, $Input_2$ and $Output$, respectively. Thus, for each crisp value, two membership degrees are determined in the corresponding MF, one for the upper pentagon and one for the lower pentagon. The Mamdani FIS implements the following methods:

- *Membership functions definition* The Membership Functions (MF) for $Input_1$, $Input_2$ and $Output$ parameters are defined.

- *Fuzzy rule (or knowledge) base* A set R of fuzzy rules is defined, where each rule $r \in R$ is a simple if-then statement with a condition and a conclusion. The rule's condition consists of MF_{Input_1} and MF_{Input_2} membership functions, while its conclusion indicates an MF_{Output} membership function.

- *Fuzzification* The $Input_1$ and $Input_2$ crisp values are converted to degrees of membership indicated as $Input'_1$ and $Input'_2$ by a lookup in MF_{Input_1} and MF_{Input_2} membership functions respectively.

- *Combining the fuzzified inputs (fuzzy operations)* A Z'_r degree is calculated considering the rule's condition, indicating the strength of the r rule. Furthermore, in case that a rule's condition has multiple parts, the fuzzy operators 'AND' and 'OR' may be used to combine more than one conditions. The 'Algebraic product' and the 'Algebraic sum' are applied for the 'AND' and the 'OR' operators respectively. In our study, the 'Algebraic product' is calculated using formula (14), while the 'Algebraic sum' is calculated using formula (15).

$$Z'_{u,i,r} = Input'_1 \hat{\cdot} Input'_2 = Input'_1 \cdot Input'_2 \tag{14}$$

$$Z'_{u,i,r} = (Input'_1 + Input'_2) - (Input'_1 \cdot Input'_2) \tag{15}$$

- *Implication method* The implication method estimates the consequence $MF_{Output^c_r}$ of the rule conclusion, considering both the rule conclusion MF_{Output_r} and the rule strength Z'_r. More specifically, the MF_{Output_r} height is trimmed with respect to the Z'_r degree, using formula (16), which applies the Min method.

$$MF_{Output^c_{r_{Height}}} = min\{MF_{Output_{r_{Height}}}, Z'_r\} \tag{16}$$

- *Aggregation method* The aggregation method combines the R rules' consequences to calculate the $Output^A$ fuzzy set, using formula (17), which applies the Max method.

$$Output^A = MF_{Output^c_1} \cup MF_{Output^c_2} \cup \ldots \cup MF_{Output^c_R} \tag{17}$$

- *Defuzzification* During the defuzzification, the $Output^A$ fuzzy set is transformed to the crisp value *Output*. Formula (18) that applies the Weighted Average method is used, where μ_r is the height and h_r is the centroid of each rule obtained from the $Output^A$. Also, symbols U and L represent the upper and the lower pentagon of each rule respectively.

$$Output = \frac{\sum_{r=1}^{R} (\mu^U_r \cdot h^U_r + \mu^L_r \cdot h^L_r)}{\sum_{r=1}^{R} (h^U_r + h^L_r)} \tag{18}$$

3.5. The Pentagonal Fuzzy TOPSIS (PFT)

The Pentagonal Fuzzy TOPSIS (PFT) algorithm is an improved version of the TOPSIS using interval-valued pentagonal fuzzy numbers. In general, TOPSIS introduced in [56], is based on the concept that the best alternative should have the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution. The PFT method assumes that the linguistic values of criteria attributes are represented by IVPFN numbers.

Suppose $A = \{A_1, A_2, ..., A_n\}$ is the set of possible alternatives, $C = \{C_1, C_2, \ldots, C_m\}$ is the set of criteria and $w_1, w2, \ldots, w_m$ are the weights of each criterion. The steps of the method are as follows:

Step 1. *Construction of the decision matrix:* Each x_{ij} element of the $n \times m$ decision matrix D is an interval-valued pentagonal fuzzy number which expresses the performance of alternative i for criterion j. Thus

$$D = \begin{array}{c|ccc} & C_1 & \ldots & C_m \\ \hline A_1 & x_{11} & \ldots & x_{1m} \\ \vdots & \vdots & \ddots & \vdots \\ A_n & x_{n1} & \ldots & x_{nm} \end{array} \tag{19}$$

where: $x_{ij} = [(x^L_{ij1}, x^L_{ij2}, x^L_{ij3}, x^L_{ij4}, x^L_{ij5}, v^L_{ij}, v^L_{ij1}, v^L_{ij2}), (x^U_{ij1}, x^U_{ij2}, x^U_{ij3}, x^U_{ij4}, x^U_{ij5}, v^U_{ij}, v^U_{ij1}, v^U_{ij2})]$. In case there are Q decision makers the decision matrix and the criteria weights include the average of the performance values and weights respectively, of the decision makers. Hence, assuming that for the k-th decision maker x_{ijk} is the performance of alternative i for criterion j, and w_{jk} is the importance weight for criterion j, the average of the performance values and weights are given by

$$x_{ij} = \frac{1}{Q} \sum_{k=1}^{Q} x_{ijk} \tag{20}$$

and

$$w_j = \frac{1}{Q} \sum_{k=1}^{Q} w_{jk}. \tag{21}$$

Step 2. *Normalization of the decision matrix:* Consider that Ω_b is the set of benefits attributes and Ω_c is the set of costs attributes. Then, the elements of the normalized decision matrix are computed as

$$r_{ij} = [(\frac{x^L_{ij1}}{b_j}, \frac{x^L_{ij2}}{b_j}, \frac{x^L_{ij3}}{b_j}, \frac{x^L_{ij4}}{b_j}, \frac{x^L_{ij5}}{b_j}, v^L_{ij}, v^L_{ij1}, v^L_{ij2}), \\ (\frac{x^U_{ij1}}{b_j}, \frac{x^U_{ij2}}{b_j}, \frac{x^U_{ij3}}{b_j}, \frac{x^U_{ij4}}{b_j}, \frac{x^U_{ij5}}{b_j}, v^U_{ij}, v^U_{ij1}, v^U_{ij2})] \tag{22}$$

where $b_j = \max_i x^U_{ij4}$ for each $j \in \Omega_b$, or

$$r_{ij} = [(\frac{c_j}{x^L_{ij5}}, \frac{c_j}{x^L_{ij4}}, \frac{c_j}{x^L_{ij3}}, \frac{c_j}{x^L_{ij2}}, \frac{c_j}{x^L_{ij1}}, v^L_{ij}, v^L_{ij2}, v^L_{ij1}), \\ (\frac{c_j}{x^U_{ij5}}, \frac{c_j}{x^U_{ij4}}, \frac{c_j}{x^U_{ij3}}, \frac{c_j}{x^U_{ij2}}, \frac{c_j}{x^U_{ij1}}, v^U_{ij}, v^U_{ij2}, v^U_{ij1})] \tag{23}$$

where $c_j = \min_i x^L_{ij4}$ for each $j \in \Omega_c$.

Step 3. *Construction of the weighted normalized decision matrix:* The weighted normalized decision matrix is constructed by multiplying each element of the normalized decision matrix r_{ij} with the respective weight w_j according to the formula

$$u_{ij} = [(r^L_{ij1} \cdot w_j, r^L_{ij2} \cdot w_j, r^L_{ij3} \cdot w_j, r^L_{ij4} \cdot w_j, r^L_{ij5} \cdot w_j, v^L_{ij}, \\ v^L_{ij1}, v^L_{ij2}), \ (r^U_{ij1} \cdot w_j, r^U_{ij2} \cdot w_j, r^U_{ij3} \cdot w_j, r^U_{ij4} \cdot w_j, \\ r^U_{ij5} \cdot w_j, v^U_{ij}, v^U_{ij1}, v^U_{ij2})] \tag{24}$$

Step 4. *Determination of the positive and negative ideal solution:* The positive ideal solution is defined

$$X^+ = [(x^{+L}_{ij1}, x^{+L}_{ij2}, x^{+L}_{ij3}, x^{+L}_{ij4}, x^{+L}_{ij5}, v^{+L}_{ij}, v^{+L}_{ij1}, v^{+L}_{ij2}), \\ (x^{+U}_{ij1}, x^{+U}_{ij2}, x^{+U}_{ij3}, x^{+U}_{ij4}, x^{+U}_{ij5}, v^{+U}_{ij}, v^{+U}_{ij1}, v^{+U}_{ij2})] = \\ [(\bigwedge_i u^L_{ij1}, \bigwedge_i u^L_{ij2}, \bigwedge_i u^L_{ij3}, \bigwedge_i u^L_{ij4}, \bigwedge_i u^L_{ij5}, v^L_{ij}, v^L_{ij1}, v^L_{ij2}), \\ (\bigwedge_i u^U_{ij1}, \bigwedge_i u^U_{ij2}, \bigwedge_i u^U_{ij3}, \bigwedge_i u^U_{ij4}, \bigwedge_i u^U_{ij5}, v^U_{ij}, v^U_{ij1}, v^U_{ij2})] \tag{25}$$

where $\bigwedge_i \equiv \max_i$ in case $j \in \Omega_b$ and $\bigwedge_i \equiv \min_i$ in case $j \in \Omega_c$.

The negative ideal solutions are defined accordingly

$$X^- = [(x^{-L}_{ij1}, x^{-L}_{ij2}, x^{-L}_{ij3}, x^{-L}_{ij4}, x^{-L}_{ij5}, v^{-L}_{ij}, v^{-L}_{ij1}, v^{-L}_{ij2}), \\ (x^{-U}_{ij1}, x^{-U}_{ij2}, x^{-U}_{ij3}, x^{-U}_{ij4}, x^{-U}_{ij5}, v^{-U}_{ij}, v^{-U}_{ij1}, v^{-U}_{ij2})] = \\ [(\bigvee_i u^L_{ij1}, \bigvee_i u^L_{ij2}, \bigvee_i u^L_{ij3}, \bigvee_i u^L_{ij4}, \bigvee_i u^L_{ij5}, v^L_{ij}, v^L_{ij1}, v^L_{ij2}), \\ (\bigvee_i u^U_{ij1}, \bigvee_i u^U_{ij2}, \bigvee_i u^U_{ij3}, \bigvee_i u^U_{ij4}, \bigvee_i u^U_{ij5}, v^U_{ij}, v^U_{ij1}, v^U_{ij2})] \tag{26}$$

where $\bigvee_i \equiv \min_i$ in case $j \in \Omega_b$ and $\bigvee_i \equiv \max_i$ in case $j \in \Omega_c$.

Step 5. Measurement of the distance of each alternative from the ideal solutions: The distances of each alternative from the positive ideal solution are evaluated as follows

$$d^+_{i1} = \sum_{j=1}^{m} \{\frac{1}{5}[(u^L_{ij1} - x^{+L}_{ij1})^2 + (u^L_{ij2} - x^{+L}_{ij2})^2 + (u^L_{ij3} - x^{+L}_{ij3})^2 + (u^L_{ij4} - x^{+L}_{ij4})^2 + (u^L_{ij5} - x^{+L}_{ij5})^2]\}^{\frac{1}{2}} \tag{27}$$

$$d^+_{i2} = \sum_{j=1}^{m} \{\frac{1}{5}[(u^U_{ij1} - x^{+U}_{ij1})^2 + (u^U_{ij2} - x^{+U}_{ij2})^2 + (u^U_{ij3} - x^{+U}_{ij3})^2 + (u^U_{ij4} - x^{+U}_{ij4})^2 + (u^U_{ij5} - x^{+U}_{ij5})^2]\}^{\frac{1}{2}} \tag{28}$$

Likewise the distances of each alternative from the negative ideal solution are estimated

$$d^-_{i1} = \sum_{j=1}^{m} \{15[(u^L_{ij1} - x^{-L}_{ij1})^2 + (u^L_{ij2} - x^{-L}_{ij2})^2 + (u^L_{ij3} - x^{-L}_{ij3})^2 + (u^L_{ij4} - x^{-L}_{ij4})^2 + (u^L_{ij5} - x^{-L}_{ij5})^2]\}^{\frac{1}{2}} \tag{29}$$

$$d^-_{i2} = \sum_{j=1}^{m} \{\frac{1}{5}[(u^U_{ij1} - x^{-U}_{ij1})^2 + (u^U_{ij2} - x^{-U}_{ij2})^2 + (u^U_{ij3} - x^{-U}_{ij3})^2 + (u^U_{ij4} - x^{-U}_{ij4})^2 + (u^U_{ij5} - x^{-U}_{ij5})^2]\}^{\frac{1}{2}} \tag{30}$$

Consequently, similarly to [46] the distance of the alternatives from the positive and negative ideal solutions are expressed by intervals such as $[d^+_{i1}, d^+_{i2}]$ and $[d^-_{i1}, d^-_{i2}]$, instead of single values. In this way less information is lost.

Step 6. *Calculation of the relative closeness:* The relative closeness of the distances from the ideal solutions are computed as

$$RC_{i1} = \frac{d^-_{i1}}{d^+_{i1} + d^-_{i1}} \tag{31}$$

and

$$RC_{i2} = \frac{d^-_{i2}}{d^+_{i2} + d^-_{i2}} \tag{32}$$

The compound relative closeness is obtained from the average of the above values

$$RC_i = \frac{RC_{i1} + RC_{i2}}{2} \tag{33}$$

Step 7. Alternatives ranking: The alternatives are ranked according to their RC_i values. The best alternative is that with the higher RC_i value.

4. The proposed VHO management scheme

The proposed VHO management scheme uses the methods described in the previous section (Section 3). Its design has been optimized to be applied in 5G network architectures where both Fog and Cloud infrastructures are available. The VHO process includes the VHO Initiation, the Velocity Monitoring, the Network Selection and the VHO Execution subprocesses as presented in Fig. 2.

Initially, the VHO Initiation is executed in the Fog considering the Quality of Service (QoS) and the Signal to Noise plus Interference Ratio (SINR) that the vehicle perceives from its current network to evaluate the necessity to perform a handover. Both the Fog and the Cloud cooperate to accomplish the Velocity Monitoring process. Finally, the Cloud performs the Network Selection among the available networks depending on vehicle's velocity. As follows, the vehicle is informed through the Fog infrastructure, to make a handover to the selected network.

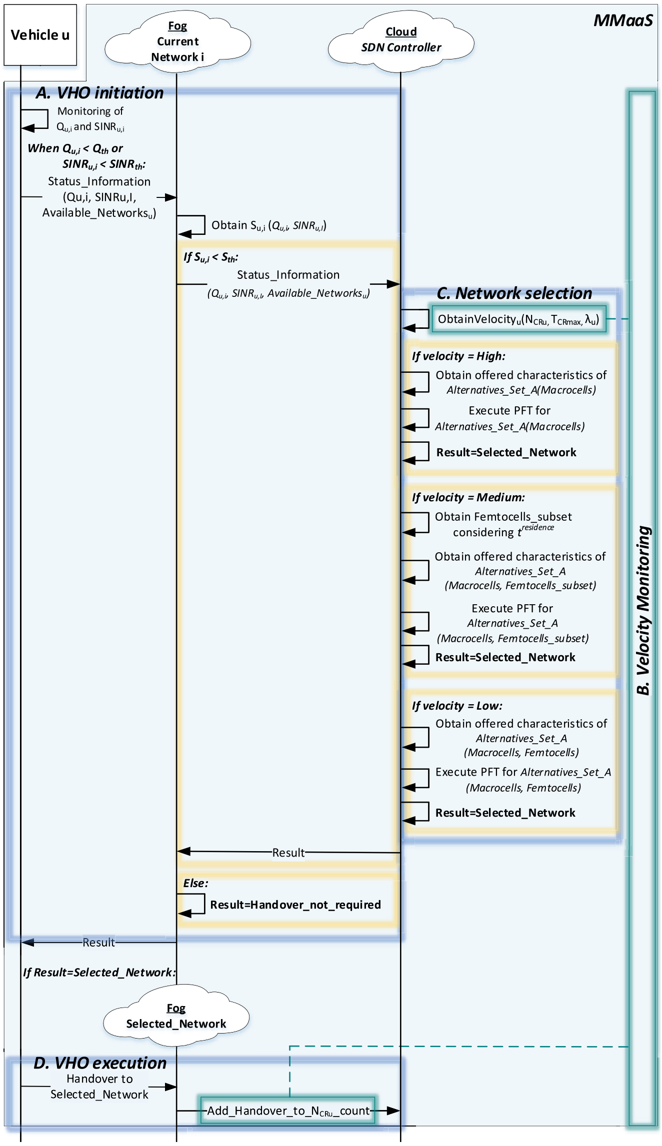


Fig. 2. The proposed methodology.

The following subsections describe in depth each one of the aforementioned subprocesses.

4.1. VHO initiation

During the VHO initiation process the $S_{u,i}$ indicator is defined, determining the satisfaction grade of user u from his current network i. More specifically, the $S_{u,i}$ value is estimated considering as input the $SINR_{u,i}$ and the $Q_{u,i}$ parameters. The $SINR_{u,i}$ represents the Signal to Noice plus Interference, while the $Q_{u,i}$ represents the quality of the users' services offered from the current network. $Q_{u,i}$ is calculated using formula (34), where $th_{u,i,k}$, $d_{u,i,k}$, $j_{u,i,k}$ and $pl_{u,i,k}$ represent the throughput, the delay, the jitter and the packet loss ratio respectively, obtained by user u for the service k. Additionally, the $w_{th,k}$, $w_{d,k}$, $w_{j,k}$ and $w_{p,kl}$ represent the

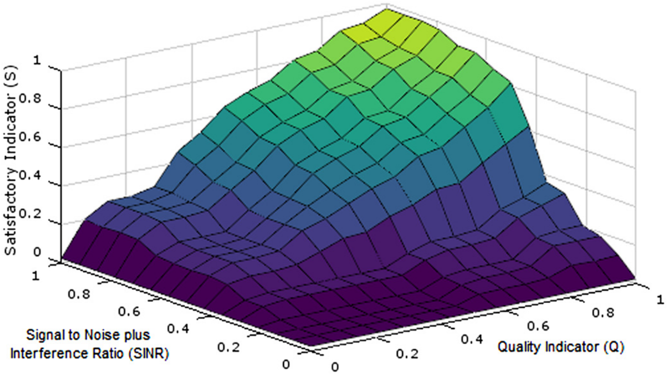


Fig. 3. The S values range as obtained using the FIS.

weights of the aforementioned parameters estimated using the PF-ANP method, while N represents the number of the parameters considered and K the number of the available services.

$$Q_{u,i} = \left(\sum_{k=1}^{K}\left((w_{th,k}\cdot th_{u,i,k} + w_{d,k}\cdot\frac{1}{d_{u,i,k}} + w_{j,k}\cdot\frac{1}{j_{u,i,k}} + w_{pl,k}\cdot\frac{1}{pl_{u,i,k}})/N\right)\right)/K \tag{34}$$

Accordingly, the user's equipment continuously monitors its perceived the $SINR_{u,i}$ and the $Q_{u,i}$ values. When either the $SINR_{u,i}$ or the $Q_{u,i}$ becomes less than a predefined threshold, the user equipment sends the obtained values to the Fog infrastructure. Subsequently, the Fog infrastructure uses the Mamdani satisfaction chart presented in Fig. 3, in order to determine the $S_{u,i}$ satisfaction grade. If the satisfaction grade is less than a predefined S_{th} threshold value, then the network selection process will be executed.

The satisfaction indicators chart presents the $S_{u,i}$ values obtained for each possible $SINR_{u,i}$ and $Q_{u,i}$ combination. Indicatively, when the $SINR_{u,i}$ and $Q_{u,i}$ values are too low, the produced $S_{u,i}$ value is too low as well. On the contrary, when the $SINR_{u,i}$ and $Q_{u,i}$ values are close to 1, the produced $S_{u,i}$ value is also high, indicating that the user is fully satisfied. Furthermore, when only one of the $SINR_{u,i}$ or the $Q_{u,i}$ values is close to 0, the user satisfaction is in quite low levels.

At this point it has to be noted that since the user's satisfaction is obtained at the Fog by performing a lookup at the satisfaction indicators chart, the overhead introduced at the Fog is minimal. Also, the method does not impose any significant overhead at the user equipment due to monitoring of the $SINR_{u,i}$ and $Q_{u,i}$ parameters.

4.1.1. *Evaluation of the satisfaction indicators*

The Mamdani satisfaction chart is evaluated once during the instantiation of the Fog services. Each satisfaction indicator $S_{u,i}$ of Fig. 3 is obtained using the MPFIS method, considering the $SINR_{u,i}$ and the $Q_{u,i}$ as input parameters. Both $SINR_{u,i}$ and $Q_{u,i}$ are normalized in order to have values within the range [0, 1]. Also, the MF_{SINR}, MF_Q, MF_S membership functions (MF) are defined using the EUM method, indicating the linguistic terms and the corresponding Interval Valued Pentagonal Fuzzy Numbers (I-VPFN) for the fuzzy representation of the $SINR_{u,i}$, $Q_{u,i}$ and $S_{u,i}$ respectively. Thus, for each crisp value, two membership degrees are determined in the corresponding MF, one for the upper pentagon and one for the lower pentagon. Table 2 represents the linguistic terms and the corresponding interval-valued pentagonal fuzzy numbers of MF_{SINR}, MF_Q and MF_S membership functions, which are equally distributed inside the domain $[U_{min}, U_{max}]$ = [0, 1] as

Table 2
Linguistic terms and the corresponding interval-valued pentagonal fuzzy numbers used for MF_{SINR}, MF_Q and MF_S.

MF_{SINR} membership functions

Linguistic term	Interval-valued trapezoidal fuzzy number
Absolute Bad (AB)	[(0.0, 0.0, 0.0, 0.062, 0.093, 0.8, 0.6, 0.6), (0.0, 0.0, 0.0, 0.083, 0.125, 1.0, 0.8, 0.8)]
Too Bad (TB)	[(0.072, 0.104, 0.166, 0.229, 0.26, 0.8, 0.6, 0.6), (0.041, 0.083, 0.166, 0.25, 0.291, 1.0, 0.8, 0.8)]
Bad (B)	[(0.239, 0.27, 0.333, 0.395, 0.427, 0.8, 0.6, 0.6), (0.208, 0.25, 0.333, 0.416, 0.458, 1.0, 0.8, 0.8)]
Enough (EN)	[(0.406, 0.437, 0.5, 0.562, 0.593, 0.8, 0.6, 0.6), (0.375, 0.416, 0.5, 0.583, 0.625, 1.0, 0.8, 0.8)]
More than Enough (ME)	[(0.572, 0.604, 0.667, 0.729, 0.76, 0.8, 0.6, 0.6), (0.541, 0.583, 0.667, 0.75, 0.791, 1.0, 0.8, 0.8)]
Almost Excellent (AE)	[(0.739, 0.77, 0.833, 0.895, 0.927, 0.8, 0.6, 0.6), (0.708, 0.75, 0.833, 0.916, 0.958, 1.0, 0.8, 0.8)]
Excellent (EX)	[(0.906, 0.937, 1.0, 1.0, 1.0, 0.8, 0.6, 0.6), (0.875, 0.916, 1.0, 1.0, 1.0, 1.0, 0.8, 0.8)]

MF_Q membership functions

Linguistic term	Interval-valued trapezoidal fuzzy number
Absolutely Poor (AP)	[(0.0, 0.0, 0.0, 0.046, 0.07, 0.8, 0.6, 0.6), (0.0, 0.0, 0.0, 0.062, 0.093, 1.0, 0.8, 0.8)]
Very Poor (VP)	[(0.054, 0.078, 0.125, 0.171, 0.195, 0.8, 0.6, 0.6), (0.031, 0.062, 0.125, 0.187, 0.218, 1.0, 0.8, 0.8)]
Poor (P)	[(0.179, 0.203, 0.25, 0.296, 0.32, 0.8, 0.6, 0.6), (0.156, 0.187, 0.25, 0.312, 0.343, 1.0, 0.8, 0.8)]
Medium Poor (MP)	[(0.304, 0.328, 0.375, 0.421, 0.445, 0.8, 0.6, 0.6), (0.281, 0.312, 0.375, 0.437, 0.468, 1.0, 0.8, 0.8)]
Medium (M)	[(0.429, 0.453, 0.5, 0.546, 0.57, 0.8, 0.6, 0.6), (0.406, 0.437, 0.5, 0.562, 0.593, 1.0, 0.8, 0.8)]
Medium Good (MG)	[(0.554, 0.578, 0.625, 0.671, 0.695, 0.8, 0.6, 0.6), (0.531, 0.562, 0.625, 0.687, 0.718, 1.0, 0.8, 0.8)]
Good (G)	[(0.679, 0.703, 0.75, 0.796, 0.82, 0.8, 0.6, 0.6), (0.656, 0.687, 0.75, 0.812, 0.843, 1.0, 0.8, 0.8)]
Very Good (VG)	[(0.804, 0.828, 0.875, 0.921, 0.945, 0.8, 0.6, 0.6), (0.781, 0.812, 0.875,0.937, 0.968, 1.0, 0.8, 0.8)]
Absolutely Good (AG)	[(0.929, 0.953, 1.0, 1.0, 1.0, 0.8, 0.6, 0.6), (0.906, 0.937, 1.0, 1.0, 1.0, 1.0, 0.8, 0.8)]

MF_S membership functions

Linguistic term	Interval-valued trapezoidal fuzzy number
Absolute Unsatisfactory (AU)	[(0.0, 0.0, 0.0, 0.034, 0.051, 0.8, 0.6, 0.6), (0.0, 0.0, 0.0, 0.045, 0.068, 1.0, 0.8, 0.8)]
Very Unsatisfactory (VU)	[(0.039, 0.056, 0.09, 0.125, 0.142, 0.8, 0.6, 0.6), (0.022, 0.045, 0.09, 0.136, 0.159, 1.0, 0.8, 0.8)]
Unsatisfactory (U)	[(0.13, 0.147, 0.181, 0.215, 0.232, 0.8, 0.6, 0.6), (0.113, 0.136, 0.181, 0.227, 0.25, 1.0, 0.8, 0.8)]
Slightly Unsatisfactory (SU)	[(0.221, 0.238, 0.272, 0.306, 0.323, 0.8, 0.6, 0.6), (0.204, 0.227, 0.272, 0.318, 0.34, 1.0, 0.8, 0.8)]
Less than Acceptable (LA)	[(0.312, 0.329, 0.363, 0.397, 0.414, 0.8, 0.6, 0.6), (0.295, 0.318, 0.363, 0.409, 0.431, 1.0, 0.8, 0.8)]
Slightly Acceptable (SA)	[(0.403, 0.42, 0.454, 0.488, 0.505, 0.8, 0.6, 0.6), (0.386, 0.409, 0.454, 0.5, 0.522, 1.0, 0.8, 0.8)]
Acceptable (A)	[(0.494, 0.511, 0.545, 0.579, 0.596, 0.8, 0.6, 0.6), (0.477, 0.5, 0.545, 0.59, 0.613, 1.0, 0.8, 0.8)]
More than Acceptable (MA)	[(0.585, 0.602, 0.636, 0.67, 0.687, 0.8, 0.6, 0.6), (0.568, 0.59, 0.636, 0.681, 0.704, 1.0, 0.8, 0.8)]
Slightly Satisfactory (SS)	[(0.676, 0.693, 0.727, 0.761, 0.778, 0.8, 0.6, 0.6), (0.659, 0.681, 0.727, 0.772, 0.795, 1.0, 0.8, 0.8)]
Satisfactory (S)	[(0.767, 0.784, 0.818, 0.852, 0.869, 0.8, 0.6, 0.6), (0.75, 0.772, 0.818, 0.863, 0.886, 1.0, 0.8, 0.8)]
Very Satisfactory (VS)	[(0.857, 0.875, 0.909, 0.943, 0.96, 0.8, 0.6, 0.6), (0.84, 0.863, 0.909, 0.954, 0.977, 1.0, 0.8, 0.8)]
Absolute Satisfactory (AS)	[(0.948, 0.965, 1.0, 1.0, 1.0, 0.8, 0.6, 0.6), (0.931, 0.954, 1.0, 1.0, 1.0, 1.0, 0.8, 0.8)]

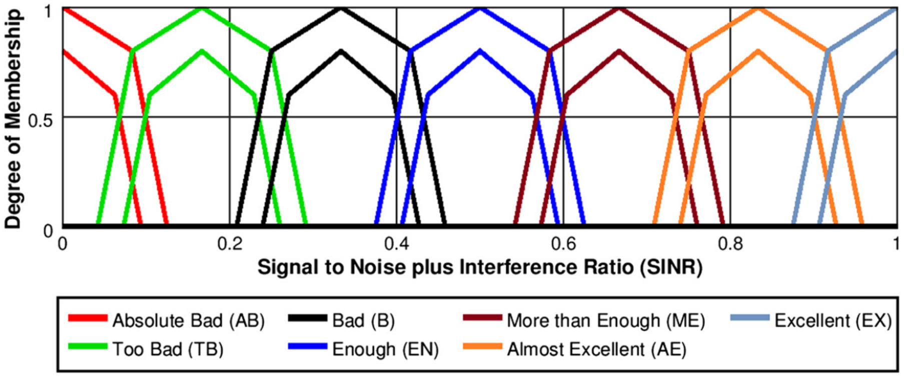


Fig. 4. MF_{SINR} membership functions balance.

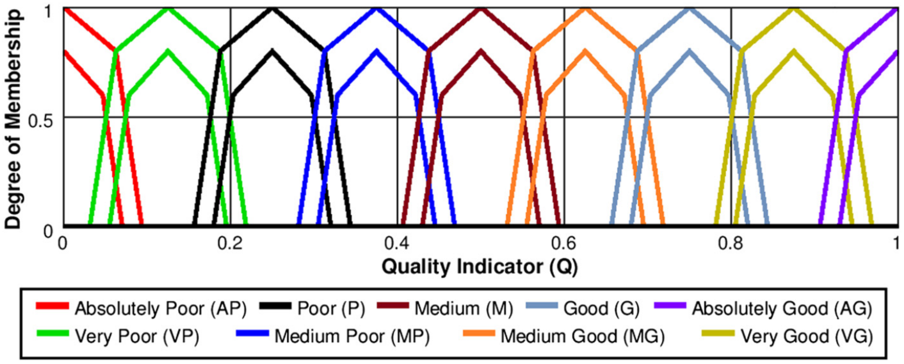


Fig. 5. MF_Q membership functions balance.

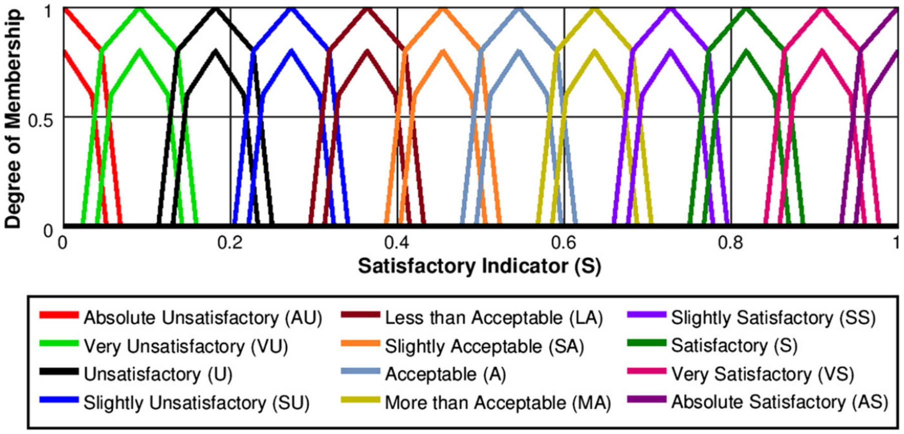


Fig. 6. MF_S membership functions balance.

illustrated in Figs. 4, 5 and 6, respectively. Furthermore, Table 3 represents the considered fuzzy rule base.

4.2. Velocity monitoring

During the entire vehicle movement, its velocity is monitored by the Fog-Cloud infrastructure. More specifically, an enhanced version of the Mobility State Estimation (MSE) model defined in 3GPP LTE Release 11 [57] is used to estimate vehicles' velocity. The MSE considers the number of handovers or reselections (N_{CR_u}) performed by a vehicle during a sliding time window (T_{CRmax}). The vehicle is categorized into one of three velocity states, namely the Normal, the Medium and the High, considering the $N_{CR_{Medium}}$ and $N_{CR_{High}}$ thresholds with $N_{CR_{Medium}} < N_{CR_{High}}$. The concept of this method is that the more handovers the vehicle performs during the T_{CRmax} period, the faster the vehicle is moving. In heterogeneous network environments including both Macrocells and Femtocells, the default T_{CRmax} value is 120 seconds, while the default $N_{CR_{Medium}}$ and $N_{CR_{High}}$ values are equal to 10 and 16 handovers, respectively [57]. Furthermore, the estimated residence time $t^{residence}_{u,i}$ of vehicle u in each available cell i is estimated using formula (35) defined in [58], where r_f is the radius of femtocell i and v_u is the velocity of the vehicle u.

$$t^{residence}_{u,i} = \frac{\pi \cdot r_i}{2 \cdot v_u} \tag{35}$$

Following, the vehicle velocity is obtained by formula (36) defined in [40].

$$v_u = \frac{\pi \cdot N_{CR_u}}{4 \cdot T_{CRmax} \cdot \sqrt{\lambda_u}} \tag{36}$$

Table 3
The Fuzzy rule (or knowledge) base.

Rule	MF_{SINR}	Operator	MF_Q	MF_S
1	AB	or	AP	AU
2	TB	and	VP	AU
3	B	and	VP	VU
4	EN	and	VP	U
5	ME	and	VP	U
6	AE	and	VP	SU
7	EX	and	VP	SU
8	TB	and	P	AU
9	B	and	P	VU
10	EN	and	P	U
11	ME	and	P	U
12	AE	and	P	SU
13	EX	and	P	SU
14	TB	and	MP	AU
15	B	and	MP	VU
16	EN	and	MP	SU
17	ME	and	MP	SU
18	AE	and	MP	LA
19	EX	and	MP	SA
20	TB	and	M	AU
21	B	and	M	VU
22	EN	and	M	LA
23	ME	and	M	SA
24	AE	and	M	A
25	EX	and	M	MA
26	TB	and	MG	VU
27	B	and	MG	U
28	EN	and	MG	SA
29	ME	and	MG	A
30	AE	and	MG	MA
31	EX	and	MG	SS
32	TB	and	G	VU
33	B	and	G	U
34	EN	and	G	A
35	ME	and	G	MA
36	AE	and	G	SS
37	EX	and	G	S
38	TB	and	VG	U
39	B	and	VG	SU
40	EN	and	VG	MA
41	ME	and	VG	SS
42	AE	and	VG	S
43	EX	and	VG	VS
44	TB	and	AG	U
45	B	and	AG	LA
46	EN	and	AG	S
47	ME	and	AG	VS
48	AE	and	AG	AS
49	EX	and	AG	AS

The λ_u parameter, obtained by the SDN controller, denotes the cell's density in the location of vehicle u.

4.3. Network selection

The mobility state of each vehicle is considered in order to select the set $A = \{A_1, A_2, \ldots, A_n\}$ of possible network alternatives based on the SINR perceived from each network. Accordingly, if the vehicle mobility state is Normal then the vehicle considers all the available networks as alternatives, including both Macrocells and Femtocells. On the contrary, if vehicle mobility state is Medium then the vehicle skips some Femtocells along its trajectory. In particular, the femtocell i is considered as alternative if $t^{residence}_{u,i} \geqslant t^{residence}_{u,mean}$, where $t^{residence}_{u,mean}$ is the average residence time of vehicle u considering all the available femtocells in its current location. Finally, if vehicle mobility state is High then only Macrocells are considered as alternatives.

Thereafter the network selection is performed using the Pentagonal interval-valued Fuzzy TOPSIS (PFT), considering both QoS aware (throughput, delay, jitter and packet loss) and operator's policy (service reliability, security and price) criteria. Since the list of network alternatives is constructed considering the vehicle's velocity and then the network selection is performed using QoS and policy related parameters, the ping pong effect is eliminated.

4.4. Handover execution

During the handover execution, the vehicle is connected to the selected network. After each successful handover of a vehicle, the number of handovers or reselections N_{CR_u} is increased, in order the aforementioned handover to be considered for the estimation of the vehicle velocity.

4.5. Computational complexity of the proposed approach

Regarding the computational complexity of the proposed approach the VHO initiation subprocess requires constant time to complete its tasks by performing simple checks against predefined thresholds, resulting in $O(1)$. Also, the network selection phase introduces a $O(n^2)$ complexity, due to the weighting and normalization of $n \times m$ decision matrices. Similar complexities are introduced by other handover algorithms proposed in the research literature. The novelty in our approach is that most of the computational complexity is performed at the Cloud/Fog infrastructure.

5. Simulation setup and results

In our experiments, the Software Defined Vehicular Cloud topology presented in Fig. 7 is considered. A mobility trace indicating the map of the city of Piraeus along with road traffic data has been created using the Open Street Map (OSM) software [59]. Then, the mobility trace has been used as input in the Simulator of Urban Mobility (SUMO) simulator [60] allowing the production of a realistic mobility pattern for the simulated vehicles including 39807 vehicles in total, moving inside the Piraeus city in a 24 hours period. The average arrival rate of the vehicles into the map is equal to 0,460729167 vehicles per second, while their average departure rate is equal to 0,46 vehicles per second. Furthermore, the network topology is being built upon the map, using the Network Simulator 3 (NS3) [61]. It includes a Fog infrastructure, as well as a Cloud infrastructure. The Fog infrastructure consists of 18 LTE Macrocell e-Node Bs (eNBs), 39 LTE Femtocell eNBs, 16 WiMAX Macrocell Base Stations (BSs), 26 WiMAX Femtocell BSs and 22 802.11p WAVE RSUs, equipped with additional computational and storage resources. The access networks have been located on the map, according to the Hellenic Telecommunications and Post Commission (EETT) [62] data about BSs' positions in the city of Piraeus. The positions and the spectrum of the BSs are presented in Tables A1–A3 (Appendix A), for the LTE, WiMAX and WAVE technologies, respectively. The SDN controller has global view of the entire network environment. The Cloud infrastructure includes a set of Virtual Machines (VMs) providing services such as Navigation Assistance (NAV), Voice over IP (VoIP), Conversational Video (CV), Buffered Streaming (BS) and Web Browsing (WB). Furthermore, a Software Defined Network (SDN) controller provides centralized control of the entire system.

Each access network supports at least one of the aforementioned Cloud services, while four Service Level Agreements (SLAs) are defined. SLA1 has the higher service priority and SLA 4 has the lower service priority. SLA1 supports all service types and provides the best values for QoS as well as policy decision criteria. SLA2 supports less service types, by not providing support for the VoIP and NAV services. Additionally, it provides slightly worse decision criteria values than those offered by the SLA1. SLA3 supports only the BS and the WB services and satisfactory QoS characteris-

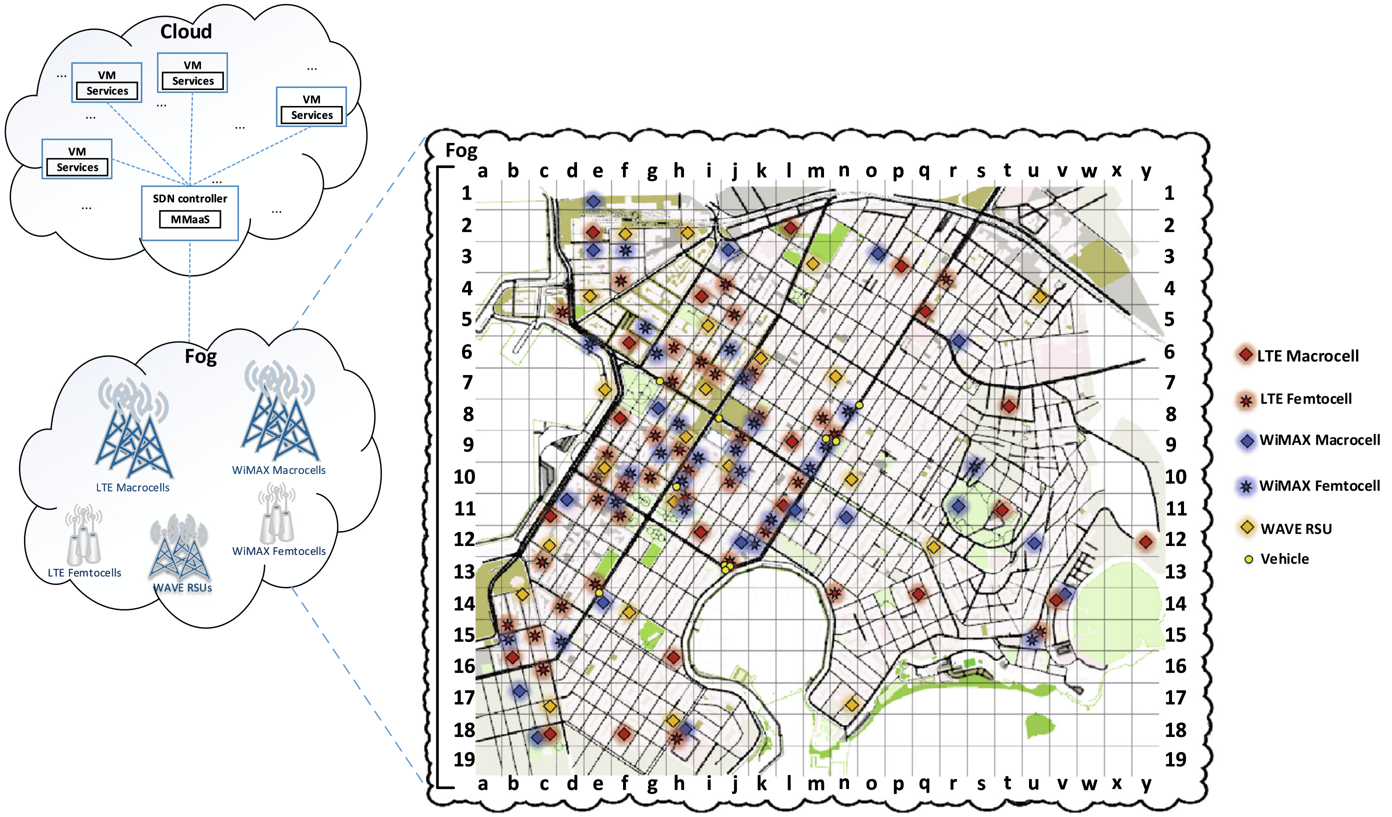


Fig. 7. The simulated topology.

Table 4
Relation of the network QoS characteristics and linguistic terms for VoIP.

Linguistic term	Throughput range (Kbps)	Delay range (ms)	Jitter range (ms)	Packet loss range
AP	≤ 164	≥ 116	≥ 65	≥ 0.4
VP	165–174	111-115	55–64	≥ 0.2–0.4
P	175–184	106-110	45–54	$> 10^{-1}$–< 0.2
MP	185–194	100–105	40–44	10^{-1}
M	195–204	95–99	35–49	10^{-2}
MG	205–214	86–94	30–34	10^{-3}
G	215–224	66–85	25–29	10^{-4}
VG	225–239	41–65	20–24	10^{-5}
AG	≥ 240	≤ 40	≤ 20	$\leq 10^{-6}$

tics and policies. Finally, SLA4 supports only the WB service while it provides acceptable decision criteria values.

Network specifications are expressed directly using linguistic terms (Appendix B). In particular, crisp values of network QoS characteristics are converted into linguistic terms which correspond to specific ranges of values per service type. Indicatively, Table 4 illustrates the mapping between ranges of network QoS characteristics values and the respective linguistic terms for the VoIP service. Table 5 summarizes the simulation parameters.

5.1. *Study of a simulation snapshot*

In this subsection, a snapshot of the simulation at time equal to 3600 seconds is considered. Specifically, the case where 10 of the vehicles are monitored is studied, while each vehicle needs to connect to a network which satisfies the requirements of its services and at the same time complies with its respective SLA agreements. Table 6 presents the available networks in the location of each vehicle.

5.1.1. *VHO initiation*

During the VHO initiation process, the user satisfaction $S_{u,i}$ is obtained using the MPFIS Satisfaction Chart, using the estimated $Q_{u,i}$ and $SINR_{u,i}$ values. It should be noted that the services weights used for the $Q_{u,i}$ estimation are calculated using the PF-ANP method. The criteria used include throughput, delay, jitter and packet loss. Fig. 8 depicts the estimated VHO initiation weights for each service. Furthermore, the $S_{th,SLA}$ thresholds given in Table 7 are estimated considering the minimum acceptable Q_{SLA} and $SINR_{SLA}$ values per SLA. Accordingly, if the $S_{u,i}$ becomes less than the respective $S_{th,SLA}$ threshold then the vehicle should perform handover to a new access network. The VHO initiation results for each vehicle are presented in Table 8. As it can be observed, vehicle 8 will remain to its current network i, while the rest vehicles will proceed to handover.

5.1.2. *Velocity monitoring*

For each one of the monitored vehicles, Table 9 presents its SLA, the services used, its geographical position and its estimated velocity.

Table 5
The simulation parameters.

Parameter	Value
Simulation duration	86400 seconds (24 hours)
Networks count	LTE Macrocell BSs: 20 LTE Femtocell BSs: 37 WiMAX Macrocell BSs: 17 WiMAX Femtocell BSs: 25 WAVE RSUs: 22 Total: 121
Cells radius	LTE/WiMAX Macrocells: 400 meters LTE/WiMAX Femtocells: 30 meters WAVE RSUs: 150 meters
Networks positions	According to the Hellenic Telecommunications and Post Commission (EETT) [62] data (see Appendix A)
Networks frequencies	See Appendix A
Service Layer Agreements (SLA) count	4
Vehicles count	39807
Average vehicles arrival rate	0,460729167 vehicles per second
Average vehicles departure rate	0,46 vehicles per second
Vehicles per SLA	SLA 1: 9952 vehicles (25,00062803 %) SLA 2: 9952 vehicles (25,00062803 %) SLA 3: 9952 vehicles (25,00062803 %) SLA 4: 9951 vehicles (24,99811591 %)
Available networks per SLA	See Appendix B
Services	Navigation Assistance (NAV) Voice over IP (VoIP) Conversational Video (CV) Buffered Streaming (BS) Web Browsing (WB)
Distribution of services to vehicles	See Appendix C
Vehicles per velocity	Normal: 13348 (33.53 %) Medium: 13348 (33.53 %) High: 13111 (32.94 %)

Table 6
The available networks for each monitored vehicle.

Vehicle	Available networks in current location
1	LTE Macro 9, LTE Macro 11, LTE Femto 17, WiMAX Macro 8, WiMAX Macro 9, WiMAX Macro 11, WiMAX Femto 13, WAVE 14
2	LTE Macro 9, LTE Macro 11, LTE Femto 17, WiMAX Macro 8, WiMAX Macro 9, WiMAX Macro 11, WiMAX Femto 13, WAVE 14
3	LTE Macro 9, LTE Macro 11, LTE Macro 13, LTE Macro 18, LTE Femto 30, WiMAX Macro 8, WiMAX Macro 9, WiMAX Macro 11, WiMAX Macro 13
4	LTE Macro 4, LTE Macro 6, LTE Macro 7, LTE Macro 9, LTE Macro 11, LTE Macro 13, WiMAX Macro 6, WiMAX Macro 8, WiMAX Macro 11, WAVE 9, WAVE 11, WAVE 13
5	LTE Macro 4, LTE Macro 6, LTE Macro 7, WiMAX Macro 6, WAVE 9
6	LTE Macro 7, LTE Macro 9, LTE Macro 11, LTE Macro 13, LTE Femto 26, WiMAX Macro 6, WiMAX Macro 7, WiMAX Macro 8, WiMAX Macro 11, WiMAX Macro 13, WiMAX Femto 15, WAVE 11, WAVE 15
7	LTE Macro 10, LTE Macro 13, LTE Macro 17, LTE Macro 18, LTE Femto 29, WiMAX Macro 7, WiMAX Macro 13, WiMAX Macro 15, WAVE 19
8	LTE Macro 9, LTE Macro 11, LTE Macro 13, LTE Macro 18, LTE Femto 30, WiMAX Macro 8, WiMAX Macro 9, WiMAX Macro 11, WiMAX Macro 13
9	LTE Macro 3, LTE Macro 5, LTE Macro 9, WiMAX Macro 5, WiMAX Macro 8, WiMAX Macro 9
10	LTE Macro 9, LTE Macro 11, LTE Macro 13, LTE Macro 18, LTE Femto 30, WiMAX Macro 8, WiMAX Macro 9, WiMAX Macro 11, WiMAX Macro 13

Table 7
The Q_{SLA}, $SINR_{SLA}$ and $S_{th,SLA}$ thresholds per SLA.

SLA	Q_{SLA}	$SINR_{SLA}$	$S_{th,SLA}$
1	0.9	0.8	0.81675
2	0.8	0.7	0.70856
3	0.7	0.6	0.54440
4	0.6	0.5	0.42725

Table 8
The VHO initiation results.

Vehicle	Current network i	$Q_{u,i}$	$SINR_{u,i}$ ($SINR^{dB}_{u,i}$)	$S_{u,i}$	S_{th,SLA_u}	Handover required
1	WAVE 14	0.871	0.14 (−5.1 dB)	0.18157	0.81843	Yes
2	LTE Macro 11	0.912	0.17 (−4.05 dB)	0.18212	0.81843	Yes
3	WiMAX Macro 8	0.948	0.29 (0.15 dB)	0.32523	0.81843	Yes
4	LTE Macro 7	0.644	0.23 (−1.95 dB)	0.12122	0.66980	Yes
5	WAVE 9	0.990	0.14 (−5.1 dB)	0.18156	0.66980	Yes
6	WAVE 11	0.827	0.04 (−8.6 dB)	0.02539	0.66980	Yes
7	WiMAX Macro 7	0.999	0.21 (−2.65 dB)	0.18965	0.57767	Yes
8	WiMAX Macro 11	0.704	0.71 (14.85 dB)	0.61247	0.57767	No
9	WiMAX Macro 5	0.988	0.25 (−1.25 dB)	0.27297	0.45457	Yes
10	LTE Macro 18	0.990	0.29 (0.15 dB)	0.35622	0.45457	Yes

Table 9
The monitored vehicles status.

Vehicle	SLA	Services	Current position (latitude, longitude)	Velocity
1	1	VoIP, CV, BS	9n (37.942128, 23.650937)	Medium
2	1	NAV, VoIP, WB	9m (37.942178, 23.650796)	Normal
3	1	NAV	13j (37.938831, 23.647276)	Medium
4	2	CV, BS	8i (37.942819, 23.647134)	Normal
5	2	BS	7g (37.943935, 23.645180)	High
6	2	CV, WB	10h (37.941048, 23.645664)	Normal
7	3	BS	14e (37.938048, 23.642797)	High
8	3	BS, WB	13j (37.988787, 23.647321)	Medium
9	4	WB	8o (37.943331, 23.652023)	High
10	4	WB	13j (37.938858, 23.647291)	Normal

5.1.3. Network selection

During the network selection process the PF-ANP method is applied in order to estimate the weights of network selection criteria per service type and SLA. Fig. 9 depicts the PF-ANP network model. Criteria are classified into two groups namely the Network QoS and the Network Policy characteristics. The Network QoS characteristics group contains network performance related criteria including throughput, delay, jitter and packet loss. Correspondingly, the Network Policy characteristics group contains operator defined rules such as price, security and service reliability. Pairwise comparison decision matrices are created based on relations among the eight selection criteria depicted in Fig. 10. Then, these pairwise comparison decision matrices are used to evaluate the priority vectors of criteria and form the supermatrix per service type and SLA. Subsequently, the weighted supermatrices and finally the limited supermatrices are obtained. Indicatively, for the SLA1 NAV service,

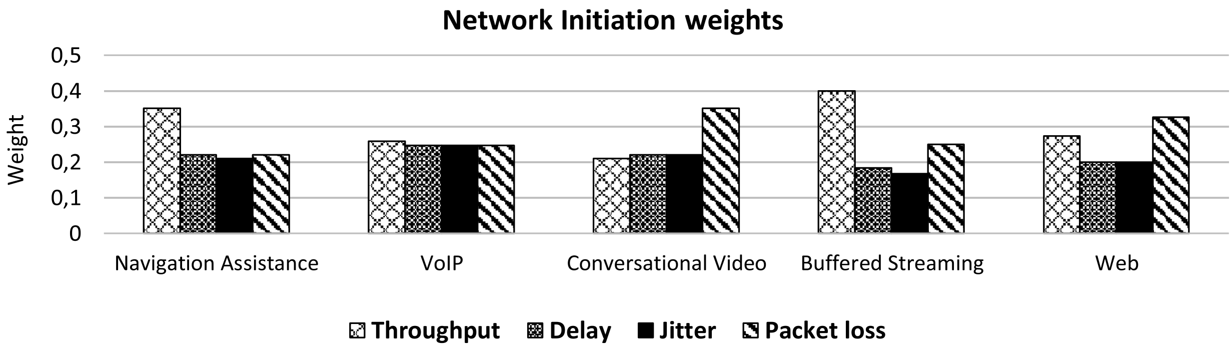


Fig. 8. Criteria weights per service for the VHO initiation.

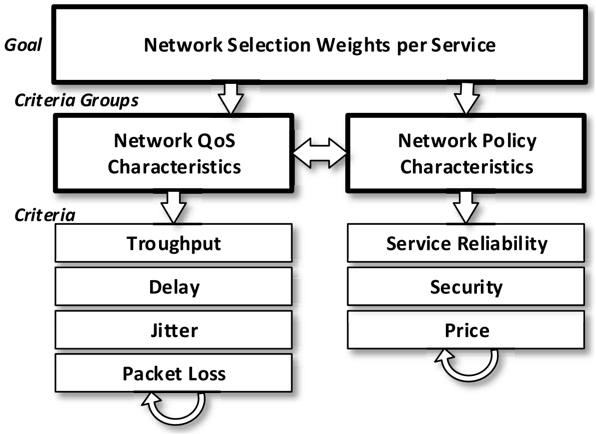


Fig. 9. The PF-ANP network model.

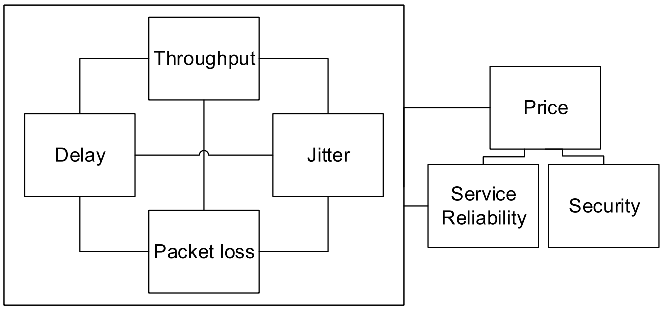


Fig. 10. Relations of criteria.

the initial, the weighted and the limited supermatrices are presented in Tables 10, 11 and 12 respectively.

The criteria weights per service and SLA obtained by the limit supermatrices are presented in Figs. 11–14. As illustrated, the weights are proportional to the constraints of each service as well as to the agreements of each SLA. In particular, the weight of the price criterion is low for SLA1, in which the service reliability and the network QoS characteristics are considered as the most important factors. In SLA2 the price criterion is more important than in SLA1, thus the respective weight is greater than that of SLA1. Consequently, the weights of the service reliability and QoS characteristics criteria in SLA2 are lower compared to the relative weights of SLA1. In SLA3 the weights of price and service reliability criteria are balanced as they are almost of equivalent importance. Finally, in SLA4 the price is the most important criterion resulting in a high estimated weight value.

As follows, the PFT algorithm selects the best network for each vehicle considering the vehicle service requirements. Fig. 15 compares the results of the proposed scheme with the ones obtained using the VAH [41], the FAT [37], the FAS [37], the FAM [37] and the FAE [38] VHO management schemes. In this figure, for each vehicle the PFT ranking of the current network as well as of the target network connection estimated by each of the six schemes are presented. From the obtained results it is clear that the suggested algorithm outperforms the existing schemes since it selects as target networks for vehicles the ones with the best ranks. Also, in special cases where the velocity of vehicles is high (e.g. for vehicle 7) the proposed scheme considers only the wide coverage candidate networks as alternatives avoiding the handovers to femtocell networks.

Additionally, for further evaluation of the proposed scheme, the user's satisfaction grade $S_{u,i}$ after the VHO completion is considered. Specifically, Fig. 16 presents the estimated $S_{u,i}$ after the execution of each VHO scheme. As it can be observed, the results are similar to the aforementioned PFT rankings, while the proposed approach succeeds higher satisfaction grades than the existing schemes.

5.2. 24 hours simulation results

For the entire 24-hour simulation, Tables C1, C2 and C3 (Appendix C) present the number of vehicles that start their movement from each LTE, WiMAX and WAVE network, respectively, as well as their corresponding velocities.

Table C4 presents the vehicles count per service and SLA. The entire services' combinations per SLA are considered, in order all the possible use cases to be studied during the simulation. The number of possible services' combinations (S_c) is estimated using formula (37) [63] where S_n represents the number of the considered services. In this experiment 5 services are considered, namely the Navigation Assistance (NAV), Voice over IP (VoIP), Conversational Video (CV), Buffered Streaming (BS) and Web Browsing (WB) and thus S_c is equal to 31. It should be noted that SLA 1 supports the entire services, while SLA 2 supports only the CV, BS and WB services. Also, SLA 3 supports only the BS and WB services, while SLA 4 supports only the WB service.

$$S_c = 2^{S_n} - 1 \tag{37}$$

The average PFT rankings of each VHO scheme are presented in Fig. 17, where the entire 39807 vehicles are considered. As it can be observed, the proposed scheme accomplishes higher ranking than the other schemes. On the contrary, the VAH scheme accomplishes the lower ranking, due to the fact that it does not consider neither QoS related parameters, nor operator policy related parameters. The rest schemes accomplish intermediate results, while the FAT results are slightly better than the ones achieved from the rest

Table 10
The PF-ANP initial supermatrix for the SLA 1 NAV service.

	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price
Throughput	[(0.37,0.36,0.34,0.33,0.32,1,0.8,0.8), (0.36,0.36,0.34,0.33,0.33,0.8,0.6,0.6)]	[(0.37,0.36,0.34,0.33,0.32,1,0.8,0.8), (0.36,0.36,0.34,0.33,0.33,0.8,0.6,0.6)]	[(0.37,0.36,0.34,0.33,0.32,1,0.8,0.8), (0.36,0.36,0.34,0.33,0.33,0.8,0.6,0.6)]	[(0.37,0.36,0.34,0.33,0.32,1,0.8,0.8), (0.36,0.36,0.34,0.33,0.33,0.8,0.6,0.6)]	[(0.37,0.36,0.349,0.33,0.32,1,0.8,0.8), (0.36,0.36,0.34,0.33,0.33,0.8,0.6,0.6)]	[(0.37,0.36,0.34,0.33,0.32,1,0.8,0.8), (0.36,0.36,0.34,0.33,0.33,0.8,0.6,0.6)]	[(0.37,0.36,0.34,0.33,0.32,1,0.8,0.8), (0.36,0.36,0.34,0.33,0.33,0.8,0.6,0.6)]
Delay	[(0.23,0.21,0.21,0.21,0.21,1,0.8,0.8), (0.21,0.21,0.21,0.21,0.21,0.8,0.6,0.6)]	[(0.23,0.21,0.21,0.21,0.21,1,0.8,0.8), (0.21,0.21,0.21,0.21,0.21,0.8,0.6,0.6)]	[(0.23,0.21,0.21,0.21,0.21,1,0.8,0.8), (0.21,0.21,0.21,0.21,0.21,0.8,0.6,0.6)]	[(0.23,0.21,0.21,0.21,0.21,1,0.8,0.8), (0.21,0.21,0.21,0.21,0.21,0.8,0.6,0.6)]	[(0.23,0.21,0.21,0.21,0.21,1,0.8,0.8), (0.21,0.21,0.21,0.21,0.21,0.8,0.6,0.6)]	[(0.23,0.21,0.21,0.21,0.21,1,0.8,0.8), (0.21,0.21,0.21,0.21,0.21,0.8,0.6,0.6)]	[(0.23,0.21,0.21,0.21,0.21,1,0.8,0.8), (0.21,0.21,0.21,0.21,0.21,0.8,0.6,0.6)]
Jitter	[(0.16,0.2,0.22,0.23,0.24,1,0.8,0.8), (0.19,0.2,0.22,0.23,0.23,0.8,0.6,0.6)]	[(0.16,0.2,0.22,0.23,0.24,1,0.8,0.8), (0.19,0.2,0.22,0.23,0.23,0.8,0.6,0.6)]	[(0.16,0.2,0.22,0.23,0.24,1,0.8,0.8), (0.19,0.2,0.22,0.23,0.23,0.8,0.6,0.6)]	[(0.16,0.2,0.22,0.23,0.24,1,0.8,0.8), (0.19,0.2,0.22,0.23,0.23,0.8,0.6,0.6)]	[(0.16,0.2,0.22,0.23,0.24,1,0.8,0.8), (0.19,0.2,0.22,0.23,0.23,0.8,0.6,0.6)]	[(0.16,0.2,0.22,0.23,0.24,1,0.8,0.8), (0.19,0.2,0.22,0.23,0.23,0.8,0.6,0.6)]	[(0.16,0.2,0.22,0.23,0.24,1,0.8,0.8), (0.19,0.2,0.22,0.23,0.23,0.8,0.6,0.6)]
Packet loss	[(0.23,0.21,0.21,0.21,0.21,1,0.8,0.8), (0.21,0.21,0.21,0.21,0.21,0.8,0.6)]	[(0.23,0.21,0.21,0.21,0.21,1,0.8,0.8), (0.21,0.21,0.21,0.21,0.21,0.8,0.6)]	[(0.23,0.21,0.21,0.21,0.21,1,0.8,0.8), (0.21,0.21,0.21,0.21,0.21,0.8,0.6)]	[(0.23,0.21,0.21,0.21,0.21,1,0.8,0.8), (0.21,0.21,0.21,0.21,0.21,0.8,0.6)]	[(0.23,0.21,0.21,0.21,0.21,1,0.8,0.8), (0.21,0.21,0.21,0.21,0.21,0.8,0.6)]	[(0.23,0.21,0.21,0.21,0.21,1,0.8,0.8), (0.21,0.21,0.21,0.21,0.21,0.8,0.6)]	[(0.23,0.21,0.21,0.21,0.21,1,0.8,0.8), (0.21,0.21,0.21,0.21,0.21,0.8,0.6)]
Service reliability	[(0.52,0.47,0.42,0.4,0.4,1,0.8,0.8), (0.48,0.45,0.42,0.41,0.4,0.8,0.6,0.6)]	[(0.52,0.47,0.42,0.4,0.4,1,0.8,0.8), (0.48,0.45,0.42,0.41,0.4,0.8,0.6,0.6)]	[(0.52,0.47,0.42,0.4,0.4,1,0.8,0.8), (0.48,0.45,0.42,0.41,0.4,0.8,0.6,0.6)]	[(0.52,0.47,0.42,0.4,0.4,1,0.8,0.8), (0.48,0.45,0.42,0.41,0.4,0.8,0.6,0.6)]	[(0.52,0.47,0.42,0.4,0.4,1,0.8,0.8), (0.48,0.45,0.42,0.41,0.4,0.8,0.6,0.6)]	[(0.52,0.47,0.42,0.4,0.4,1,0.8,0.8), (0.48,0.45,0.42,0.41,0.4,0.8,0.6,0.6)]	[(0.52,0.47,0.42,0.4,0.4,1,0.8,0.8), (0.48,0.45,0.42,0.41,0.4,0.8,0.6,0.6)]
Security	[(0.37,0.39,0.4,0.4,0.4,1,0.8,0.8), (0.39,0.4,0.4,0.4,0.4,0.8,0.6,0.6)]	[(0.37,0.39,0.4,0.4,0.4,1,0.8,0.8), (0.39,0.4,0.4,0.4,0.4,0.8,0.6,0.6)]	[(0.37,0.39,0.4,0.4,0.4,1,0.8,0.8), (0.39,0.4,0.4,0.405,0.4,0.8,0.6,0.6)]	[(0.37,0.39,0.4,0.4,0.4,1,0.8,0.8), (0.39,0.4,0.4,0.4,0.403,0.8,0.6,0.6)]	[(0.37,0.39,0.4,0.4,0.4,1,0.8,0.8), (0.39,0.4,0.4,0.4,0.4,0.8,0.6,0.6)]	[(0.37,0.39,0.4,0.4,0.4,1,0.8,0.8), (0.39,0.4,0.4,0.4,0.4,0.8,0.6,0.6)]	[(0.37,0.39,0.4,0.4,0.4,1,0.8,0.8), (0.39,0.4,0.4,0.4,0.4,0.8,0.6,0.6)]
Price	[(0.09,0.13,0.16,0.18,0.19,1,0.8,0.8), (0.12,0.14,0.16,0.18,0.18,0.8,0.6,0.6)]	[(0.09,0.13,0.16,0.18,0.19,1,0.8,0.8), (0.12,0.14,0.16,0.18,0.18,0.8,0.6,0.6)]	[(0.09,0.13,0.16,0.18,0.19,1,0.8,0.8), (0.12,0.14,0.166,0.18,0.18,0.8,0.6,0.6)]	[(0.09,0.13,0.16,0.18,0.19,1,0.8,0.8), (0.12,0.14,0.16,0.18,0.18,0.8,0.6,0.6)]	[(0.09,0.13,0.16,0.18,0.19,1,0.8,0.8), (0.12,0.14,0.16,0.18,0.18,0.8,0.6,0.6)]	[(0.09,0.13,0.16,0.18,0.19,1,0.8,0.8), (0.12,0.14,0.16,0.18,0.18,0.8,0.6,0.6)]	[(0.09,0.13,0.16,0.18,0.19,1,0.8,0.8), (0.12,0.14,0.16,0.18,0.18,0.8,0.6,0.6)]

Table 11
The PF-ANP weighted supermatrix for the SLA 1 NAV service.

	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price
Throughput	[(0.18,0.18,0.17, 0.16,0.16,1,0.8,0.8), (0.18,0.18,0.17, 0.16,0.16,0.8,0.6,0.6)]	[(0.18,0.18,0.17, 0.16,0.16,1,0.8,0.8), (0.18,0.18,0.17, 0.16,0.16,0.8,0.6,0.6)]	[(0.18,0.18,0.17, 0.16,0.16,1,0.8,0.8), (0.18,0.18,0.17, 0.16,0.16,0.8,0.6,0.6)]	[(0.18,0.18,0.17, 0.16,0.16,1,0.8,0.8), (0.18,0.18,0.17, 0.16,0.16,0.8,0.6,0.6)]	[(0.18,0.18,0.17, 0.16,0.16,1,0.8,0.8), (0.18,0.18,0.17, 0.16,0.16,0.8,0.6,0.6)]	[(0.18,0.18,0.17, 0.16,0.16,1,0.8,0.8), (0.18,0.18,0.17, 0.16,0.16,0.8,0.6,0.6)]	[(0.18,0.18,0.17, 0.16,0.16,1,0.8,0.8), (0.18,0.18,0.17, 0.16,0.16,0.8,0.6,0.6)]
Delay	[(0.11,0.1,0.1, 0.1,0.1,1,0.8,0.8), (0.1,0.1,0.1, 0.1,0.1,0.8,0.6,0.6)]	[(0.11,0.1,0.1, 0.1,0.1,1,0.8,0.8), (0.1,0.1,0.1, 0.106,0.1,0.8,0.6,0.6)]	[(0.11,0.1,0.1, 0.1,0.1,1,0.8,0.8), (0.1,0.1,0.1, 0.1,0.1,0.8,0.6,0.6)]	[(0.11,0.1,0.1, 0.1,0.1,1,0.8,0.8), (0.1,0.1,0.1,0.1, 0.1,0.8,0.6,0.6)]	[(0.11,0.1,0.1, 0.1,0.1,1,0.8,0.8), (0.1,0.1,0.1, 0.1,0.1,0.8,0.6,0.6)]	[(0.11,0.1,0.1, 0.1,0.1,1,0.8,0.8), (0.1,0.1,0.1, 0.1,0.1,0.8,0.6,0.6)]	[(0.11,0.1,0.1, 0.1,0.1,1,0.8,0.8), (0.1,0.1,0.1, 0.1,0.1,0.8,0.6,0.6)]
Jitter	[(0.08,0.1,0.11, 0.11,0.12,1,0.8,0.8), (0.09,0.1,0.11, 0.11,0.11,0.8,0.6,0.6)]	[(0.08,0.1,0.11, 0.11,0.12,1,0.8,0.8), (0.09,0.1,0.11, 0.11,0.11,0.8,0.6,0.6)]	[(0.08,0.1,0.11, 0.11,0.12,1,0.8,0.8), (0.09,0.1,0.11, 0.11,0.11,0.8,0.6,0.6)]	[(0.08,0.1,0.11, 0.11,0.12,1,0.8,0.8), (0.09,0.1,0.11, 0.11,0.11,0.8,0.6,0.6)]	[(0.08,0.1,0.11, 0.11,0.12,1,0.8,0.8), (0.09,0.1,0.11, 0.11,0.11,0.8,0.6,0.6)]	[(0.08,0.1,0.11, 0.11,0.12,1,0.8,0.8), (0.09,0.1,0.11, 0.11,0.11,0.8,0.6,0.6)]	[(0.08,0.1,0.11, 0.11,0.12,1,0.8,0.8), (0.09,0.1,0.11, 0.11,0.11,0.8,0.6,0.6)]
Packet loss	[(0.11,0.1,0.1, 0.1,0.1,1,0.8,0.8), (0.1,0.1,0.1, 0.1,0.1,0.8,0.6,0.6)]	[(0.11,0.1,0.1, 0.1,0.1,1,0.8,0.8), (0.1,0.1,0.1, 0.106,0.1,0.8,0.6,0.6)]	[(0.11,0.1,0.1, 0.1,0.1,1,0.8,0.8), (0.1,0.1,0.1, 0.1,0.1,0.8,0.6,0.6)]	[(0.11,0.1,0.1, 0.1,0.10,1,0.8,0.8), (0.1,0.1,0.1, 0.1,0.1,0.8,0.6,0.6)]	[(0.11,0.1,0.1, 0.1,0.1,1,0.8,0.8), (0.1,0.1,0.1, 0.1,0.1,0.8,0.6,0.6)]	[(0.11,0.1,0.1, 0.1,0.1,1,0.8,0.8), (0.1,0.1,0.1, 0.1,0.1,0.8,0.6,0.6)]	[(0.11,0.1,0.1, 0.1,0.1,1,0.8,0.8), (0.1,0.1,0.1, 0.1,0.1,0.8,0.6,0.6)]
Service reliability	[(0.26,0.23,0.21, 0.2,0.2,1,0.8,0.8), (0.24,0.22,0.21, 0.2,0.2,0.8,0.6,0.6)]	[(0.26,0.23,0.21, 0.2,0.2,1,0.8,0.8), (0.24,0.22,0.21, 0.2,0.2,0.8,0.6,0.6)]	[(0.26,0.23,0.21, 0.2,0.2,1,0.8,0.8), (0.24,0.22,0.21, 0.2,0.2,0.8,0.6,0.6)]	[(0.26,0.23,0.21, 0.2,0.2,1,0.8,0.8), (0.24,0.22,0.21, 0.2,0.2,0.8,0.6,0.6)]	[(0.26,0.23,0.21, 0.2,0.2,1,0.8,0.8), (0.24,0.22,0.21, 0.2,0.2,0.8,0.6,0.6)]	[(0.26,0.23,0.21, 0.2,0.2,1,0.8,0.8), (0.24,0.22,0.21, 0.2,0.2,0.8,0.6,0.6)]	[(0.26,0.23,0.21, 0.2,0.2,1,0.8,0.8), (0.24,0.2,0.21, 0.2,0.2,0.8,0.6,0.6)]
Security	[(0.18,0.19,0.2, 0.2,0.2,1,0.8,0.8), (0.19,0.2,0.2, 0.2,0.2,0.8,0.6,0.6)]	[(0.18,0.19,0.2, 0.2,0.2,1,0.8,0.8), (0.19,0.2,0.2, 0.2,0.2,0.8,0.6,0.6)]	[(0.18,0.19,0.2, 0.2,0.2,1,0.8,0.8), (0.19,0.2,0.2, 0.2,0.2,0.8,0.6,0.6)]	[(0.18,0.19,0.2, 0.2,0.2,1,0.8,0.8), (0.19,0.2,0.2, 0.2,0.2,0.8,0.6,0.6)]	[(0.18,0.19,0.2, 0.2,0.2,1,0.8,0.8), (0.19,0.2,0.2, 0.2,0.2,0.8,0.6,0.6)]	[(0.18,0.19,0.2, 0.2,0.2,1,0.8,0.8), (0.19,0.2,0.2, 0.2,0.2,0.8,0.6,0.6)]	[(0.18,0.19,0.2, 0.2,0.2,1,0.8,0.8), (0.19,0.2,0.2, 0.2,0.2,0.8,0.6,0.6)]
Price	[(0.04,0.06,0.08, 0.09,0.09,1,0.8,0.8), (0.06,0.07,0.08, 0.09,0.09,0.8,0.6,0.6)]	[(0.04,0.06,0.08, 0.09,0.09,1,0.8,0.8), (0.06,0.07,0.08, 0.09,0.09,0.8,0.6,0.6)]	[(0.04,0.06,0.08, 0.09,0.09,1,0.8,0.8), (0.06,0.07,0.08, 0.09,0.09,0.8,0.6,0.6)]	[(0.04,0.06,0.08, 0.09,0.09,1,0.8,0.8), (0.06,0.07,0.08, 0.09,0.09,0.8,0.6,0.6)]	[(0.04,0.06,0.08, 0.09,0.09,1,0.8,0.8), (0.06,0.07,0.08, 0.09,0.09,0.8,0.6,0.6)]	[(0.04,0.06,0.08, 0.09,0.09,1,0.8,0.8), (0.06,0.07,0.08, 0.09,0.09,0.8,0.6,0.6)]	[(0.04,0.06,0.08, 0.09,0.09,1,0.8,0.8), (0.06,0.07,0.08, 0.09,0.09,0.8,0.6,0.6)]

Table 12
The PF-ANP limit supermatrix for the SLA 1 NAV service.

	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price
Throughput	0.175346	0.175346	0.175346	0.175346	0.175346	0.175346	0.175346
Delay	0.109943	0.109943	0.109943	0.109943	0.109943	0.109943	0.109943
Jitter	0.104768	0.104768	0.104768	0.104768	0.104768	0.104768	0.104768
Packet loss	0.109943	0.109943	0.109943	0.109943	0.109943	0.109943	0.109943
Service reliability	0.195427	0.195427	0.195427	0.195427	0.195427	0.195427	0.195427
Security	0.188775	0.188775	0.188775	0.188775	0.188775	0.188775	0.188775
Price	0.115798	0.115798	0.115798	0.115798	0.115798	0.115798	0.115798

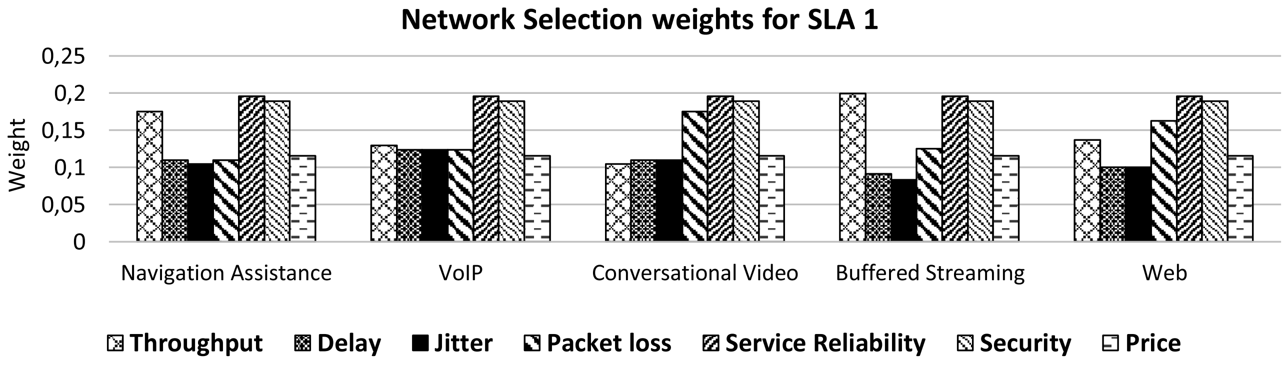


Fig. 11. The network selection weights per service for SLA 1.

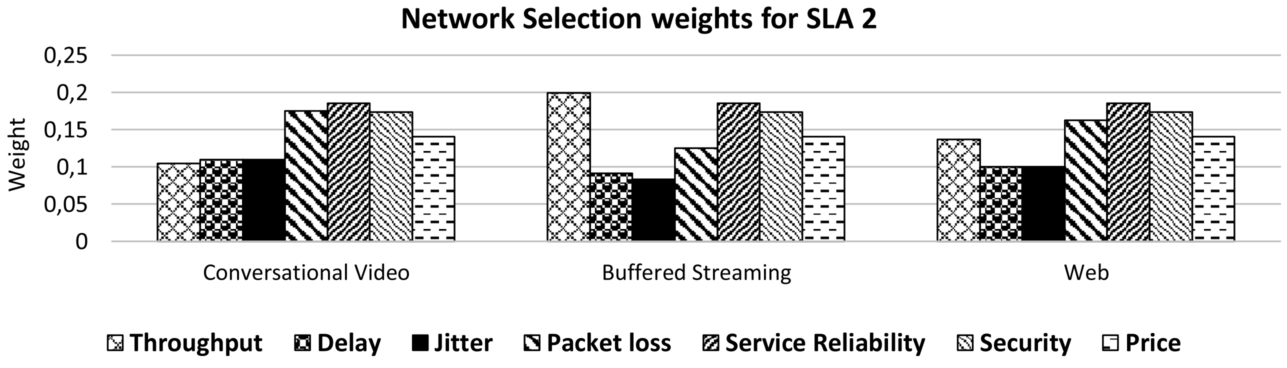


Fig. 12. The network selection weights per service for SLA 2.

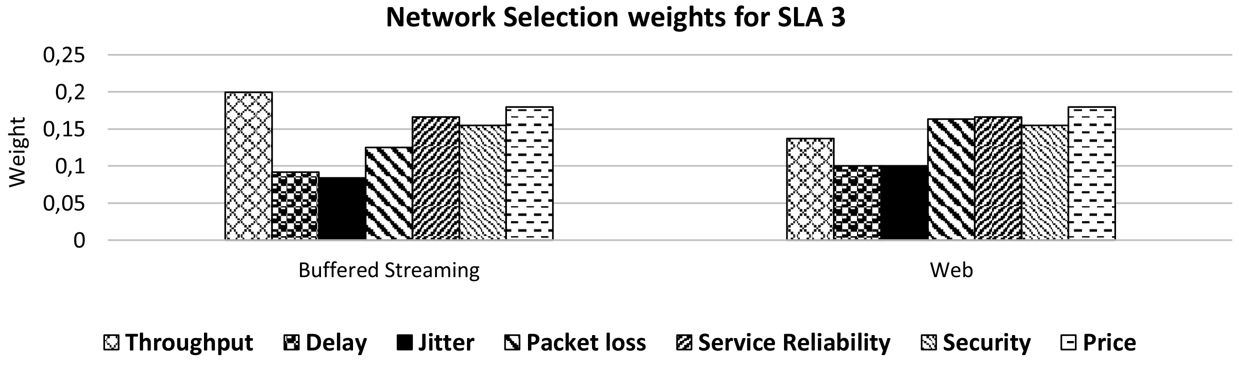


Fig. 13. The network selection weights per service for SLA 3.

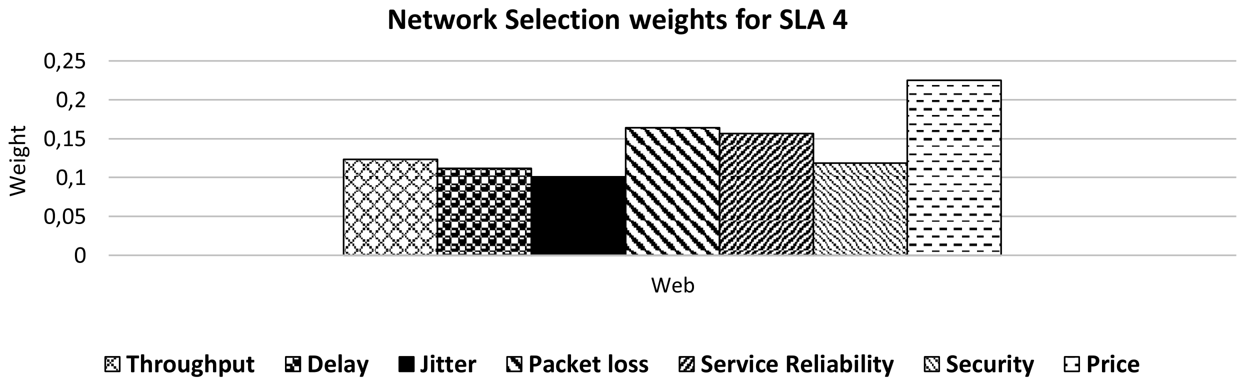


Fig. 14. The network selection weights per service for SLA 4.

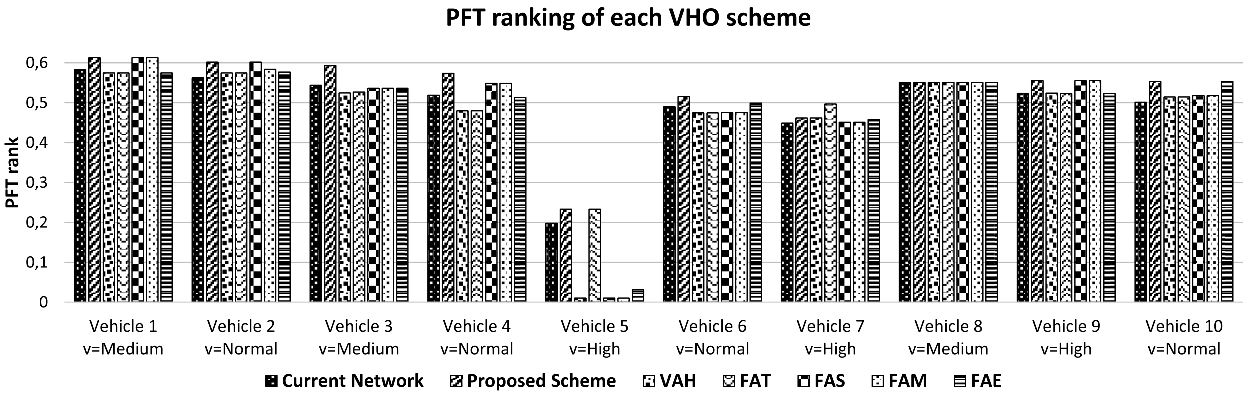


Fig. 15. The PFT ranking of each VHO scheme.

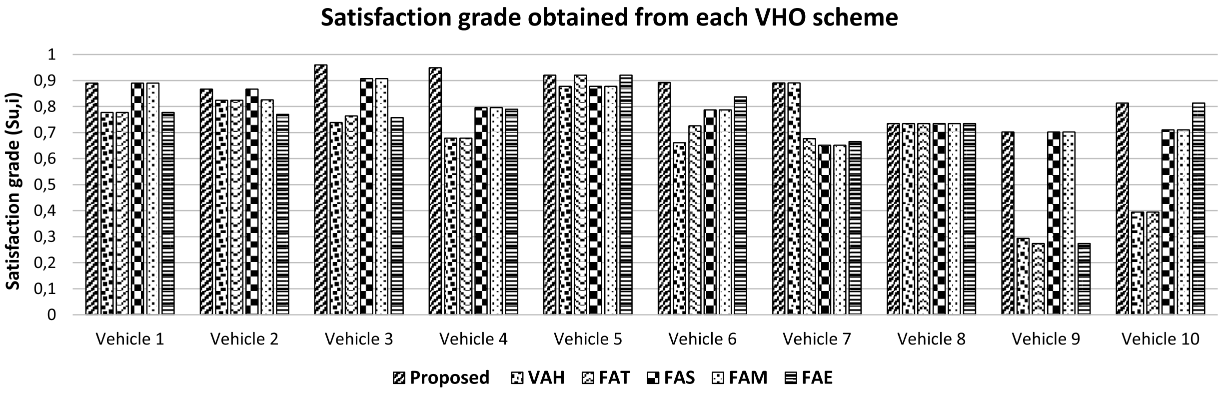


Fig. 16. The satisfaction grade obtained from each VHO scheme.

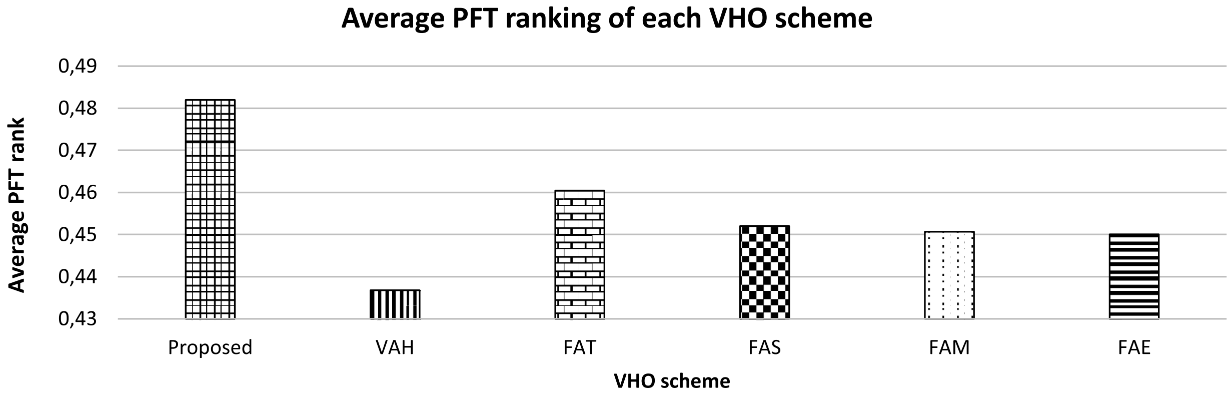


Fig. 17. The average PFT ranking of each VHO scheme during the 24 hours simulation.

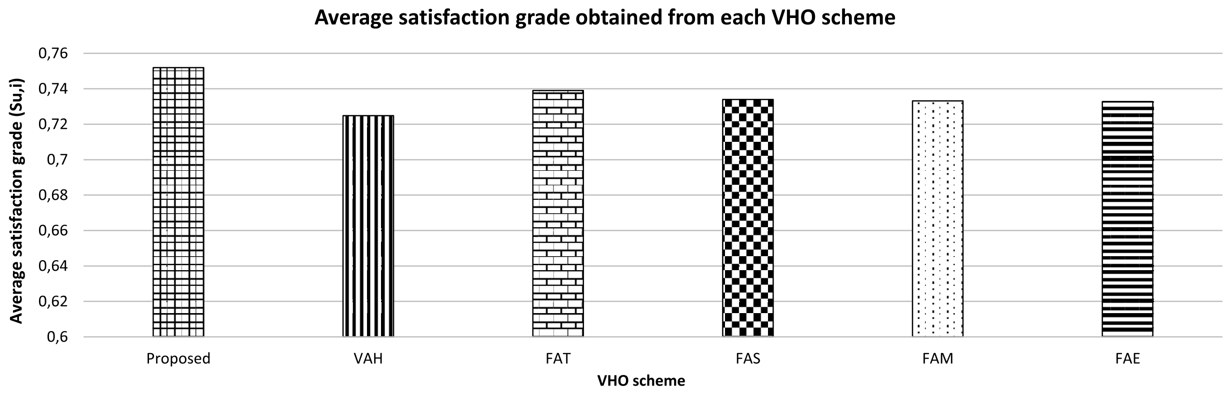


Fig. 18. The average satisfaction grade obtained from each VHO scheme during the 24 hours simulation.

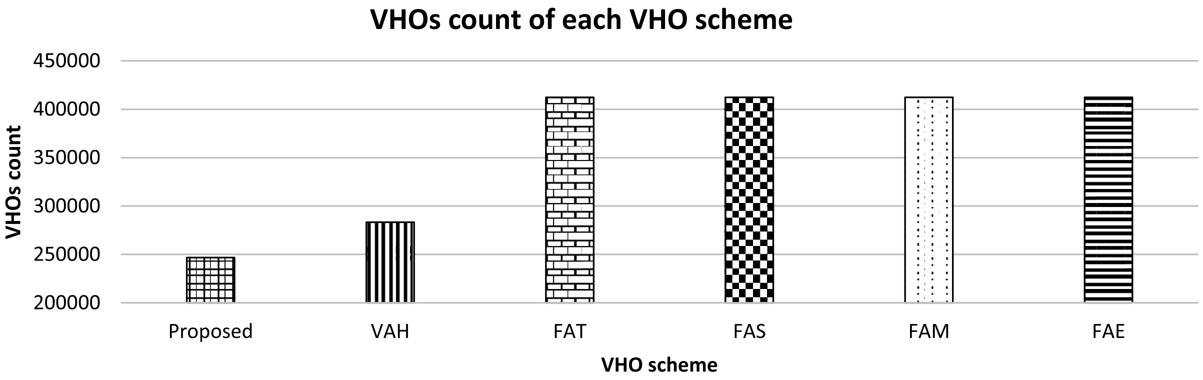


Fig. 19. The total VHOs count of each VHO scheme during the 24 hours simulation.

of the schemes. Also, Fig. 18 presents the average satisfaction grade $S_{u,i}$ estimated for each VHO scheme. The proposed approach accomplishes the highest average values, compared to the rest VHO schemes. Finally, the number of VHOs performed from a VHO management scheme should be considered as a critical parameter for the evaluation of the proposed VHO scheme efficiency, since less VHOs imply less network signaling overhead in both user and operator sides. As a result, Fig. 19 presents the total VHOs performed from each scheme, during the entire 24 hours simulation. As it is shown, the proposed scheme outperforms the other schemes, since it performs less VHOs. Also, the VAH scheme accomplishes acceptable VHOs counts, since it also considers the vehicle velocity for the handover process. However, it does not avoid useless VHOs to femtocells providing worse results than the proposed scheme. The rest of the schemes accomplish similar VHOs counts, since they are based on the perceived RSS per user for the VHO initiation process.

6. Conclusion

Mobility management in 5G-VCC systems is a complex task since it should consider multiple parameters with different relative importance. This paper proposes a VHO management scheme for 5G-VCC systems that takes into account vehicles' velocity, networks' QoS and policy characteristics, vehicular services requirements and different vehicles' SLAs to select the optimal network that will satisfy simultaneously all the services' requirements and onboard user's preferences.

VHO management services are executed at the Cloud or the Fog infrastructure alleviating the vehicle's processing load and reducing VHO latency. IVPFNs are used for the representation of both VHO Initiation and Network Selection criteria values, while the PF-ANP algorithm is used for the estimation of the criteria weights for both VHO Initiation and Network Selection. During the VHO Initiation, the MPFIS evaluates the necessity to perform a handover, while during the Network Selection, the PFT algorithm selects the most appropriate network considering the vehicle's velocity, the constraints of used vehicular services and the SLA of the vehicle.

Performance evaluation showed that the Always Best Connected (ABC) principle is fully ensured, while at the same time the proposed scheme outperforms existing VHO management algorithms in terms of the PFT ranks of the selected networks, the user satisfaction grade, as well as the VHOs count.

Acknowledgement

The publication of this paper has been partly supported by the University of Piraeus Research Center (UPRC).

Appendix A. The positions of the available networks

In this appendix the positions and the spectrum of the available access networks are presented.

Appendix B. The available networks per SLA

In this appendix the available networks per SLA are presented. (See Tables B1–B4.)

Appendix C. The distribution of vehicles during the 24 hours simulation

In this appendix the distribution of vehicles across velocity categories, access networks, services and SLAs, during the 24 hours simulation is presented.

Table A1
The positions of the available LTE Access Networks.

Network	Position	Geographic latitude	Geographic longitude	Downlink & uplink spectrum in MHz (LTE band)
LTE Macro 1	2e	37.948056	23.643056	1805–1825 & 1710–1730 (3)
LTE Macro 2	2l	37.947500	23.650278	2150–2170 & 1960–1980 (1)
LTE Macro 3	3p	37.946667	23.653611	2130–2150 & 1940–1960 (1)
LTE Macro 4	4i	37.946111	23.646389	2110–2130 & 1920–1940 (1)
LTE Macro 5	5q	37.945556	23.654167	1805–1825 & 1710–1730 (3)
LTE Macro 6	6f	37.945000	23.644444	1825–1845 & 1730–1750 (3)
LTE Macro 7	8f	37.942778	23.643611	1845–1865 & 1750–1770 (3)
LTE Macro 8	8t	37.942778	23.656944	1825–1845 & 1730–1750 (3)
LTE Macro 9	9l	37.941944	23.649444	925–945 & 880–900 (8)
LTE Macro 10	11c	37.940000	23.641111	1805–1825 & 1710–1730 (3)
LTE Macro 11	11l	37.939722	23.648611	778–798 & 723–743 (28)
LTE Macro 12	11t	37.939722	23.656111	2150–2170 & 1960–1980 (1)
LTE Macro 13	12i	37.939722	23.645833	758–778 & 703–723 (28)
LTE Macro 14	12y	37.938333	23.661389	1845–1865 & 1750–1770 (3)
LTE Macro 15	14q	37.938056	23.653889	2110–2130 & 1920–1940 (1)
LTE Macro 16	14v	37.937222	23.658333	2130–2150 & 1940–1960 (1)
LTE Macro 17	16b	37.936667	23.640000	2110–2130 & 1920–1940 (1)
LTE Macro 18	16h	37.936667	23.645556	1825–1845 & 1730–1750 (3)
LTE Macro 19	18c	37.934722	23.640833	2130–2150 & 1940–1960 (1)
LTE Macro 20	18f	37.934444	23.643889	2150–2170 & 1960–1980 (1)
LTE Femto 1	4f	37.946944	23.644444	925–945 & 880–900 (8)
LTE Femto 2	4j	37.946111	23.647222	758–778 & 703–723 (28)
LTE Femto 3	4r	37.946389	23.655000	925–945 & 880–900 (8)
LTE Femto 4	5d	37.945833	23.641944	758–778 & 703–723 (28)
LTE Femto 5	5j	37.945556	23.647500	778–798 & 723–743 (28)
LTE Femto 6	6h	37.944444	23.645833	2180–2200 & 2000–2020 (23)
LTE Femto 7	6i	37.944444	23.646667	1475.9–1495.9 & 1427.9–1447.9 (11)
LTE Femto 8	7h	37.944167	23.645833	860–875 & 815–830 (18)
LTE Femto 9	7i	37.943889	23.647222	2130–2150 & 1940–1960 (1)
LTE Femto 10	7k	37.943889	23.648056	2180–2200 & 2000–2020 (23)
LTE Femto 11	8k	37.942778	23.648611	1475.9–1495.9 & 1427.9–1447.9 (11)
LTE Femto 12	8m	37.942500	23.650556	2180–2200 & 2000–2020 (23)
LTE Femto 13	9e	37.941667	23.643333	860–875 & 815–830 (18)
LTE Femto 14	9g	37.942222	23.645000	2180–2200 & 2000–2020 (23)
LTE Femto 15	9h	37.941944	23.645833	860–875 & 815–830 (18)
LTE Femto 16	9j	37.942222	23.647778	2180–2200 & 2000–2020 (23)
LTE Femto 17	9n	37.942222	23.651111	1475.9–1495.9 & 1427.9–1447.9 (11)
LTE Femto 18	10e	37.941944	23.643333	2130–2150 & 1940–1960 (1)
LTE Femto 19	10f	37.941389	23.644167	2180–2200 & 2000–2020 (23)
LTE Femto 20	10g	37.941111	23.644444	860–875 & 815–830 (18)
LTE Femto 21	10h	37.941389	23.645833	2180–2200 & 2000–2020 (23)
LTE Femto 22	10j	37.941389	23.647500	860–875 & 815–830 (18)
LTE Femto 23	10l	37.941111	23.649722	1475.9–1495.9 & 1427.9–1447.9 (11)
LTE Femto 24	11e	37.940556	23.643056	1475.9–1495.9 & 1427.9–1447.9 (11)
LTE Femto 25	11f	37.940278	23.643611	860–875 & 815–830 (18)
LTE Femto 26	11h	37.940833	23.645833	1475.9–1495.9 & 1427.9–1447.9 (11)
LTE Femto 27	12k	37.940000	23.648889	1180–2200 & 2000–2020 (23)
LTE Femto 28	13c	37.939444	23.641111	1475.9–1495.9 & 1427.9–1447.9 (11)
LTE Femto 29	13e	37.938333	23.642778	925–945 & 880–900 (8)
LTE Femto 30	13j	37.939444	23.648333	1175.9–1495.9 & 1427.9–1447.9 (11)
LTE Femto 31	14d	37.938333	23.642222	1180–2200 & 2000–2020 (23)
LTE Femto 32	14n	37.938333	23.650556	1805–1825 & 1710–1730 (3)
LTE Femto 33	15b	37.937222	23.639722	925–945 & 880–900 (8)
LTE Femto 34	15c	37.937222	23.640833	778–798 & 723–743 (28)
LTE Femto 35	15u	37.936944	23.657778	925–945 & 880–900 (8)
LTE Femto 36	16c	37.936389	23.641111	860–875 & 815–830 (18)
LTE Femto 37	18h	37.934444	23.645278	925–945 & 880–900 (8)

Table A2
The positions of the available WiMAX Access Networks.

Network	Position	Geographic latitude	Geographic longitude	Downlink & uplink spectrum in MHz (WiMAX 2 band)
WiMAX Macro 1	1e	37.949444	23.642500	3500–3510 & 3400–3410 (5L)
WiMAX Macro 2	3e	37.947778	23.643333	3510–3520 & 3410–3420 (5L)
WiMAX Macro 3	3j	37.947222	23.647500	3530–3540 & 3430–3440 (5L)
WiMAX Macro 4	3o	37.947222	23.652778	3540–3550 & 3440–3450 (5L)
WiMAX Macro 5	6r	37.944722	23.655000	3590–3600 & 3490–3600 (5L)
WiMAX Macro 6	8g	37.943333	23.645278	3590–3600 & 3490–3600 (5L)
WiMAX Macro 7	11d	37.940833	23.641944	3500–3510 & 3400–3410 (5L)
WiMAX Macro 8	11l	37.940556	23.649722	3530–3540 & 3430–3440 (5L)
WiMAX Macro 9	11n	37.940000	23.651389	3540–3550 & 3440–3450 (5L)
WiMAX Macro 10	11r	37.940278	23.655278	3550–3560 & 3450–3460 (5L)
WiMAX Macro 11	12j	37.939494	23.648333	3510–3520 & 3410–3420 (5L)
WiMAX Macro 12	12u	37.939444	23.657778	3500–3510 & 3400–3410 (5L)
WiMAX Macro 13	14e	37.938056	23.643333	3580–3590 & 3480–3490 (5L)
WiMAX Macro 14	14v	37.937222	23.658611	3510–3520 & 3410–3420 (5L)
WiMAX Macro 15	17b	37.935833	23.639722	3540–3550 & 3440–3450 (5L)
WiMAX Macro 16	18c	37.934722	23.640833	3530–3540 & 3430–3440 (5L)
WiMAX Macro 17	18i	37.934444	23.645278	2305–2315 & 2345–2355 (2)
WiMAX Femto 1	3f	37.947500	23.644444	3520–3530 & 3420–3430 (5L)
WiMAX Femto 2	5g	37.945278	23.644167	3550–3560 & 3450–3460 (5L)
WiMAX Femto 3	6e	37.945000	23.642222	3560–3570 & 3460–3470 (5L)
WiMAX Femto 4	6g	37.944444	23.645278	3570–3580 & 3470–3480 (5L)
WiMAX Femto 5	6j	37.944444	23.647222	3580–3500 & 3480–3490 (5L)
WiMAX Femto 6	7j	37.943889	23.647778	3520–3530 & 3420–3430 (5L)
WiMAX Femto 7	8h	37.942222	23.646111	2305–2315 & 2345–2355 (2)
WiMAX Femto 8	8k	37.942500	23.648056	3550–3560 & 3450–3460 (5L)
WiMAX Femto 9	8n	37.942778	23.651389	3520–3530 & 3420–3430 (5L)
WiMAX Femto 10	9g	37.942222	23.645278	2305–2315 & 2345–2355 (2)
WiMAX Femto 11	9i	37.941667	23.646389	3550–3560 & 3450–3460 (5L)
WiMAX Femto 12	9j	37.941944	23.647500	2305–2315 & 2345–2355 (2)
WiMAX Femto 13	9m	37.942222	23.651111	2305–2315 & 2345–2355 (2)
WiMAX Femto 14	10f	37.941389	23.644167	3520–3530 & 3420–3430 (5L)
WiMAX Femto 15	10h	37.941389	23.645833	3520–3530 & 3420–3430 (5L)
WiMAX Femto 16	10j	37.941389	23.647500	3550–3560 & 3450–3460 (5L)
WiMAX Femto 17	10m	37.941389	23.650000	3520–3530 & 3420–3430 (5L)
WiMAX Femto 18	10s	37.941389	23.655556	3520–3530 & 3420–3430 (5L)
WiMAX Femto 19	11f	37.940278	23.643333	2305–2315 & 2345–2355 (2)
WiMAX Femto 20	11h	37.940556	23.645556	2305–2315 & 2345–2355 (2)
WiMAX Femto 21	11k	37.939722	23.648611	2305–2315 & 2345–2355 (2)
WiMAX Femto 22	12k	37.929167	23.648056	3520–3530 & 3420–3430 (5L)
WiMAX Femto 23	15b	37.937222	23.640000	2305–2315 & 2345–2355 (2)
WiMAX Femto 24	15d	37.936944	23.641667	3520–3530 & 3420–3430 (5L)
WiMAX Femto 25	15u	37.936944	23.657778	2305–2315 & 2345–2355 (2)

Table A3
The positions of the available WAVE Access Networks.

Network	Position	Geographic latitude	Geographic longitude	Spectrum in MHz (DSRC Europe band)
WAVE 1	2f	37.948056	23.644444	5915–5925 (SCH4)
WAVE 2	2h	37.947500	23.646389	5905–5915 (SCH3)
WAVE 3	3m	37.946667	23.650278	5895–5905 (SCH2)
WAVE 4	4e	37.946111	23.642500	5895–5905 (SCH2)
WAVE 5	4u	37.945556	23.658056	5875–5885 (SCH1)
WAVE 6	5i	37.945000	23.646944	5915–5925 (SCH4)
WAVE 7	6k	37.944167	23.648056	5905–5915 (SCH3)
WAVE 8	7e	37.943056	23.643333	5875–5885 (SCH1)
WAVE 9	7i	37.943889	23.646667	5895–5905 (SCH2)
WAVE 10	7n	34.943889	23.651111	5875–5885 (SCH1)
WAVE 11	9h	37.942222	23.646389	5915–5925 (SCH4)
WAVE 12	10e	37.941667	23.643333	5895–5905 (SCH2)
WAVE 13	10j	37.941667	23.647500	5875–5885 (SCH1)
WAVE 14	10n	37.941111	23.651667	5905–5915 (SCH3)
WAVE 15	11h	37.940556	23.645556	5905–5915 (SCH3)
WAVE 16	12c	37.939444	23.641389	5875–5885 (SCH1)
WAVE 17	12q	37.938889	23.654444	5875–5885 (SCH1)
WAVE 18	14b	37.938056	23.640556	5915–5925 (SCH4)
WAVE 19	14f	37.937778	23.644167	5905–5915 (SCH3)
WAVE 20	17c	37.935000	23.641389	5895–5905 (SCH2)
WAVE 21	17n	37.935278	23.651389	5895–5905 (SCH2)
WAVE 22	18i	37.934722	23.645278	5875–5885 (SCH1)

Table B1
The available LTE networks of SLA 1.

Network	SLA 1																																		
	NAV							VoIP							CV							BS							Web						
	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price
LTE Macro 1	AG	AG	G	VG	MG	G	AP	AG	AG	G	VG	G	VG	VP	G	VG	G	MG	MG	M	AP	M	MG	AG	M	G	AG	P	AG	AG	G	VG	VG	AG	AP
LTE Macro 2	VG	AG	G	G	AG	AG	AP	M	MG	MG	M	G	M	P	AG	AG	M	VG	M	MG	AP	MG	G	MG	M	MG	AG	VP	VG	AG	G	G	G	AG	P
LTE Macro 3	VG	AG	M	G	M	G	VP	M	MG	MG	M	MG	VG	VP	MG	G	G	M	VG	MG	VP	G	VG	MG	MG	VG	M	P	VG	AG	G	G	M	AG	VP
LTE Macro 4	M	MG	M	M	VG	AG	P	M	MG	MG	M	G	G	P	VG	AG	AG	G	VG	AG	P	AG	AG	M	VG	MG	G	P	MG	G	MG	M	G	G	VP
LTE Macro 5	AG	AG	VG	VG	VG	AG	VP	AG	AG	VG	VG	M	VG	AP	G	VG	AG	MG	AG	M	AP	MG	G	VG	MG	AG	G	VP	G	VG	AG	MG	M	G	VP
LTE Macro 6	M	MG	G	M	VG	G	P	MG	G	MG	M	VG	MG	AP	VG	AG	AG	G	G	MG	VP	G	G	VG	MG	VG	VG	P	AG	AG	VG	VG	VG	AG	VP
LTE Macro 7	MG	G	MG	M	AG	G	VP	MG	G	G	M	M	VG	VP	MG	G	G	M	M	MG	P	VG	AG	AG	G	G	MG	P	AG	AG	G	VG	G	VG	P
LTE Macro 8	MG	G	AG	MG	AG	M	P	AG	AG	G	VG	AG	AG	AP	AG	AG	AG	VG	AG	G	P	G	G	M	MG	AG	AG	P	G	VG	MG	MG	VG	AG	AP
LTE Macro 9	M	MG	VG	M	AG	M	VP	M	MG	AG	M	MG	M	AP	G	VG	G	MG	MG	VG	P	VG	AG	VG	G	VG	VG	P	M	MG	VG	M	AG	AG	P
LTE Macro 10	MG	G	AG	MG	MG	MG	AP	AG	AG	M	VG	VG	M	P	G	VG	G	MG	M	AG	VP	G	VG	G	MG	AG	AG	P	G	VG	MG	MG	G	G	VP
LTE Macro 11	M	MG	VG	M	VG	MG	VP	M	MG	MG	M	AG	MG	VP	G	VG	G	MG	M	VG	AP	M	MG	MG	M	G	G	P	G	G	MG	MG	G	VG	AP
LTE Macro 12	M	MG	M	M	VG	G	AP	VG	AG	AG	G	G	MG	AP	VG	AG	G	G	AG	G	VP	AG	AG	MG	VG	G	VG	AP	AG	AG	VG	VG	MG	MG	P
LTE Macro 13	VG	AG	MG	G	G	MG	AP	M	MG	M	M	MG	MG	P	AG	AG	VG	VG	G	M	P	AG	AG	VG	VG	MG	G	AP	VG	AG	VG	G	VG	AG	AP
LTE Macro 14	VG	AG	AG	G	MG	M	AP	AG	AG	VG	VG	VG	G	P	VG	AG	G	G	G	AG	VP	VG	AG	G	G	G	M	AP	G	VG	G	MG	G	AG	AP
LTE Macro 15	M	MG	MG	M	G	VG	P	AG	AG	G	VG	G	M	P	M	MG	G	M	VG	VG	AP	M	MG	AG	M	VG	AG	VP	AG	AG	M	VG	VG	G	AP
LTE Macro 16	AG	AG	MG	VG	AG	VG	VP	VG	AG	VG	G	MG	MG	P	VG	AG	AG	G	AG	MG	VP	G	G	MG	MG	AG	M	P	G	VG	MG	MG	G	VG	P
LTE Macro 17	G	VG	MG	MG	MG	M	VP	AG	AG	AG	VG	AG	M	P	G	VG	VG	MG	MG	AG	P	G	VG	VG	MG	G	AG	AP	VG	AG	VG	G	G	MG	AP
LTE Macro 18	MG	G	MG	M	G	G	VP	VG	AG	G	G	VG	VG	VP	G	VG	G	MG	AG	MG	AP	MG	G	MG	M	VG	MG	AP	M	MG	AG	M	G	G	VP
LTE Macro 19	AG	AG	MG	VG	AG	VG	VP	MG	G	MG	M	G	M	VP	G	VG	AG	MG	G	G	P	G	VG	M	MG	VG	MG	AP	VG	AG	VG	G	VG	VG	P
LTE Macro 20	M	MG	MG	M	AG	AG	VP	MG	G	G	M	M	G	P	MG	G	G	M	AG	MG	VP	G	VG	G	MG	MG	M	AP	MG	G	AG	M	VG	VG	P
LTE Femto 1	MG	G	AG	M	MG	M	P	VG	AG	M	G	VG	M	VP	MG	G	VG	M	VG	AG	AP	VG	AG	M	G	G	VG	VP	G	VG	MG	MG	AG	G	VP
LTE Femto 2	VG	AG	M	G	M	M	AP	AG	AG	G	VG	M	M	AP	MG	G	M	M	VG	MG	AP	MG	G	M	M	VG	MG	P	G	VG	MG	MG	G	MG	P
LTE Femto 3	AG	AG	MG	VG	VG	MG	P	AG	AG	G	VG	AG	VG	VP	G	VG	G	MG	VG	G	P	AG	AG	VG	VG	G	G	VP	VG	AG	MG	G	MG	VG	AP
LTE Femto 4	MG	G	AG	M	VG	AG	VP	G	VG	VG	MG	VG	AG	VP	G	VG	G	MG	AG	MG	VP	MG	G	G	M	M	AG	AP	AG	AG	G	VG	MG	G	VP
LTE Femto 5	MG	G	M	M	G	G	VP	M	MG	MG	M	AG	M	P	VG	AG	AG	G	VG	AG	AP	VG	AG	AG	G	G	VG	P	G	VG	VG	MG	AG	VG	P
LTE Femto 6	AG	AG	M	VG	VG	VG	AP	AG	AG	AG	VG	MG	M	P	M	MG	AG	M	G	VG	AP	M	MG	MG	M	VG	AG	AP	MG	G	G	M	MG	AG	P
LTE Femto 7	MG	G	M	M	M	MG	AP	VG	AG	VG	G	VG	M	VP	AG	AG	G	VG	MG	MG	AP	MG	G	MG	M	VG	VG	P	AG	AG	G	VG	AG	G	P
LTE Femto 8	M	MG	AG	M	MG	M	VP	AG	AG	M	VG	M	M	VP	AG	AG	AG	VG	G	AG	P	G	VG	G	MG	MG	M	P	AG	AG	AG	VG	VG	G	AP
LTE Femto 9	G	VG	M	MG	AG	VG	VP	MG	G	G	M	M	MG	AP	G	VG	MG	MG	MG	MG	AP	MG	G	G	M	MG	AG	P	M	MG	MG	M	MG	AG	AP
LTE Femto 10	VG	AG	AG	G	G	M	AP	VG	AG	VG	G	VG	VG	VP	AG	AG	VG	VG	MG	AG	AP	VG	AG	M	G	AG	MG	AP	VG	AG	VG	G	G	AG	AP
LTE Femto 11	AG	AG	G	VG	VG	AG	P	AG	AG	G	VG	M	MG	AP	G	G	M	MG	M	M	P	AG	AG	G	VG	MG	M	P	AG	AG	G	VG	MG	VG	VP
LTE Femto 12	MG	G	M	M	VG	MG	P	M	MG	VG	M	VG	AG	AP	MG	G	AG	M	G	G	AP	AG	AG	MG	VG	G	G	AP	M	MG	G	M	VG	VG	P
LTE Femto 13	MG	G	MG	M	M	M	P	VG	AG	M	G	M	M	VP	AG	AG	M	VG	AG	G	VP	MG	G	AG	M	G	MG	VP	AG	AG	G	VG	G	MG	AP
LTE Femto 14	G	VG	M	MG	M	AG	VP	MG	G	G	M	AG	G	VP	VG	AG	VG	G	VG	MG	VP	AG	AG	M	VG	MG	G	VP	G	VG	MG	MG	G	AG	AP
LTE Femto 15	MG	G	G	M	G	G	AP	MG	G	G	M	AG	MG	P	M	MG	AG	M	AG	M	VP	MG	G	MG	M	G	AG	AP	VG	AG	MG	G	MG	MG	VP
LTE Femto 16	VG	AG	M	G	VG	MG	VP	AG	AG	M	VG	AG	G	VP	G	VG	MG	MG	G	MG	P	G	G	MG	G	AG	VG	VP	AG	AG	M	VG	M	AG	AP
LTE Femto 17	VG	AG	M	G	AG	VG	P	VG	AG	AG	G	VG	MG	VP	MG	G	AG	M	VG	VG	P	AG	AG	VG	VG	G	M	AP	G	G	MG	MG	G	VG	AP
LTE Femto 18	MG	G	M	M	VG	G	P	G	VG	M	MG	MG	G	VP	VG	AG	MG	G	AG	MG	P	G	VG	MG	MG	VG	MG	AP	G	VG	VG	MG	VG	AG	VP
LTE Femto 19	VG	AG	G	G	AG	M	P	VG	AG	AG	G	G	AG	AP	AG	AG	M	VG	VG	M	AP	VG	AG	G	G	G	G	P	VG	AG	MG	G	MG	G	P
LTE Femto 20	G	VG	G	MG	MG	AG	AP	M	MG	MG	M	MG	M	VP	VG	AG	AG	G	MG	MG	AP	VG	AG	VG	G	G	G	VP	MG	G	G	M	G	MG	VP
LTE Femto 21	M	MG	G	M	VG	AG	VP	M	MG	M	M	MG	AG	AP	G	VG	G	MG	MG	VG	AP	M	MG	G	M	MG	M	AP	VG	AG	MG	G	VG	MG	P
LTE Femto 22	AG	AG	MG	VG	VG	AG	VP	G	VG	MG	MG	AG	VG	VP	AG	AG	AG	VG	VG	AG	P	M	MG	VG	M	G	G	P	MG	G	VG	M	M	M	VP
LTE Femto 23	M	MG	G	M	M	AG	P	AG	AG	M	VG	MG	AG	AP	AG	AG	MG	VG	G	MG	P	G	VG	AG	MG	VG	G	AP	M	MG	M	M	AG	G	P
LTE Femto 24	MG	G	MG	M	AG	AG	AP	AG	AG	MG	VG	M	M	VP	MG	G	MG	M	G	G	AP	M	MG	VG	M	M	G	P	VG	AG	MG	G	AG	G	P
LTE Femto 25	G	VG	AG	MG	G	MG	AP	G	VG	G	MG	MG	MG	VP	AG	AG	AG	VG	VG	VG	P	VG	AG	AG	G	G	G	AP	AG	AG	AG	VG	VG	AG	VP
LTE Femto 26	G	VG	G	MG	M	G	VP	MG	G	AG	M	G	G	VP	AG	AG	M	VG	G	G	VP	G	VG	G	MG	VG	G	VP	M	MG	VG	M	G	VG	AP
LTE Femto 27	MG	G	G	M	G	M	AP	VG	AG	G	G	VG	AG	P	MG	G	G	MG	AG	AG	VP	G	VG	AG	MG	G	VG	P	AG	AG	AG	VG	VG	G	AP
LTE Femto 28	M	MG	G	M	MG	G	VP	MG	G	G	M	G	G	VP	MG	G	AG	M	G	G	AP	G	G	VG	MG	G	MG	VP	G	VG	VG	MG	G	MG	P
LTE Femto 29	VG	AG	M	G	M	MG	AP	AG	AG	VG	VG	VG	AG	P	G	VG	MG	MG	MG	M	VP	AG	AG	AG	VG	MG	MG	VP	M	MG	VG	M	MG	G	AP
LTE Femto 30	AG	AG	AG	VG	M	AG	VP	G	VG	M	MG	MG	MG	AP	MG	G	G	M	G	G	VP	AG	AG	G	VG	G	AG	P	M	MG	M	M	G	G	VP
LTE Femto 31	VG	AG	AG	G	AG	MG	P	AG	AG	VG	VG	VG	AG	AP	MG	G	G	M	G	M	AP	M	MG	MG	M	MG	M	AP	AG	AG	G	VG	AG	G	AP
LTE Femto 32	VG	AG	AG	G	VG	MG	AP	G	VG	M	MG	G	MG	VP	VG	AG	VG	G	M	MG	VP	MG	G	M	M	MG	G	AP	M	MG	M	M	VG	MG	VP
LTE Femto 33	AG	AG	MG	VG	AG	MG	P	G	VG	M	MG	M	VG	VP	VG	AG	AG	G	G	AG	P	VG	AG	G	G	VG	VG	VP	G	VG	VG	MG	G	VG	P
LTE Femto 34	AG	AG	G	VG	MG	MG	VP	VG	AG	MG	G	MG	MG	P	VG	AG	M	G	G	MG	VP	M	MG	VG	M	AG	AG	VP	MG	G	VG	M	G	M	P
LTE Femto 35	VG	AG	G	G	MG	M	VP	G	VG	M	MG	AG	VG	P	VG	AG	VG	G	MG	MG	P	VG	AG	G	G	MG	AG	P	G	VG	G	MG	VG	M	P
LTE Femto 36	G	VG	M	MG	MG	G	AP	MG	G	VG	M	MG	AG	VP	VG	AG	G	G	AG	MG	AP	MG	G	VG	M	AG	MG	P	G	VG	MG	MG	M	G	AP
LTE Femto 37	G	VG	AG	MG	M	MG	P	AG	AG	VG	VG	VG	AG	AP	AG	AG	VG	VG	M	G	AP	AG	AG	AG	VG	MG	MG	AP	G	VG	VG	MG	VG	MG	P

Table B2
The available WiMAX and WAVE networks of SLA 1.

Network	SLA 1																																		
	NAV							VoIP							CV							BS							Web						
	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price
WiMAX Macro 1	MG	G	G	M	G	VG	P	G	VG	VG	MG	VG	G	P	M	MG	M	M	VG	M	P	G	G	VG	MG	G	MG	AP	MG	G	M	M	AG	G	AP
WiMAX Macro 2	MG	G	M	M	MG	G	P	MG	G	VG	M	MG	G	P	AG	AG	G	VG	AG	MG	AP	AG	AG	VG	VG	MG	M	AP	G	VG	AG	MG	AG	M	P
WiMAX Macro 3	G	VG	MG	MG	G	G	VP	MG	G	M	M	VG	M	P	VG	AG	MG	G	G	M	P	M	MG	G	M	MG	M	VP	VG	AG	MG	G	AG	M	VP
WiMAX Macro 4	MG	G	M	M	AG	VG	VP	MG	G	M	M	AG	MG	AP	VG	AG	MG	G	VG	M	VP	AG	AG	AG	VG	MG	G	P	G	VG	M	MG	G	AG	AP
WiMAX Macro 5	AG	AG	AG	VG	MG	M	VP	VG	AG	G	G	MG	AG	P	VG	AG	M	G	AG	M	AP	MG	G	VG	M	G	G	P	AG	AG	G	VG	M	G	VP
WiMAX Macro 6	M	MG	MG	M	G	M	P	MG	G	VG	M	VG	VG	AP	VG	AG	G	G	VG	M	P	G	VG	MG	MG	VG	VG	AP	G	VG	G	MG	VG	VG	VP
WiMAX Macro 7	AG	AG	G	VG	M	VG	AP	AG	AG	MG	VG	VG	G	P	G	VG	MG	MG	VG	M	AP	G	VG	M	MG	AG	G	AP	MG	G	M	M	AG	G	AP
WiMAX Macro 8	M	MG	VG	M	AG	MG	VP	VG	AG	MG	G	MG	VG	AP	M	MG	VG	M	G	G	VP	MG	G	G	M	G	AG	VP	G	VG	MG	MG	M	MG	P
WiMAX Macro 9	AG	AG	M	VG	M	MG	P	M	MG	M	M	AG	VG	AP	AG	AG	G	VG	G	M	VP	MG	G	MG	M	G	M	AP	M	MG	MG	M	AG	G	VP
WiMAX Macro 10	MG	G	M	M	VG	G	P	AG	AG	AG	VG	MG	G	VP	AG	AG	G	VG	G	MG	VP	G	VG	M	MG	M	VG	AP	VG	AG	AG	G	G	VG	VP
WiMAX Macro 11	M	MG	G	M	VG	MG	AP	MG	G	AG	M	G	MG	P	G	VG	M	MG	G	M	AP	G	VG	VG	MG	VG	G	P	M	MG	VG	M	VG	G	VP
WiMAX Macro 12	G	VG	AG	MG	G	M	P	AG	AG	VG	VG	G	G	P	VG	AG	M	G	G	AG	AP	VG	AG	G	G	G	MG	P	VG	AG	G	G	M	MG	P
WiMAX Macro 13	G	VG	MG	MG	AG	M	VP	M	MG	VG	M	M	G	P	AG	AG	VG	VG	VG	G	VP	M	MG	AG	M	AG	G	AP	G	VG	G	MG	AG	AG	VP
WiMAX Macro 14	AG	AG	AG	VG	G	M	P	M	MG	M	M	M	VG	P	VG	AG	G	G	AG	VG	P	MG	G	G	M	M	VG	AP	MG	G	MG	M	G	MG	VP
WiMAX Macro 15	VG	AG	VG	G	MG	G	AP	AG	AG	G	VG	G	M	VP	MG	G	VG	M	VG	MG	P	M	MG	M	M	AG	G	P	G	VG	G	MG	VG	MG	AP
WiMAX Macro 16	M	MG	M	M	VG	MG	AP	VG	AG	MG	G	M	VG	AP	M	MG	M	M	MG	MG	AP	G	G	VG	MG	VG	G	P	AG	AG	AG	VG	G	AG	AP
WiMAX Macro 17	M	MG	G	M	G	AG	AP	M	MG	MG	M	AG	AG	VP	MG	G	G	M	AG	VG	VP	AG	AG	VG	VG	G	MG	AP	VG	AG	VG	G	VG	MG	VP
WiMAX Femto 1	VG	AG	AG	G	G	MG	AP	M	MG	M	M	VG	MG	P	MG	G	MG	M	G	MG	AP	VG	AG	G	G	AG	G	AP	G	VG	VG	MG	VG	G	P
WiMAX Femto 2	M	MG	G	M	MG	AG	VP	G	VG	AG	MG	AG	AG	P	M	MG	MG	M	VG	VG	VP	G	VG	M	MG	M	VG	VP	MG	G	VG	M	G	VG	P
WiMAX Femto 3	M	MG	G	M	AG	G	AP	M	MG	AG	M	G	M	AP	VG	AG	VG	G	G	G	AP	MG	G	VG	M	M	AG	VP	M	MG	MG	M	AG	AG	AP
WiMAX Femto 4	MG	G	VG	M	MG	VG	P	AG	AG	AG	VG	VG	MG	P	G	VG	G	MG	MG	MG	VP	M	MG	M	M	M	MG	P	G	G	G	MG	G	M	AP
WiMAX Femto 5	AG	AG	G	VG	G	M	VP	VG	AG	MG	G	MG	AG	VP	VG	AG	AG	G	AG	VG	VP	VG	AG	M	G	VG	VG	P	MG	G	M	M	MG	M	AP
WiMAX Femto 6	M	MG	MG	M	G	VG	AP	MG	G	AG	M	M	MG	P	VG	AG	G	G	MG	M	AP	MG	G	VG	M	G	G	VP	AG	AG	G	VG	VG	VG	VP
WiMAX Femto 7	MG	G	G	M	MG	M	VP	M	MG	M	M	VG	VG	P	G	VG	VG	MG	G	VG	P	M	MG	G	M	G	VG	P	AG	AG	VG	VG	G	AG	P
WiMAX Femto 8	G	VG	G	MG	G	MG	AP	VG	AG	M	G	G	VG	P	AG	AG	MG	VG	AG	G	P	VG	AG	AG	G	MG	AG	VP	AG	AG	VG	VG	VG	MG	AP
WiMAX Femto 9	MG	G	MG	M	VG	M	P	M	MG	M	M	AG	G	AP	MG	G	G	M	G	MG	VP	M	MG	VG	M	AG	M	AP	MG	G	MG	M	G	G	AP
WiMAX Femto 10	AG	AG	AG	VG	M	AG	AP	G	VG	AG	MG	M	MG	AP	G	VG	M	MG	G	AG	VP	VG	AG	G	G	VG	G	P	AG	AG	AG	VG	MG	MG	P
WiMAX Femto 11	MG	G	G	M	G	AG	P	VG	AG	AG	G	VG	G	P	AG	AG	AG	VG	MG	G	P	AG	AG	VG	VG	G	VG	AP	AG	AG	AG	VG	VG	AG	VP
WiMAX Femto 12	G	VG	G	MG	AG	VG	P	M	MG	MG	M	M	MG	AP	MG	G	MG	M	VG	G	P	G	VG	G	MG	VG	AG	VP	G	VG	MG	MG	G	M	P
WiMAX Femto 13	AG	AG	MG	VG	VG	VG	VP	M	MG	AG	M	G	M	AP	G	VG	VG	MG	G	VG	P	AG	AG	VG	VG	G	VG	VP	VG	AG	MG	G	MG	M	AP
WiMAX Femto 14	AG	AG	VG	VG	M	G	AP	AG	AG	M	VG	M	M	AP	VG	AG	MG	G	MG	G	VP	AG	AG	VG	VG	VG	G	AP	MG	G	G	M	VG	G	AP
WiMAX Femto 15	AG	AG	G	VG	G	MG	VP	MG	G	VG	M	G	MG	VP	G	G	MG	MG	G	AG	AP	AG	AG	M	VG	MG	G	P	G	VG	M	MG	MG	MG	P
WiMAX Femto 16	M	MG	M	M	MG	M	VP	G	VG	M	MG	G	M	AP	VG	G	MG	G	G	AG	P	VG	AG	MG	G	AG	VG	P	AG	AG	AG	VG	AG	G	P
WiMAX Femto 17	M	MG	G	M	MG	M	AP	G	VG	VG	MG	M	M	AP	G	VG	AG	MG	AG	VG	P	MG	G	VG	M	VG	AG	VP	VG	AG	AG	G	AG	MG	P
WiMAX Femto 18	G	VG	AG	MG	M	VG	VP	AG	AG	VG	VG	VG	M	VP	VG	AG	G	G	MG	G	P	M	MG	AG	M	G	VG	P	VG	AG	VG	G	AG	M	VP
WiMAX Femto 19	M	MG	M	M	G	M	VP	AG	AG	M	VG	AG	M	VP	AG	AG	G	VG	G	M	AP	G	VG	MG	MG	G	MG	AP	VG	AG	M	G	G	VG	P
WiMAX Femto 20	G	VG	AG	MG	G	AG	VP	M	MG	M	M	M	MG	AP	G	VG	MG	MG	M	AG	P	MG	G	G	M	VG	G	P	M	MG	AG	M	VG	VG	AP
WiMAX Femto 21	MG	G	M	M	MG	AG	P	M	MG	M	M	M	AG	P	M	MG	AG	M	M	AG	P	G	VG	M	MG	VG	G	AP	VG	AG	G	G	G	G	AP
WiMAX Femto 22	VG	AG	AG	G	MG	M	AP	G	VG	M	MG	M	AG	VP	G	VG	G	MG	VG	M	AP	M	MG	VG	M	M	VG	VP	MG	G	M	M	G	MG	AP
WiMAX Femto 23	MG	G	G	M	MG	M	AP	VG	AG	AG	G	AG	M	VP	MG	G	MG	M	G	MG	AP	MG	G	G	M	G	AG	AP	VG	AG	G	G	VG	AG	VP
WiMAX Femto 24	G	VG	M	MG	VG	G	VP	AG	AG	AG	VG	MG	MG	AP	G	VG	MG	MG	MG	M	VP	G	VG	AG	MG	G	MG	AP	VG	AG	VG	G	G	G	P
WiMAX Femto 25	MG	G	VG	M	MG	VG	AP	VG	AG	G	G	VG	G	P	MG	G	G	M	AG	MG	P	VG	AG	AG	G	MG	MG	AP	MG	G	AG	M	VG	MG	AP

Table B2 (*continued*)

Network	SLA 1																																		
	NAV							VoIP							CV							BS							Web						
	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price
WAVE 1	AG	AG	G	VG	VG	VG	VP	G	VG	VG	MG	AG	AG	P	MG	G	M	M	VG	G	P	MG	G	G	M	VG	AG	P	VG	AG	G	G	AG	M	VP
WAVE 2	VG	AG	MG	G	AG	MG	VP	MG	G	MG	M	G	M	P	VG	AG	AG	G	G	M	VP	M	MG	VG	M	G	VG	AP	M	MG	VG	M	VG	MG	P
WAVE 3	VG	AG	M	G	M	VG	AP	M	MG	G	M	VG	VG	VP	AG	AG	MG	VG	VG	MG	VP	MG	G	M	M	VG	G	P	MG	G	G	G	M	VG	VP
WAVE 4	AG	AG	AG	VG	AG	AG	P	G	VG	M	MG	MG	MG	VP	G	G	M	MG	AG	G	VP	AG	AG	G	VG	AG	MG	VP	G	VG	MG	MG	G	VG	AP
WAVE 5	M	MG	M	M	AG	VG	AP	MG	G	VG	M	VG	AG	AP	G	VG	VG	MG	MG	MG	AP	AG	AG	G	VG	MG	MG	P	M	MG	AG	M	M	G	AP
WAVE 6	M	MG	VG	MG	MG	M	VP	G	VG	AG	MG	AG	VG	AP	M	MG	G	M	MG	G	VP	AG	AG	M	VG	G	VG	AP	MG	G	G	M	G	MG	AP
WAVE 7	M	MG	AG	M	MG	VG	VP	VG	AG	MG	G	M	G	P	VG	AG	VG	G	AG	G	VP	AG	AG	VG	VG	G	G	P	VG	AG	G	G	AG	VG	AP
WAVE 8	MG	G	G	MG	MG	MG	VP	M	MG	M	M	AG	MG	P	VG	AG	AG	G	M	MG	AP	AG	AG	G	VG	M	MG	P	VG	AG	AG	G	G	VG	AP
WAVE 9	MG	G	G	MG	G	M	P	M	MG	M	M	VG	MG	VP	M	MG	M	M	VG	VG	P	AG	AG	M	VG	VG	G	AP	M	MG	G	M	AG	G	P
WAVE 10	MG	G	G	M	AG	VG	P	M	MG	VG	M	AG	M	VP	AG	AG	M	VG	MG	G	VP	M	MG	G	M	MG	G	VP	MG	G	VG	M	G	AG	AP
WAVE 11	M	MG	G	M	G	AG	AP	VG	AG	G	G	M	M	VP	G	VG	G	MG	MG	MG	VP	AG	AG	G	VG	AG	MG	VP	VG	AG	G	G	VG	M	P
WAVE 12	AG	AG	MG	VG	M	VG	VP	AG	AG	VG	VG	VG	G	VP	M	MG	VG	M	G	VG	VP	VG	AG	MG	G	MG	VG	AP	AG	AG	M	VG	G	AG	AP
WAVE 13	M	MG	G	M	G	M	VP	MG	G	VG	M	VG	MG	P	AG	AG	G	VG	VG	G	VP	VG	AG	MG	G	AG	G	AP	AG	AG	VG	VG	VG	VG	P
WAVE 14	AG	AG	AG	VG	G	VG	AP	G	VG	VG	MG	G	M	AP	G	G	G	MG	VG	AG	P	M	MG	G	M	G	MG	P	MG	G	MG	M	AG	G	VP
WAVE 15	G	VG	G	MG	M	MG	VP	AG	AG	VG	VG	G	MG	AP	AG	AG	G	VG	AG	M	VP	M	MG	VG	M	G	MG	P	MG	G	G	M	G	AG	VP
WAVE 16	VG	AG	MG	M	VG	G	VP	G	VG	MG	MG	VG	AG	VP	G	VG	AG	MG	G	G	AP	VG	AG	AG	G	MG	G	AP	G	VG	G	MG	AG	G	AP
WAVE 17	M	MG	VG	M	VG	VG	P	VG	AG	AG	G	M	MG	VP	M	MG	G	M	AG	MG	VP	VG	AG	MG	G	MG	M	AP	VG	AG	G	G	AG	VG	P
WAVE 18	G	VG	G	MG	MG	AG	AP	MG	G	M	M	VG	VG	AP	MG	G	M	M	VG	G	VP	AG	AG	G	VG	AG	G	P	M	MG	AG	M	VG	G	P
WAVE 19	VG	AG	MG	G	MG	M	P	G	VG	AG	MG	VG	G	AP	VG	AG	G	G	AG	G	P	MG	G	AG	M	MG	VG	AP	AG	AG	AG	VG	M	AG	AP
WAVE 20	M	MG	M	M	G	G	AP	MG	G	AG	M	G	MG	VP	VG	AG	MG	G	AG	AG	AP	M	MG	MG	M	VG	AG	P	M	MG	VG	M	AG	AG	VP
WAVE 21	M	MG	VG	M	VG	AG	P	G	VG	AG	MG	MG	G	AP	G	VG	M	MG	MG	MG	P	G	VG	G	MG	AG	VG	VP	G	VG	M	MG	MG	G	P
WAVE 22	MG	G	G	MG	MG	G	VP	MG	G	G	M	G	AG	AP	AG	AG	MG	VG	MG	AG	VP	VG	AG	G	G	G	MG	VP	AG	AG	G	VG	G	AG	AP

Table B3
The available LTE networks of SLA 2, SLA 3 and SLA 4.

Network	SLA 2																					SLA 3														SLA 4						
	CV							BS							Web							BS							Web							Web						
	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price
LTE Macro 1	G	G	G	MG	MG	P	P	MP	M	MG	P	G	MP	P	G	G	G	MG	G	MP	P	MP	M	MG	P	M	MP	M	P	MP	MG	P	MG	MP	M	VP	P	VP	AP	VP	P	VG
LTE Macro 2	M	MG	P	MP	M	MP	M	MG	G	M	M	P	MG	M	G	G	MP	MG	MP	MG	P	P	MP	MP	P	P	MP	M	M	MG	MP	MP	MP	MG	MG	M	M	AP	MP	MP	P	G
LTE Macro 3	MG	G	G	M	G	MG	MP	P	MP	M	P	P	P	M	MG	G	P	M	M	P	M	P	MP	P	P	P	P	M	MG	MG	P	M	M	P	G	AP	VP	VP	AP	M	VP	AG
LTE Macro 4	M	MG	P	MP	P	MP	MP	G	G	P	MG	P	G	P	MG	G	M	M	G	M	P	MP	M	P	P	P	P	M	MG	MG	MP	M	MG	P	M	M	M	MP	MP	VP	P	AG
LTE Macro 5	MP	M	M	P	P	M	M	MG	G	G	M	MG	G	M	MG	G	P	M	M	G	M	MG	MG	MG	M	P	MP	M	M	MG	P	MP	M	MP	M	AP	VP	P	AP	AP	P	AG
LTE Macro 6	MP	M	MP	P	G	MG	M	G	G	G	MG	MP	G	M	M	MG	G	MP	MG	MP	MP	MG	MG	MP	M	MP	P	M	M	MG	MP	MP	MP	P	G	P	MP	MP	VP	VP	P	G
LTE Macro 7	MG	G	G	M	P	M	P	M	MG	MG	MP	M	P	M	M	MG	P	MP	G	M	P	MP	M	P	P	MP	P	MG	MP	M	P	P	P	P	M	AP	VP	VP	AP	AP	VP	VG
LTE Macro 8	G	G	P	MG	P	MP	M	G	G	P	MG	MG	G	MP	M	MG	M	MP	G	M	P	P	MP	P	MP	P	M	G	M	MG	P	MP	MP	MP	M	P	MP	AP	VP	VP	MP	AG
LTE Macro 9	MG	G	P	M	M	G	MP	MP	M	MG	P	G	MP	P	M	MG	MG	MP	MG	MG	P	P	MP	MP	VP	M	P	G	P	MP	M	VP	P	MP	G	P	MP	P	VP	P	VP	AG
LTE Macro 10	G	G	G	MG	M	M	M	MG	G	G	M	MP	MG	M	P	MP	P	P	G	M	MP	MP	M	P	P	MP	P	G	P	MP	P	P	M	MP	MG	P	MP	VP	P	AP	MP	VG
LTE Macro 11	M	MG	MP	MP	P	MG	MP	P	MP	MG	P	G	P	M	G	G	P	MG	G	G	M	P	MP	MG	P	P	P	MG	M	MG	P	MP	MP	P	G	P	MP	VP	VP	MP	P	AG
LTE Macro 12	MP	M	G	P	MP	G	M	MP	M	MG	P	M	MG	MP	MP	M	P	P	MG	MG	P	MP	M	MG	P	M	MP	MG	MP	M	P	P	MP	M	M	MP	M	VP	P	VP	AP	VG
LTE Macro 13	G	G	G	MG	G	MP	MP	P	MP	MG	P	MG	G	M	P	MP	P	MP	P	P	MP	P	MP	MG	P	MP	M	M	P	MP	P	VP	P	P	G	P	MP	P	VP	P	VP	VG
LTE Macro 14	M	MG	MG	MP	G	P	M	G	G	G	MG	P	M	MP	P	MP	G	P	G	G	P	M	MG	M	MP	P	MP	M	P	MP	MG	P	MP	P	G	P	MP	M	VP	MP	AP	G
LTE Macro 15	M	MG	MG	MP	G	MP	P	P	MP	M	P	MG	MP	MP	MG	G	P	M	P	P	P	P	MP	M	P	P	P	M	MP	M	P	P	P	VP	G	MP	M	P	P	P	VP	VG
LTE Macro 16	MG	G	MP	M	P	MG	P	G	G	MG	MG	MG	P	M	M	MG	MG	MP	M	MP	M	P	MP	M	P	P	P	M	M	MG	P	MP	M	P	M	M	M	P	MP	MP	P	G
LTE Macro 17	MP	M	P	P	P	G	M	P	MP	P	P	P	MG	P	M	MG	P	MP	MP	MG	P	P	MP	P	P	P	M	G	P	MP	P	P	MP	M	MG	P	MP	AP	VP	VP	VP	G
LTE Macro 18	MG	G	M	M	MP	M	MP	MG	G	MG	M	P	MP	M	M	MG	G	MP	M	G	P	P	MP	P	P	P	MP	G	P	MP	P	VP	MP	P	G	AP	VP	P	AP	P	AP	VG
LTE Macro 19	MP	M	MP	P	M	P	M	G	G	MP	MG	MG	P	M	MP	M	MG	P	MP	MG	M	MP	M	MP	MP	MP	P	M	MP	M	MP	P	MP	MP	G	MP	M	P	P	P	MP	AG
LTE Macro 20	MG	G	MG	M	M	MG	M	M	MG	G	MP	MG	M	MP	MG	G	G	M	G	M	M	MP	M	P	P	P	M	G	MP	M	M	P	P	M	MG	P	MP	AP	P	AP	AP	AG
LTE Femto 1	P	MP	G	P	G	M	MP	G	G	M	MG	MG	P	P	MP	M	P	P	M	P	P	P	MP	P	P	MG	P	MG	MP	M	P	P	M	P	M	MP	M	VP	P	AP	VP	G
LTE Femto 2	P	MP	MP	P	M	MG	MP	M	MG	P	MP	P	MG	MP	MP	M	P	MP	G	M	M	M	MG	P	MP	P	MP	G	P	MP	P	VP	P	P	G	P	MP	AP	VP	AP	VP	G
LTE Femto 3	G	G	MG	MG	M	G	M	MG	G	G	M	MP	P	P	MP	M	MP	P	P	M	M	P	MP	P	P	MP	P	MG	MP	M	MP	P	P	P	M	VP	P	MP	AP	P	AP	VG
LTE Femto 4	G	G	P	MG	G	M	P	MG	G	MG	M	P	MP	P	MG	G	M	M	P	G	MP	MP	M	MG	P	P	P	G	MP	M	MP	P	P	P	G	MP	M	MP	P	VP	P	VG
LTE Femto 5	G	G	M	MG	P	MP	M	MG	G	MG	M	MG	P	M	P	MP	G	P	G	M	P	P	MP	P	P	MP	P	G	P	MP	MP	P	MG	P	G	P	MP	MP	VP	P	VP	VG
LTE Femto 6	P	MP	M	P	G	P	P	P	MP	MG	P	M	G	MP	MP	M	G	P	P	M	MP	P	MP	MG	P	P	P	MG	MP	M	MG	P	P	MP	MG	MP	M	AP	P	VP	MP	G
LTE Femto 7	M	MG	P	MP	M	M	MP	MG	G	MG	M	MP	P	P	MG	G	G	M	MP	M	M	M	MG	MP	MP	P	P	M	P	MP	P	P	P	P	G	P	MP	P	VP	VP	P	VG
LTE Femto 8	G	G	MP	MG	MP	M	P	P	MP	G	P	MG	MP	P	G	G	MP	MG	G	M	P	P	MP	P	P	MP	P	G	MG	MG	MP	M	P	P	G	M	M	P	MP	P	VP	VG
LTE Femto 9	MG	G	M	M	MG	M	P	MG	G	M	M	MG	MP	M	M	MG	M	MP	MP	MG	M	P	MP	M	P	MP	MP	G	M	MG	M	MP	MP	M	G	MP	M	MP	P	MP	MP	G
LTE Femto 10	P	MP	MG	P	MP	MG	M	G	G	P	MG	MP	MP	MP	MP	M	G	P	G	G	P	MP	M	P	P	MP	MP	M	MP	M	P	P	M	MG	G	P	MP	P	P	P	P	AG
LTE Femto 11	G	G	P	MG	P	MP	M	MP	M	G	P	MG	M	P	MG	G	M	M	M	MG	P	MP	M	P	P	P	M	M	P	MP	M	P	P	P	MG	P	P	P	P	VP	VP	AG
LTE Femto 12	P	MP	M	P	MP	P	MP	MP	M	MG	P	G	P	MP	MP	M	G	P	MG	M	M	P	MP	M	P	M	P	MG	P	MP	P	VP	MP	MP	M	P	MP	VP	VP	VP	MP	G
LTE Femto 13	M	MG	P	MP	MP	M	MP	MG	G	G	M	MP	P	MP	MP	M	MG	P	G	MG	P	MG	MG	MG	M	MP	P	G	MP	M	M	P	MG	MP	M	P	MP	VP	VP	VP	VP	VG
LTE Femto 14	MG	G	G	M	MG	MP	MP	MG	G	P	M	MG	M	P	P	MP	MP	P	MP	G	P	P	MP	P	P	M	MP	G	P	MP	MP	P	MP	MP	M	VP	P	VP	P	VP	MP	VG
LTE Femto 15	P	MP	G	P	G	P	MP	MG	G	M	M	MG	M	P	MG	G	MG	M	MP	M	M	MG	MG	P	M	MP	MP	MG	P	MP	MP	P	MP	M	M	P	MP	VP	VP	VP	M	VG
LTE Femto 16	M	MG	P	MP	G	MG	P	MG	G	MG	M	M	G	M	G	G	M	MG	MP	M	P	P	MP	MP	P	P	P	M	MG	MG	MP	M	MP	MP	M	MP	M	MP	P	MP	AP	VG
LTE Femto 17	MG	G	MG	M	G	MG	M	MG	G	P	M	MG	MG	P	P	MP	P	P	M	G	MP	MG	MG	P	M	MG	MP	MG	P	MP	P	VP	MP	MG	G	P	MP	AP	VP	MP	M	G
LTE Femto 18	MP	M	P	P	G	MG	M	P	MP	MG	P	MG	MP	M	MG	G	M	M	MG	M	M	P	MP	MP	P	M	MP	G	MG	MG	M	M	MG	P	MG	M	M	AP	MP	M	VP	AG
LTE Femto 19	G	G	M	MG	G	P	MP	MP	M	MP	P	G	MG	MP	G	G	M	MG	P	MG	MP	MP	M	P	P	M	MG	MG	MG	MG	M	M	P	MP	M	M	M	M	MP	AP	MP	AG
LTE Femto 20	M	MG	M	MP	MG	P	MP	MP	M	M	P	G	MP	MP	MG	G	MG	M	MG	MG	M	MP	M	M	P	P	MP	G	P	MP	M	P	M	P	M	VP	P	AP	AP	M	VP	G
LTE Femto 21	P	MP	P	P	P	M	P	P	MP	G	P	MG	MP	MP	MG	G	M	M	G	M	M	P	MP	MP	VP	MP	MP	MG	MG	MG	M	M	M	M	M	M	M	MP	MP	P	AP	G
LTE Femto 22	MG	G	G	M	MP	MG	P	P	MP	MG	P	G	MP	MP	MG	G	G	M	M	M	MP	P	MP	MP	P	P	P	MG	MG	MG	M	M	M	M	G	AP	VP	M	AP	AP	P	AG
LTE Femto 23	MG	G	M	M	M	M	MP	MG	G	G	M	M	M	M	M	MG	M	MP	G	P	P	MP	M	M	P	M	P	G	M	MG	P	MP	M	P	M	MP	M	VP	P	P	P	AG
LTE Femto 24	M	MG	M	MP	G	G	M	MP	M	M	P	P	MG	M	MG	G	P	M	MP	P	M	MP	M	M	P	P	P	G	M	MG	P	MP	P	P	M	M	M	VP	MP	P	VP	G
LTE Femto 25	G	G	G	MG	G	MG	MP	P	MP	MG	P	MG	MG	MP	M	MG	MG	MP	G	G	P	P	MP	MP	VP	MG	P	G	M	MG	M	MP	MP	MG	M	P	MP	M	VP	VP	VP	VG
LTE Femto 26	MG	G	M	M	MG	P	M	MG	G	MG	M	MP	MP	MP	G	G	MP	MG	M	M	M	P	MP	MG	P	P	MP	M	M	MG	M	MP	P	MP	G	M	M	M	MP	P	P	G
LTE Femto 27	MG	G	G	M	G	G	MP	P	MP	P	P	MG	P	MP	G	G	M	MG	P	P	M	VP	P	P	VP	M	P	M	M	MG	M	MP	P	P	MG	MP	M	AP	P	VP	VP	AG
LTE Femto 28	P	MP	MP	P	M	P	P	G	G	MP	MG	MP	P	MP	M	MG	P	MP	MG	M	MP	MG	MG	P	M	P	P	M	M	MG	P	MP	P	M	M	P	MP	AP	VP	AP	AP	G
LTE Femto 29	G	G	P	MG	P	P	MP	G	G	G	MG	M	MP	MP	MP	M	P	P	M	M	MP	MG	MG	M	M	MG	M	M	MP	M	P	P	M	M	M	MP	M	P	P	P	VP	AG
LTE Femto 30	G	G	M	MG	MG	P	P	P	MP	M	P	MG	M	M	P	MP	G	P	M	MP	M	MP	M	MG	P	M	MP	MG	M	MG	MG	MP	MP	MP	MG	MP	M	M	P	MP	MP	VG
LTE Femto 31	M	MG	G	MP	G	P	P	M	MG	P	MP	P	MP	MP	MP	M	G	P	MP	MP	P	MP	M	P	P	P	MP	MG	MP	M	P	P	MP	P	M	VP	P	AP	VP	VP	P	G
LTE Femto 32	M	MG	G	MP	MP	MG	M	MP	M	MP	P	P	MG	MP	M	MG	MP	MP	MG	P	P	MP	M	MP	P	P	MP	MG	MP	M	P	P	M	P	G	P	MP	AP	VP	MP	AP	AG
LTE Femto 33	MG	G	P	M	MP	MP	P	M	MG	P	MP	MG	P	M	MP	M	G	P	M	G	MP	MP	M	P	P	MP	P	M	MP	M	M	P	M	M	G	MP	M	M	P	VP	M	AG
LTE Femto 34	P	MP	P	P	P	M	MP	M	MG	G	MP	M	MP	MP	MP	M	MG	P	G	MP	MP	MP	M	M	MP	M	P	MG	P	MP	P	VP	M	MP	G	VP	P	P	AP	M	P	VG
LTE Femto 35	P	MP	P	P	MP	MP	P	G	G	G	MG	P	MP	P	MG	G	G	M	G	MP	M	P	MP	MG	MP	P	P	M	P	MP	MP	P	MP	P	G	P	MP	MP	VP	MP	P	AG
LTE Femto 36	M	MG	G	MP	MG	P	P	M	MG	MP	MP	M	P	M	P	MP	MP	MP	P	G	M	P	MP	P	P	M	P	M	VP	P	P	MP	P	M	M	VP	P	VP	P	P	AP	VG
LTE Femto 37	P	MP	G	P	M	M	P	MG	G	MP	M	M	MG	P	P	MP	MP	P	MP	MG	M	M	MG	MP	MP	M	MG	G	P	MP	MP	P	MP	M	MG	P	MP	VP	P	AP	VP	VG

Table B4
The available WiMAX and WAVE networks of SLA 2, SLA 3 and SLA 4.

Network	SLA 2																					SLA 3														SLA 4						
	CV							BS							Web							BS							Web							Web						
	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price
WiMAX Macro 1	MP	M	M	P	P	P	P	G	G	G	MG	G	M	P	M	MG	MP	MP	MG	MG	P	M	MG	MG	MP	P	MP	G	M	MG	MP	MP	M	P	G	AP	VP	AP	AP	M	VP	G
WiMAX Macro 2	G	G	MG	MG	G	MG	P	P	MP	P	P	M	MP	P	M	MG	MP	MP	M	P	MP	P	MP	P	P	P	MP	M	M	MG	MP	MP	M	P	M	M	M	AP	MP	P	P	AG
WiMAX Macro 3	MG	G	MG	M	G	MP	P	P	MP	P	P	P	P	M	P	MP	P	P	M	M	M	P	MP	P	P	P	P	MG	P	MP	P	P	MP	M	G	VP	P	VP	AP	AP	MP	G
WiMAX Macro 4	M	MG	P	MP	P	P	MP	MP	M	MG	P	MG	G	MP	MG	G	MP	M	MP	G	MP	MP	M	MG	P	MP	M	M	MG	MG	MP	M	P	M	G	AP	VP	VP	AP	P	MP	G
WiMAX Macro 5	MP	M	MP	P	G	P	MP	MP	M	P	P	MG	G	MP	MG	G	M	M	M	MP	P	MP	M	P	P	MP	MP	MG	P	MP	M	P	MP	P	M	AP	VP	P	AP	AP	VP	AG
WiMAX Macro 6	MP	M	G	P	G	M	M	G	G	M	MG	P	MP	M	M	MG	MP	MP	MG	P	MP	MG	M	M	M	P	MP	MG	M	MG	MP	MP	P	P	M	VP	P	MP	AP	P	AP	VG
WiMAX Macro 7	M	MG	MG	MP	MG	MP	P	MG	G	M	M	MG	MG	MP	MP	M	P	P	M	G	MP	MP	M	P	P	MP	MP	M	MP	M	P	P	P	P	MG	P	MP	AP	VP	MP	AP	AG
WiMAX Macro 8	M	MG	M	MP	G	MP	MP	M	MG	G	MP	M	P	MP	MP	M	MP	P	P	MG	P	M	M	M	MP	MP	P	M	MP	M	MP	P	P	P	MG	P	MP	MP	VP	P	VP	AG
WiMAX Macro 9	M	MG	M	MP	G	M	M	MP	M	P	P	MP	P	P	MP	M	MP	P	MP	G	P	MP	M	P	P	MP	P	G	MP	M	P	P	P	MP	MG	MP	M	VP	P	AP	AP	VG
WiMAX Macro 10	P	MP	MG	P	MG	M	MP	MP	M	M	P	MP	MP	P	P	MP	MG	P	G	MP	MP	MP	M	M	P	MP	MP	M	P	MP	MG	P	P	P	MG	P	MP	AP	VP	P	P	G
WiMAX Macro 11	MP	M	P	P	G	M	MP	P	MP	G	P	G	MP	M	M	MG	MG	MP	P	MG	MP	M	MG	M	MP	MP	MP	G	P	MP	MP	P	MP	P	M	VP	P	VP	AP	MP	P	AG
WiMAX Macro 12	MG	G	M	M	P	MG	M	P	MP	G	P	G	MG	P	P	MP	G	P	P	MP	M	P	MP	MP	P	M	P	MG	VP	P	P	P	P	MP	M	AP	VP	P	AP	AP	VP	G
WiMAX Macro 13	MP	M	MP	P	G	M	P	M	MG	G	MP	P	MG	P	MP	M	MP	P	G	MG	M	P	MP	M	P	P	MG	G	P	MP	MP	P	M	P	MG	P	MP	MP	VP	M	VP	VG
WiMAX Macro 14	MP	M	MG	P	M	G	M	P	MP	G	P	M	G	MP	MG	G	MP	M	G	MP	M	VP	P	MG	P	M	P	M	M	MG	P	MP	MP	MP	MG	P	MP	VP	VP	MP	AP	G
WiMAX Macro 15	MG	G	P	M	P	P	M	P	MP	P	P	MG	M	MP	P	MP	G	P	M	MP	MP	P	MP	P	P	P	MP	G	P	MP	M	P	P	MP	G	VP	P	VP	AP	P	AP	AG
WiMAX Macro 16	MP	M	P	P	MG	MG	MP	G	G	MP	MG	G	G	M	MG	G	M	M	MP	M	MP	M	MG	MP	MP	MP	MP	M	MG	MG	M	M	P	M	G	P	MP	AP	VP	P	MP	VG
WiMAX Macro 17	MG	G	MP	M	P	MP	M	G	G	MG	MG	M	MP	MP	M	MG	MG	MP	MG	MG	MP	M	MG	MP	MP	M	MP	G	P	MP	P	VP	MG	MG	MG	P	MP	AP	VP	P	VP	G
WiMAX Femto 1	MP	M	MG	P	G	MG	P	M	MG	M	MP	MG	MG	MP	G	G	M	MG	G	MG	P	M	MG	MP	MP	P	MG	M	MP	M	M	P	MP	MP	MG	AP	VP	M	AP	VP	P	AG
WiMAX Femto 2	M	MG	MP	MP	M	P	MP	MG	G	M	M	MP	MP	MP	MG	G	P	M	P	MG	P	P	MP	MP	P	MP	MP	M	MP	M	P	P	P	P	G	MP	M	AP	P	VP	AP	VG
WiMAX Femto 3	P	MP	MP	P	G	M	M	MG	G	M	M	P	MP	MP	MP	M	M	P	M	M	MP	P	MP	MP	P	P	P	G	MP	M	M	P	M	M	M	VP	P	P	AP	AP	P	AG
WiMAX Femto 4	G	G	P	MG	MP	P	MP	P	MP	MP	P	P	MG	P	G	G	G	MG	P	MP	P	P	MP	P	P	P	MP	M	M	MG	MP	MP	P	MP	M	MP	M	P	P	AP	P	VG
WiMAX Femto 5	G	G	MP	MG	M	G	M	M	MG	P	MP	MP	P	P	MP	M	MP	P	P	M	MP	M	MG	P	MP	P	P	M	MP	M	MP	P	P	M	G	P	MP	AP	P	AP	VP	G
WiMAX Femto 6	M	MG	M	MP	MP	M	P	M	MG	MG	MP	P	MG	M	MP	M	G	P	M	MP	M	M	MG	MP	MP	P	M	MG	MP	M	MP	P	M	P	G	AP	VP	VP	AP	MP	P	VG
WiMAX Femto 7	M	MG	MG	MP	MG	M	M	P	MP	P	P	MG	P	M	MG	G	MP	M	MG	M	M	P	MP	P	P	P	P	G	MP	M	MP	P	M	M	G	VP	P	MP	AP	P	VP	VG
WiMAX Femto 8	G	G	M	MG	P	MP	MP	MG	G	M	M	MP	G	MP	P	MP	M	P	MP	M	MP	P	MP	P	P	MP	P	M	P	MP	P	P	MP	M	MG	P	MP	VP	VP	MP	P	AG
WiMAX Femto 9	MG	G	G	M	P	MP	P	MP	M	MG	P	MG	P	P	P	MP	M	P	G	G	P	MP	M	P	P	MP	P	G	P	MP	M	VP	MG	P	M	AP	VP	M	AP	MP	VP	G
WiMAX Femto 10	MG	G	MP	M	MP	MP	M	MP	M	G	P	M	MP	MP	P	MP	P	P	MG	MG	M	MP	M	M	P	M	MP	G	P	MP	P	P	MG	M	M	VP	P	AP	AP	P	P	AG
WiMAX Femto 11	M	MG	M	MP	M	G	MP	G	G	P	MG	MP	MP	P	MP	M	M	P	M	MP	MP	MG	MG	P	M	MP	MP	MG	MP	M	M	P	MG	MP	G	AP	VP	M	AP	VP	VP	AG
WiMAX Femto 12	MP	M	MG	P	G	G	P	M	MG	G	MP	G	MG	P	MP	M	M	P	M	MP	MP	MP	M	P	P	MP	MG	G	MP	M	M	P	MP	P	M	AP	VP	MP	AP	MP	P	AG
WiMAX Femto 13	G	G	MG	MG	G	P	MP	G	G	P	MG	G	MG	P	MP	M	MG	P	MP	MP	P	M	MG	P	MP	P	MG	G	MP	M	P	P	MP	MP	M	P	MP	P	VP	MP	AP	VG
WiMAX Femto 14	MP	M	P	P	M	G	P	M	MG	MP	MP	MP	G	MP	MP	M	M	P	P	G	P	M	MG	MP	MP	P	MG	MG	P	MP	M	P	P	P	M	VP	P	AP	VP	AP	AP	AG
WiMAX Femto 15	G	G	M	MG	MP	MP	M	MP	M	P	P	MG	MP	P	G	G	MP	MG	MG	P	M	MP	M	P	P	MG	MP	G	M	MG	MP	MP	MP	P	G	M	M	MP	MP	MP	VP	G
WiMAX Femto 16	G	G	MG	MG	G	MG	MP	P	MP	M	P	MG	P	P	M	MG	MG	MP	M	MP	M	P	MP	M	P	P	P	M	M	MG	MG	MP	M	MP	MG	VP	P	MP	AP	AP	AP	VG
WiMAX Femto 17	MG	G	P	M	G	MP	P	MP	M	P	P	P	P	MP	G	G	MP	MG	MP	P	M	MP	M	P	P	VP	P	G	P	MP	MP	P	MP	P	M	VP	P	AP	AP	P	VP	G
WiMAX Femto 18	G	G	G	MG	P	MP	P	M	MG	MP	MP	P	MP	M	G	G	MG	MG	M	M	MP	P	MP	VP	P	P	P	M	P	MP	MP	P	M	P	MG	P	MP	VP	P	VP	P	AG
WiMAX Femto 19	MG	G	MP	M	MG	M	P	P	MP	MG	P	M	MP	M	MP	M	MP	P	G	MP	M	P	MP	MG	P	M	MP	M	P	MP	P	P	P	P	M	P	MP	P	VP	P	P	VG
WiMAX Femto 20	MG	G	MG	M	M	MG	P	MP	M	MP	P	G	P	MP	MP	M	P	P	P	MP	MP	MP	M	MP	P	MG	P	M	P	MP	P	P	P	MP	MG	P	MP	P	P	VP	AP	G
WiMAX Femto 21	P	MP	P	P	M	P	M	G	G	M	MG	P	M	P	M	MG	MP	MP	M	G	MP	MG	MG	P	M	P	MP	G	M	MG	MP	MP	MP	M	M	M	M	VP	MP	MP	P	AG
WiMAX Femto 22	P	MP	P	P	G	P	M	P	MP	G	P	P	G	MP	M	MG	P	MP	P	P	MP	P	MP	M	P	P	MG	MG	P	MP	P	P	P	P	MG	P	MP	AP	VP	VP	AP	AG
WiMAX Femto 23	MG	G	MG	M	G	MG	P	MG	G	MP	M	M	M	P	MG	G	M	M	MG	MG	M	M	MG	MP	MP	M	P	MG	M	MG	MP	MP	M	MG	MG	P	MP	P	VP	AP	AP	VG
WiMAX Femto 24	MG	G	MP	M	M	MP	M	MP	M	MG	P	P	P	M	M	MG	P	MP	G	M	M	MP	M	MG	P	P	P	MG	MP	M	P	P	MG	M	G	MP	M	P	P	AP	MP	AG
WiMAX Femto 25	MG	G	M	M	G	P	MP	MG	G	M	M	MG	MG	P	MP	M	M	P	G	MG	M	MG	M	P	M	MG	MP	M	P	MP	M	P	MG	M	MG	VP	P	P	AP	AP	MP	AG

(continued on next page)

Table B4 (*continued*)

Network	SLA 2																					SLA 3														SLA 4						
	CV							BS							Web							BS							Web							Web						
	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price	Throughput	Delay	Jitter	Packet loss	Service reliability	Security	Price
WAVE 1	MG	G	MP	M	MG	G	MP	P	MP	MP	P	MP	M	P	MP	M	M	P	MG	P	M	P	MP	MP	P	MP	M	MG	P	MP	M	VP	MP	P	G	P	MP	M	VP	VP	P	G
WAVE 2	M	MG	P	MP	P	M	M	P	MP	G	P	G	G	P	M	MG	MG	MP	P	MP	MP	P	MP	MP	VP	MP	MP	G	MP	M	M	P	P	MP	MG	VP	P	MP	AP	AP	MP	AG
WAVE 3	M	MG	MP	MP	G	MP	MP	MP	M	M	P	MG	G	P	MP	M	G	P	MP	MG	P	MP	M	MP	P	MP	M	MG	MP	M	M	P	P	MG	M	AP	VP	M	AP	VP	P	AG
WAVE 4	G	G	M	MG	M	MG	P	MP	M	G	P	G	P	MP	M	MG	M	MP	G	G	P	MP	MP	M	P	P	P	M	P	MP	M	P	MP	MP	M	VP	P	M	AP	AP	AP	AG
WAVE 5	MG	G	MP	M	MG	P	P	P	MP	G	P	MP	MG	M	MP	M	MG	P	M	P	P	P	MP	MP	P	MP	P	G	MP	M	M	P	P	P	G	VP	P	P	AP	P	AP	VG
WAVE 6	M	MG	G	MP	M	G	P	M	MG	M	MP	MG	G	MP	P	MP	G	P	MP	P	M	MP	M	P	P	MG	M	G	P	MP	MG	P	MP	P	G	P	MP	P	VP	VP	VP	AG
WAVE 7	P	MP	MG	P	P	MP	P	MG	G	MG	M	M	MP	MP	MP	M	MG	P	MG	MP	P	M	MG	MG	MP	P	MP	G	P	MP	P	VP	MG	MP	M	VP	P	VP	VP	MP	MP	G
WAVE 8	G	G	P	MG	P	M	MP	MG	G	M	M	P	M	MP	G	G	G	MG	P	MP	MP	M	M	MP	MP	P	M	G	P	MP	M	VP	P	MP	G	P	MP	P	VP	AP	MP	G
WAVE 9	MP	M	P	P	MP	M	M	G	G	P	MG	MP	G	P	P	MP	MP	P	P	MG	M	MG	M	P	M	MP	M	M	P	MP	MP	P	P	P	G	VP	P	AP	P	VP	P	AG
WAVE 10	G	G	MP	MG	MG	MP	M	MP	M	MP	P	MG	G	P	P	MP	G	P	G	MP	P	MP	M	MP	P	MG	MP	G	P	MP	MP	P	P	MP	MG	P	MP	VP	VP	P	AP	VG
WAVE 11	MP	M	P	P	MP	MG	M	MP	M	MG	P	M	P	M	G	G	M	MG	G	M	P	MP	M	M	P	P	P	MG	MG	MG	M	M	MP	MP	G	M	M	M	MP	P	VP	G
WAVE 12	M	MG	MG	MP	G	P	MP	M	MG	MG	MP	MG	G	P	MG	G	MP	M	G	G	M	M	M	MP	MP	M	MG	G	M	MG	MP	MP	MG	MP	M	M	M	MP	MP	VP	MP	VG
WAVE 13	G	G	G	MG	MP	G	P	G	G	MG	MG	MG	G	P	G	G	M	MG	MG	MP	P	MG	MG	P	M	MG	MP	G	P	MP	M	P	MP	P	M	VP	P	M	AP	MP	P	AG
WAVE 14	G	G	MP	MG	M	MG	MP	P	MP	G	P	G	P	P	M	MG	MP	MP	P	G	M	P	MP	P	P	MG	P	MG	MP	M	MP	P	P	P	MG	VP	P	VP	AP	AP	VP	AG
WAVE 15	P	MP	G	P	M	P	M	MP	M	G	P	P	MP	MP	P	MP	MG	P	G	MP	MP	MP	M	M	P	P	MP	MG	P	MP	P	P	MP	MP	M	P	MP	VP	VP	AP	VP	AG
WAVE 16	G	G	P	MG	MG	MG	M	MP	M	M	P	MG	P	P	M	MG	MP	MP	P	G	M	MP	M	P	P	MG	P	G	MP	M	MP	P	P	M	M	MP	M	VP	P	AP	VP	G
WAVE 17	P	MP	P	P	MG	M	M	M	MG	MG	MP	M	MP	M	MG	G	MG	M	MP	MP	MP	MP	M	MP	P	M	MP	MG	MP	M	M	P	MP	MP	G	P	MP	P	VP	AP	AP	AG
WAVE 18	MG	G	MP	M	G	G	MP	MG	G	MG	M	MP	MP	M	P	MP	M	P	MP	G	M	P	MP	MG	P	P	MP	M	P	MP	P	P	MP	MP	M	AP	VP	P	AP	AP	MP	AG
WAVE 19	M	MG	M	MP	MG	MP	M	MP	M	MP	P	M	P	P	MG	G	G	M	P	MP	P	MP	M	P	P	MP	P	M	MP	M	MP	P	P	MP	MG	AP	VP	MP	AP	AP	VP	G
WAVE 20	M	MG	P	MP	MP	P	P	MP	M	P	P	G	M	MP	M	MG	G	MP	G	MP	P	P	MP	P	P	MG	MP	MG	M	MG	P	MP	MP	MP	M	P	MP	AP	VP	VP	P	AG
WAVE 21	G	G	M	MG	MP	MG	MP	M	MG	P	MP	G	G	P	MP	M	P	P	M	M	M	P	P	P	P	M	M	M	MP	M	P	P	M	M	G	MP	M	VP	P	VP	P	VG
WAVE 22	G	G	M	MG	MG	MG	M	MG	G	G	M	G	M	M	MP	M	MG	P	G	MG	P	P	MP	P	P	MG	MP	M	MP	M	M	P	M	M	MG	VP	P	AP	AP	P	M	VG

Table C1
Number of vehicles that start from each LTE network and their corresponding velocities.

Network	Number of vehicles (%)	Normal velocity	Medium velocity	High velocity
LTE Macro 1	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Macro 2	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Macro 3	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Macro 4	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Macro 5	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Macro 6	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Macro 7	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Macro 8	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Macro 9	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Macro 10	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Macro 11	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Macro 12	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Macro 13	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Macro 14	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Macro 15	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Macro 16	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Macro 17	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Macro 18	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Macro 19	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Macro 20	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Femto 1	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Femto 2	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Femto 3	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Femto 4	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Femto 5	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Femto 6	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Femto 7	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Femto 8	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Femto 9	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Femto 10	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Femto 11	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Femto 12	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Femto 13	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Femto 14	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Femto 15	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Femto 16	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Femto 17	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Femto 18	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Femto 19	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Femto 20	329 (0,82648%)	109 (0,27382%)	111 (0,27884%)	109 (0,27382%)
LTE Femto 21	329 (0,82648%)	110 (0,27633%)	110 (0,27633%)	109 (0,27382%)
LTE Femto 22	329 (0,82648%)	110 (0,27633%)	110 (0,27633%)	109 (0,27382%)
LTE Femto 23	329 (0,82648%)	110 (0,27633%)	110 (0,27633%)	109 (0,27382%)
LTE Femto 24	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
LTE Femto 25	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
LTE Femto 26	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
LTE Femto 27	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
LTE Femto 28	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
LTE Femto 29	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
LTE Femto 30	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
LTE Femto 31	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
LTE Femto 32	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
LTE Femto 33	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
LTE Femto 34	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
LTE Femto 35	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
LTE Femto 36	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
LTE Femto 37	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)

Table C2
Number of vehicles that start from each WiMAX network and their corresponding velocities.

Network	Number of vehicles (%)	Normal velocity	Medium velocity	High velocity
WiMAX Macro 1	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Macro 2	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Macro 3	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Macro 4	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Macro 5	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Macro 6	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Macro 7	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Macro 8	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Macro 9	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Macro 10	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Macro 11	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Macro 12	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Macro 13	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Macro 14	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Macro 15	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Macro 16	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Macro 17	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 1	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 2	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 3	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 4	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 5	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 6	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 7	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 8	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 9	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 10	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 11	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 12	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 13	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 14	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 15	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 16	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 17	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 18	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 19	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 20	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 21	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 22	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 23	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 24	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WiMAX Femto 25	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)

Table C3
Number of vehicles that start from each WAVE network and their corresponding velocities.

Network	Number of vehicles (%)	Normal velocity	Medium velocity	High velocity
WAVE 1	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WAVE 2	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WAVE 3	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WAVE 4	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WAVE 5	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WAVE 6	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WAVE 7	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WAVE 8	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WAVE 9	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WAVE 10	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WAVE 11	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WAVE 12	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WAVE 13	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WAVE 14	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WAVE 15	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WAVE 16	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WAVE 17	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WAVE 18	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WAVE 19	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WAVE 20	329 (0,82648%)	111 (0,27884%)	110 (0,27633%)	108 (0,27130%)
WAVE 21	328 (0,82397%)	111 (0,27884%)	109 (0,27382%)	108 (0,27130%)
WAVE 22	328 (0,82397%)	111 (0,27884%)	109 (0,27382%)	108 (0,27130%)

Table C4
Vehicles count per service and SLA.

Services	SLA 1 vehicles (%)	SLA 2 vehicles (%)	SLA 3 vehicles (%)	SLA 4 vehicles (%)	Sum
NAV	322 (0,808902%)	–	–	–	322 (0,808902%)
VoIP	321 (0,806390%)	–	–	–	321 (0,806390%)
CV	321 (0,806390%)	1422 (3,572236%)	–	–	1743 (4,378626%)
BS	321 (0,806390%)	1422 (3,572236%)	3318 (8,335217%)	–	5061 (12,71384%)
WB	321 (0,806390%)	1422 (3,572236%)	3317 (8,332705%)	9951 (24,99811%)	15011 (37,70944%)
NAV, VoIP	321 (0,806390%)	–	–	–	321 (0,806390%)
NAV, CV	321 (0,806390%)	–	–	–	321 (0,806390%)
NAV, BS	321 (0,806390%)	–	–	–	321 (0,806390%)
NAV, WB	321 (0,806390%)	–	–	–	321 (0,806390%)
VoIP, CV	321 (0,806390%)	–	–	–	321 (0,806390%)
VoIP, BS	321 (0,806390%)	–	–	–	321 (0,806390%)
VoIP, WB	321 (0,806390%)	–	–	–	321 (0,806390%)
CV, BS	321 (0,806390%)	1422 (3,572236%)	–	–	1743 (4,378626%)
CV, WB	321 (0,806390%)	1422 (3,572236%)	–	–	1743 (4,378626%)
BS, WB	321 (0,806390%)	1421 (3,569723%)	3317 (8,332705%)	–	5059 (12,7088%)
NAV, VoIP, CV	321 (0,806390%)	–	–	–	321 (0,806390%)
NAV, VoIP, BS	321 (0,806390%)	–	–	–	321 (0,806390%)
NAV, VoIP, WB	321 (0,806390%)	–	–	–	321 (0,806390%)
NAV, CV, BS	321 (0,806390%)	–	–	–	321 (0,806390%)
NAV, CV, WB	321 (0,806390%)	–	–	–	321 (0,806390%)
NAV, BS, WB	321 (0,806390%)	–	–	–	321 (0,806390%)
VoIP, CV, BS	321 (0,806390%)	–	–	–	321 (0,806390%)
VoIP, CV, WB	321 (0,806390%)	–	–	–	321 (0,806390%)
VoIP, BS, WB	321 (0,806390%)	–	–	–	321 (0,806390%)
CV, BS, WB	321 (0,806390%)	1421 (3,569723%)	–	–	1742 (4,376114%)
NAV, VoIP, CV, BS	321 (0,806390%)	–	–	–	321 (0,806390%)
NAV, VoIP, CV, WB	321 (0,806390%)	–	–	–	321 (0,806390%)
NAV, VoIP, BS, WB	321 (0,806390%)	–	–	–	321 (0,806390%)
NAV, CV, BS, WB	321 (0,806390%)	–	–	–	321 (0,806390%)
VoIP, CV, BS, WB	321 (0,806390%)	–	–	–	321 (0,806390%)
NAV, VoIP, CV, BS, WB	321 (0,806390%)	–	–	–	321 (0,806390%)
Sum:	9952 (25,00062%)	9952 (25,00062%)	9952 (25,00062%)	9951 (24,99811%)	39807 (100%)

References

[1] R. Vilalta, V. Lopez, A. Giorgetti, S. Peng, V. Orsini, L. Velasco, R. Serral-Gracia, D. Morris, S. De Fina, F. Cugini, et al., TelCofog: a unified flexible fog and cloud computing architecture for 5G networks, IEEE Commun. Mag. 55 (2017) 36–43.

[2] A. Fahmin, Y.-C. Lai, M.S. Hossain, Y.-D. Lin, Performance modeling and comparison of NFV integrated with SDN: under or aside? J. Netw. Comput. Appl. 113 (2018) 119–129, Elsevier.

[3] F.Z. Yousaf, M. Bredel, S. Schaller, F. Schneider, NFV and SDN-key technology enablers for 5G networks, IEEE J. Sel. Areas Commun. (2017).

[4] C.-M. Huang, M.-S. Chiang, D.-T. Dao, H.-M. Pai, S. Xu, H. Zhou, Vehicle-to-Infrastructure (V2I) offloading from cellular network to 802.11p Wi-Fi network based on the Software-Defined Network (SDN) architecture, Veh. Commun. 9 (2017) 288–300.

[5] F. Malandrino, C.-F. Chiasserini, S. Kirkpatrick, The impact of vehicular traffic demand on 5G caching architectures: a data-driven study, Veh. Commun. 8 (2017) 13–20, Internet of Vehicles.

[6] T. Bilen, B. Canberk, K.R. Chowdhury, Handover management in software-defined ultra-dense 5G networks, IEEE Netw. 31 (2017) 49–55.

[7] H. Wang, S. Chen, M. Ai, H. Xu, Localized mobility management for 5G ultra dense network, IEEE Trans. Veh. Technol. 66 (2017) 8535–8552.

[8] D. Calabuig, S. Barmpounakis, S. Gimenez, A. Kousaridas, T.R. Lakshmana, J. Lorca, P. Lunden, Z. Ren, P. Sroka, E. Ternon, et al., Resource and mobility management in the network layer of 5G cellular ultra-dense networks, IEEE Commun. Mag. 55 (2017) 162–169.

[9] TS 36.213 version 14.2.0: Evolved Universal Terrestrial Radio Access Network (E-UTRAN) (Release 14), Technical Specification, 3GPP, 2017.

[10] P802.16/d4—IEEE Draft Standard for Air Interface for Broadband Wireless Access Systems (revision of IEEE Std 802.16-2012). IEEE Standard, 2017.

[11] 1609.12-2016—IEEE Standard for Wireless Access in Vehicular Environments (WAVE)—Networking Services, IEEE Standard, 2016.

[12] P. Hu, S. Dhelim, H. Ning, T. Qiu, Survey on fog computing: architecture, key technologies, applications and open issues, J. Netw. Comput. Appl. 98 (2017) 27–42, Elsevier.

[13] K. Zhang, Y. Mao, S. Leng, Y. He, Y. Zhang, Mobile-edge computing for vehicular networks: a promising network paradigm with predictive off-loading, IEEE Veh. Technol. Mag. 12 (2017) 36–44.

[14] B. Yang, W.K. Chai, Z. Xu, K.V. Katsaros, G. Pavlou, Cost-efficient NFV-enabled mobile edge-cloud for low latency mobile applications, IEEE Trans. Netw. Serv. Manag. (2018).

[15] X. Huang, R. Yu, J. Kang, Y. He, Y. Zhang, Exploring mobile edge computing for 5G-enabled software defined vehicular networks, IEEE Wirel. Commun. 24 (2017) 55–63.

[16] M. Sookhak, F.R. Yu, Y. He, H. Talebian, N.S. Safa, N. Zhao, M.K. Khan, N. Kumar, Fog vehicular computing: augmentation of fog computing using vehicular cloud computing, IEEE Veh. Technol. Mag. 12 (2017) 55–64.

[17] C. Huang, R. Lu, K.-K.R. Choo, Vehicular fog computing: architecture, use case, and security and forensic challenges, IEEE Commun. Mag. 55 (2017) 105–111.

[18] A. Michalas, A. Sgora, D.D. Vergados, An integrated MIH-FPMIPv6 mobility management approach for evolved-packet system architectures, J. Netw. Comput. Appl. 91 (2017) 104–119, Elsevier.

[19] T. Taleb, A. Ksentini, R. Jantti, “Anything as a service” for 5G mobile systems, IEEE Netw. 30 (2016) 84–91.

[20] R.I. Rony, A. Jain, E. Lopez-Aguilera, E. Garcia-Villegas, I. Demirkol, Joint access-backhaul perspective on mobility management in 5G networks, in: Standards for Communications and Networking (CSCN), 2017 IEEE Conference on, IEEE, 2017, pp. 115–120.

[21] A. Jain, E. Lopez-Aguilera, I. Demirkol, Mobility management as a service for 5G networks, arXiv preprint, arXiv:1705.09101, 2017.

[22] L. Zhang, L. Ge, X. Su, J. Zeng, Fuzzy logic based vertical handover algorithm for trunking system, in: Wireless and Optical Communication Conference (WOCC), 2017 26th, IEEE, 2017, pp. 1–5.

[23] A.B. Zineb, M. Ayadi, S. Tabbane, Fuzzy MADM based vertical handover algorithm for enhancing network performances, in: Software, Telecommunications and Computer Networks (SoftCOM), 2015 23rd International Conference on, IEEE, 2015, pp. 153–159.

[24] S.D. Roy, S.R.V. Reddy, Signal strength ratio based vertical handoff decision algorithms in integrated heterogeneous networks, Wirel. Pers. Commun. 77 (2014) 2565–2585.

[25] S.D. Roy, S. Anup, Received signal strength based vertical handoff algorithm in 3G cellular network, in: Signal Processing, Communication and Computing (ICSPCC), 2012 IEEE International Conference on, IEEE, 2012, pp. 326–330.

[26] E. Skondras, A. Michalas, A. Sgora, D.D. Vergados, A vertical handover management scheme for VANET cloud computing systems, in: Computers and Communications (ISCC), 2017 IEEE Symposium on, IEEE, 2017, pp. 1–6.

[27] D.B. Mohd, I. Muhammad, et al., IEEE 802.21 based vertical handover in WiFi and WiMAX networks, in: Computers & Informatics (ISCI), 2012 IEEE Symposium on, IEEE, 2012, pp. 140–144.

[28] F. Guidolin, I. Pappalardo, A. Zanella, M. Zorzi, Context-aware handover policies in HetNets, IEEE Trans. Wirel. Commun. 15 (2016) 1895–1906.

[29] A. Sarma, S. Chakraborty, S. Nandi, Deciding handover points based on context-aware load balancing in a WiFi–WiMAX heterogeneous network environment, IEEE Trans. Veh. Technol. 65 (2016) 348–357.

[30] M. Lahby, C. Leghris, A. Adib, New multi access selection method based on mahalanobis distance, Appl. Math. Sci. 6 (2012) 2745–2760.

[31] Lahby, et al., New Multi Access Selection Method Using Differentiated Weight of Access Interface, IEEE, 2012, pp. 237–242.

[32] V. Gupta, Network selection in 3G-WLAN interworking environment using TOPSIS, in: Industrial and Information Systems (ICIIS), 2016 11th International Conference on, IEEE, 2016, pp. 512–517.

[33] N.S. Fitriasari, S.A. Fitriani, R.A. Sukamto, Comparison of weighted product method and technique for order preference by similarity to ideal solution method: complexity and accuracy, in: Science in Information Technology (ICSITech), 2017 3rd International Conference on, IEEE, 2017, pp. 453–458.

[34] X. Wang, D. Qu, K. Li, H. Cheng, S.K. Das, M. Huang, R. Wang, S. Chen, A flexible and generalized framework for access network selection in heterogeneous wireless networks, Pervasive Mob. Comput. 40 (2017) 556–576.

[35] Q. Wu, W. Li, R. Wang, P. Yu, An access network selection mechanism for heterogeneous wireless environments, J. Comput. Inf. Syst. 9 (2013) 1799–1807.

[36] H. Wang, Z. Wang, G. Feng, H. Lv, X. Chen, Q. Zhu, Intelligent access selection in cognitive networks: a fuzzy neural network approach, J. Comput. Inf. Syst. 8 (2012) 8877–8884.

[37] R.K. Goyal, S. Kaushal, A.K. Sangaiah, The utility based non-linear fuzzy AHP optimization model for network selection in heterogeneous wireless networks, Appl. Soft Comput. 67 (2018) 800–811.

[38] D.E. Charilas, O.I. Markaki, J. Psarras, P. Constantinou, Application of fuzzy AHP and ELECTRE to network selection, in: Mobile Lightweight Wireless Systems, Springer, 2009, pp. 63–73.

[39] M.B. Brahim, Z.H. Mir, W. Znaidi, F. Filali, N. Hamdi, QoS-aware video transmission over hybrid wireless network for connected vehicles, IEEE Access 5 (2017) 8313–8323.

[40] A. Merwaday, I. Güvenç, Handover count based velocity estimation and mobility state detection in dense HetNets, IEEE Trans. Wirel. Commun. 15 (2016) 4673–4688.

[41] R. Arshad, H. ElSawy, S. Sorour, T.Y. Al-Naffouri, M.-S. Alouini, Velocity-aware handover management in two-tier cellular networks, IEEE Trans. Wirel. Commun. 16 (2017) 1851–1867.

[42] L.A. Zadeh, Fuzzy sets, Inf. Control 8 (1965) 338–353, Elsevier.

[43] R. Sambuc, Fonctions and floues: application a l'aide au diagnostic en pathologie thyroidienne, Faculté de Médecine de Marseille, 1975.

[44] P. Liu, F. Jin, A multi-attribute group decision-making method based on weighted geometric aggregation operators of interval-valued trapezoidal fuzzy numbers, Appl. Math. Model. 36 (2012) 2498–2509, Elsevier.

[45] C. Cornelis, G. Deschrijver, E. Kerre, Advances and challenges in interval-valued fuzzy logic, Fuzzy Sets Syst. 157 (2006) 622–627, Elsevier.

[46] B. Ashtiani, F. Haghighirad, A. Makui, et al., Extension of fuzzy TOPSIS method based on interval-valued fuzzy sets, Appl. Soft Comput. 9 (2009) 457–461, Elsevier.

[47] A. Panda, M. Pal, A study on pentagonal fuzzy number and its corresponding matrices, Pac. Sci. Rev. B, Humanit. Soc. Sci. 1 (2015) 131–139, Elsevier.

[48] M.-S. Chen, S.-W. Wang, Fuzzy clustering analysis for optimizing fuzzy membership functions, Fuzzy Sets Syst. 103 (1999) 239–254, Elsevier.

[49] M.E. Cintra, H.A. Camargo, M.C. Monard, Genetic generation of fuzzy systems with rule extraction using formal concept analysis, Inf. Sci. 349 (2016) 199–215, Elsevier.

[50] T.L. Saaty, Decision Making with Dependence and Feedback: The Analytic Network Process, RWS Publications, Pittsburgh, 1996.

[51] T. Wu, X.-W. Liu, S.-L. Liu, A fuzzy ANP with interval type-2 fuzzy sets approach to evaluate enterprise technological innovation ability, in: Fuzzy Systems (FUZZ-IEEE), 2015 IEEE International Conference on, IEEE, 2015, pp. 1–8.

[52] T.L. Saaty, L.G. Vargas, Diagnosis with dependent symptoms: Bayes theorem and the analytic hierarchy process, Oper. Res. 46 (1998) 491–502, Informs.

[53] J.-S. Lee, C.-L. Teng, An enhanced hierarchical clustering approach for mobile sensor networks using fuzzy inference systems, IEEE Int. Things J. 4 (2017) 1095–1103.

[54] J. Andreu-Perez, F. Cao, H. Hagras, G.-Z. Yang, A self-adaptive online brain machine interface of a humanoid robot through a general type-2 fuzzy inference system, IEEE Trans. Fuzzy Syst. 26 (2018) 101–116.

[55] C. Li, J. Gao, J. Yi, G. Zhang, Analysis and design of functionally weighted single-input-rule-modules connected fuzzy inference systems, IEEE Trans. Fuzzy Syst. 26 (2018) 56–71.

[56] C.-L. Hwang, K. Yoon, Multiple Attribute Decision Making, Springer, 1981.

[57] TS 36.839 version 11.1.0: mobility enhancements in heterogeneous networks (Release 11), Technical Specification, 3GPP, 2012.

[58] J.-W. Lee, S.-J. Yoo, Probabilistic path and data capacity based handover decision for hierarchical macro-and femtocell networks, Mob. Inf. Syst. 2016 (2016).

[59] Open Street Map (OSM), https://www.openstreetmap.org, 2018 (Accessed 2018).

[60] M. Behrisch, L. Bieker, J. Erdmann, D. Krajzewicz, SUMO–Simulation of Urban MObility: an overview, in: Proceedings of SIMUL 2011, the Third International Conference on Advances in System Simulation, ThinkMind, 2011.

[61] Network simulator 3 (NS3) https://www.nsnam.org/, 2018 (Accessed 2018).

[62] Hellenic Telecommunications and Post Commission (EETT), http://keraies.eett.gr/, 2018 (Accessed 2018).

[63] J. Riordan, Introduction to Combinatorial Analysis, Courier Corporation, 2012.