A Network Selection Scheme with Adaptive Criteria Weights for 5G Vehicular Systems

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***Abstract*—Fifth Generation Vehicular Cloud Computing (5G-VCC) systems use heterogeneous network access technologies to fulfill the requirements of modern vehicular services. Efficient network selection algorithms are required to satisfy the constraints of Driver Assistance (DA) services, Passengers Entertainment and Information (PEnI) services and Medical (MED) services that provided to vehicular users. The presence of MED services affects the importance of other services in situations where patients with immediate health status exist within the vehicle. This paper proposes a network selection scheme which considers the patient health status to adapt the importance of each service. The scheme consists of two Fuzzy Multi Attribute Decision Making (FMADM) algorithms: the Trapezoidal Fuzzy Adaptive Analytic Network Process (TF-AANP) to calculate the relative importance of each vehicular service and the selection criteria, as well as the Trapezoidal Fuzzy Topsis with Adaptive Criteria Weights (TFT-ACW) to accomplish the ranking of the candidate networks. Both algorithms use Interval-Valued Trapezoidal Fuzzy Numbers (IVTFN). Performance evaluation shows that the suggested method outperforms existing algorithms by satisfying the constraints of MED services when the patient health status becomes immediate.**

I. Introduction

In a typical 5G-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 a Cloud infrastructure through the available Access Networks. The Cloud infrastructure offers vehicular services, including Driver Assistance (DA) services, Passengers Entertainment and Information (PEnI) services, as well as Medical (MED) services with strict Quality of Service (QoS) requirements. Indicatively, DA services include Navigation Assistance (NAV) [1] and Parking Assistance (PRK) [2] services. Accordingly, PEnI services include Conversational Video (CV) [3], Voice over IP (VoIP) [4], Buffered Streaming (BS) [5] and Web Browsing (WB) [6] services. Finally, MED services include Live Healthcare Video (LHVideo) [7], Medical Images (MedImages) [8], Health Monitoring (HMonitoring) [9] and Clinical Data Transmission (CData) [10] services.

The presence of MED services raises questions about the importance of other services in situations where there are patients with immediate health status within the vehicle. Thus, the importance of each service, along with the patient's health status must be considered during the network selection.

Several Fuzzy Multiple Attribute Decision Making (FMADM) methods have been proposed for network selection. FMADM methods utilize 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) [11], the Fuzzy AHP - SAW (FAS) [11], the Fuzzy SAW (FSAW) [12], the Fuzzy AHP MEW (FAM) [11] and the Fuzzy AHP - ELECTRE (FAE) [13]. However, the existing algorithms consider only the selection criteria weights for each service, while they don't take into consideration the relative importance between the services. Thus, in such cases, the services obtain equal importance with each other, which occurs to inappropriate network selections where MED services are provided to passengers with immediate health status, along with DA or PEnI services. In such cases, MED services must obtain higher importance than the other services during the network selection process, in order the most appropriate network to be selected for satisfying their strict constraints. In this paper, an improved version of the Trapezoidal Fuzzy Topsis (TFT) [14] method is proposed. The scheme consists of two FMADM algorithms, namely the Trapezoidal Fuzzy Adaptive Analytic Network Process (TF-AANP) to calculate the relative importance of the vehicular services and the selection criteria, as well as the Trapezoidal Fuzzy Topsis with Adaptive Criteria Weights (TFT-ACW) to accomplish the ranking of the candidate networks.

The remainder of the paper is as follows: Section II describes the proposed scheme, while Section III presents the simulation setup and the evaluation results. Finally, section IV concludes the discussed work.

II. The Proposed Network Selection Scheme

The proposed method consists of two MADM algorithms: the Trapezoidal Fuzzy Adaptive Analytic Network Process (TF-AANP) to calculate the relative importance of the services and of the selection criteria, as well as the Trapezoidal Fuzzy Topsis with Adaptive Criteria Weights (TFT-ACW) to accomplish the ranking of the candidate networks. Interval-Valued Trapezoidal Fuzzy Numbers (IVTFN) [15] are used for the representation of both criteria values and their importance weights.

An Interval-Valued Fuzzy Number (IVFN) introduced by Sambuc [16] is defined as $\tilde{a} = [\tilde{a}^L, \tilde{a}^U]$ consisting of the lower $\tilde{a}^L$ and the upper $\tilde{a}^U$ 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. In particular, the IVTFN, is the most general form of fuzzy number and can be represented as: $\tilde{a} = [\tilde{a}^L, \tilde{a}^U] = [(a_1^L, a_2^L, a_3^L, a_4^L, v^L), (a_1^U, a_2^U, a_3^U, a_4^U, v^U))]$ where: $0 \leq a_1^L \leq a_2^L \leq a_3^L \leq a_4^L \leq 1$, $0 \leq a_1^U \leq a_2^U \leq a_3^U \leq a_4^U \leq 1$, $0 \leq v^L \leq v^U \leq 1$ and $\tilde{a}^L \subset \tilde{a}^U$. The operational rules of the interval-valued trapezoidal fuzzy numbers are defined in [15].

TABLE I: The lingustic terms that used for criteria pairwise comparisons.

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

A. Trapezoidal Fuzzy Adaptive Analytic Network Process (TF-AANP)

A decision problem that is analyzed with the TF-AANP 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. The TF-AANP is composed of seven major steps:

a) Estimation of the importance of each service: The fuzzy pairwise comparison matrix $\tilde{P}$ is derived for the services using the linguistic terms presented in table I, which correspond to the nine-point importance scale introduced in [17]. The standard form of the $\tilde{P}$ matrix is expressed as follows:

$$\tilde{P} = \begin{bmatrix} 1 & \cdots & \tilde{p}_{1j} & \cdots & \tilde{p}_{1S} \\ \vdots & & \vdots & & \vdots \\ 1/\tilde{p}_{1s} & \cdots & 1 & \cdots & \tilde{p}_{sS} \\ \vdots & & \vdots & & \vdots \\ 1/\tilde{p}_{1S} & \cdots & 1/\tilde{p}_{jS} & \cdots & 1 \end{bmatrix} \quad (1)$$

while S denotes the number of the services. Subsequently, the geometric mean $r_{\tilde{P}_s}$ of each service (row) s in $\tilde{P}$ is estimated according to formula 2, where $\otimes$ denotes the multiplication operator of two fuzzy numbers as defined in [18].

$$r_{\tilde{P}_s} = (\tilde{p}_{s1} \otimes \tilde{p}_{s2} \otimes \dots \otimes \tilde{p}_{sS})^{\frac{1}{S}} \quad (2)$$

Then, the priority vector $\tilde{\Omega}_{\tilde{P}_s}$ of services is constructed as follows:

$$\tilde{\Omega}_{\tilde{P}_s} = [\ \tilde{\omega}_{\tilde{p}1} \quad \tilde{\omega}_{\tilde{p}2} \quad \dots \quad \tilde{\omega}_{\tilde{p}S}\ ] \quad (3)$$

where each $\tilde{\omega}_{\tilde{p}s} = \left[(\omega^U_{\tilde{p}1}, \omega^U_{\tilde{p}2}, \omega^U_{\tilde{p}3}, \omega^U_{\tilde{p}4}, v^U_{ps}); (\omega^L_{\tilde{p}1}, \omega^L_{\tilde{p}2}, \omega^L_{\tilde{p}3}, \omega^L_{\tilde{p}4}, v^L_{ps})\right]$ is calculated using formula 4. The $\oplus$ indicates the addition operator of two fuzzy numbers as defined in [18].

$$\tilde{\omega}_{\tilde{p}s} = r_{\tilde{P}_s} / (r_{\tilde{P}_1} \oplus r_{\tilde{P}_2} \oplus \dots \oplus r_{\tilde{P}_s} \oplus \dots \oplus r_{\tilde{P}_S}) \quad (4)$$

b) Model Construction and Problem Structuring for each service: During this step, for each $s \in S$ service the problem is analyzed and decomposed into a rational system, consisted of a network of nodes.

c) Pairwise comparison matrices and priority vectors: In this step, for each $s \in S$ service, the fuzzy pairwise comparison matrix $\tilde{A}_s$ is derived for each TF-AANP cluster using the linguistic terms presented in table I. The standard form of the $\tilde{A}$ matrix is expressed as follows:

$$\tilde{A_s} = \begin{bmatrix} 1 & \cdots & \tilde{a}_{s1j} & \cdots & \tilde{a}_{s1n} \\ \vdots & & \vdots & & \vdots \\ 1/\tilde{a}_{s1i} & \cdots & 1 & \cdots & \tilde{a}_{sin} \\ \vdots & & \vdots & & \vdots \\ 1/\tilde{a}_{1sn} & \cdots & 1/\tilde{a}_{sjn} & \cdots & 1 \end{bmatrix} \quad (5)$$

while n denotes the number of the cluster elements. Subsequently, the geometric mean $r_{\tilde{A}_{si}}$ of each row i in $\tilde{A}_s$ is estimated according to formula 6.

$$r_{\tilde{A}_s i} = (\tilde{a}_{si1} \otimes \tilde{a}_{si2} \otimes \dots \otimes \tilde{a}_{sin})^{\frac{1}{n}} \quad (6)$$

Then, the priority vector $\tilde{\Omega}_{si}$ of cluster elements is constructed as follows:

$$\tilde{\Omega}_{si} = [\ \tilde{\omega}_{s1} \quad \tilde{\omega}_{s2} \quad \dots \quad \tilde{\omega}_{sn}\ ] \quad (7)$$

where each $\tilde{\omega}_s i = \left[(\omega^U_{s1}, \omega^U_{s2}, \omega^U_{s3}, \omega^U_{s4}, v^U_{si}); (\omega^L_{s1}, \omega^L_{s2}, \omega^L_{s3}, \omega^L_{s4}, v^L_{si})\right]$ is calculated using formula 8. The $\oplus$ indicates the addition operator of two fuzzy numbers as defined in [18].

$$\tilde{\omega}_s i = r_{\tilde{A}_{si}} / (r_{\tilde{A}_{s1}} \oplus r_{\tilde{A}_{s2}} \oplus \dots \oplus r_{\tilde{A}_{si}} \oplus \dots \oplus r_{\tilde{A}_{sn}}) \quad (8)$$

d) Construction of the Supermatrices: In this step, a fuzzy supermatrix $\tilde{W}_s$ of the TF-AANP model is constructed for each service representing the inner and outer dependencies of the TF-AANP network. It 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 $\tilde{\Omega}_s$ are grouped and placed in the appropriate positions in the supermatrix based on the flow of influence from one cluster to another, or from a cluster to itself, as in the loop. For example if we assume a TF-AANP network of q clusters, C_k with $k = [1, 2, , q]$ and each cluster has n_q

elements, denoted as $e_{k1}, e_{k2}, , e_{kn_k}$, then the supermatrix is expressed as:

$$\tilde{W_s} = \begin{array}{cc} & \begin{array}{ccccc} \begin{matrix} C_1 \\ e_{11} \cdots e_{1n_1} \end{matrix} & \cdots & \begin{matrix} C_k \\ e_{k1} \cdots e_{kn_k} \end{matrix} & \cdots & \begin{matrix} C_q \\ e_{q1} \cdots e_{qn_q} \end{matrix} \end{array} \\ \begin{matrix} C_1 & \begin{matrix} e_{11} \\ \vdots \\ e_{1n_1} \end{matrix} \\ \vdots & \\ C_k & \begin{matrix} e_{k1} \\ \vdots \\ e_{kn_k} \end{matrix} \\ \vdots & \\ C_q & \begin{matrix} e_{q1} \\ \vdots \\ e_{qn_q} \end{matrix} \end{matrix} & \begin{bmatrix} \tilde{W}_{s11} & \cdots & \tilde{W}_{s1j} & \cdots & \tilde{W}_{s1q} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \tilde{W}_{sk1} & \cdots & \tilde{W}_{skj} & \cdots & \tilde{W}_{skq} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \tilde{W}_{sq1} & \cdots & \tilde{W}_{sqj} & \cdots & \tilde{W}_{sqq} \end{bmatrix} \end{array} \tag{9}$$

e) Construction of the Weighted Supermatrices: During this step, the supermatrix of each service is transformed to a stochastic one,the Weighted Supermatrix $\tilde{W}'_s$ using formula 10.

$$\tilde{W}'_{s,k,j} = \tilde{W}_{s,k,j}/q \tag{10}$$

f) Calculation of the Limited Supermatrices: In this step, initially the deffuzified Weighted Supermatrix W_s of each service is estimated by applying the Weighted Average method. According to this method formula 11 is used, where the parameters v_s and d_s represent the height and the centroid of each $\tilde{W}'_{s,k,j}$ trapezoid respectively. Subsequently, each W_s is raised to limiting powers until all the entries converge. By this way the overall priorities are calculated, and thus the cumulative influence of each element on every other interacting element is obtained [19]. At this point, all the columns of each produced Limit Supermatrix L_s, are the same and their values show the importance of each element e of the TF-AANP network for the corresponding service s.

$$W_{s,k,j} = \frac{v_s^U \cdot d_s^U + v_s^L \cdot d_s^L}{d_s^U + d_s^L} \tag{11}$$

g) Estimation of the Criteria Weights: In this step, the weight w_e for each element e of the TF-AANP network is calculated using formula 12 where the importance $\tilde{\omega}_{\tilde{P}s}$ of each service s is considered.

$$w_e = \sum_{s=1}^{S} \tilde{\omega}_{\tilde{P},s} * L_{s,e} \tag{12}$$

B. Trapezoidal Fuzzy Topsis with Adaptive Criteria Weights (TFT-ACW)

The candidate networks are ranked using the TFT-ACW algorithm, which improves the TFT [14] by using the adaptive weights that estimated from the TF-AANP method. Thus, the imprortance of the opinion of each service (decision maker) is considered, since the opinions of some decision makers could have higher importance from the ones of other decision maker. In general, similar to TFT, the TFT-ACW method is based on the concept that the best alternative should have the shortest distance from the positive ideal solution and the longer distance from the negative ideal solution. Also, it assumes that the linguistic values of criteria attributes are represented by interval-valued trapezoidal fuzzy numbers. More specifically, suppose $AL = \{AL_1, AL_2, \ldots, AL_z\}$ is the set of possible alternatives, $CR = \{CR_1, CR_2, \ldots, CR_n\}$ is the set of criteria and $w_1, w_2, \ldots, w_n$ are the importance weights of the respective criteria obtained from the application of the TF-AANP algorithm. The steps of the method are as follows:

a) Construction of the decision matrix: Each $\tilde{g}_{ie}$ element of the $z \times n$ decision matrix $\tilde{D}$ is an IVTFN number expressing the performance of alternative i for criterion e. Thus

$$\tilde{D} = \begin{array}{c|ccc} & CR_1 & \cdots & CR_n \\ \hline AL_1 & \tilde{g}_{11} & \cdots & \tilde{g}_{1n} \\ \vdots & \vdots & \ddots & \vdots \\ AL_z & \tilde{g}_{z1} & \cdots & \tilde{g}_{zn} \end{array} \tag{13}$$

where $\tilde{g}_{ie} = \left[(g_{ie1}^L, g_{ie2}^L, g_{ie3}^L, g_{ie4}^L, v_{ie}^L), (g_{ie1}^U, g_{ie2}^U, g_{ie3}^U, g_{ie4}^U, v_{ie}^U)\right]$.

In the case that there are S services (decision makers) the decision matrix include the average of the performance values. Hence, assuming that for the s^{th} decision maker $\tilde{g}_{iex}$ is the performance of alternative i for criterion (element) e, the average of the performance values is given by formula 14.

$$\tilde{g}_{ie} = \sum_{s=1}^{S} (\tilde{g}_{ies} \cdot \tilde{\omega}_{\tilde{P}s}) \tag{14}$$

b) Normalization of the decision matrix: Consider that Γ_b is the set of benefits attributes and Γ_c is the set of costs attributes. Then, the elements of the normalized decision matrix are calculated using either formula 15 or 16, where $b_e = \max_i g_{ie4}^U$ for each $e \in \Gamma_b$ and $c_e = \min_i g_{ie4}^L$ for each $e \in \Gamma_c$.

$$\tilde{g}'_{ie} = \left[\left(\frac{g_{ie1}^L}{b_e}, \frac{g_{ie2}^L}{b_e}, \frac{g_{ie3}^L}{b_e}, \frac{g_{ie4}^L}{b_e}, v_{ie}^L\right), \left(\frac{g_{ie1}^U}{b_e}, \frac{g_{ie2}^U}{b_e}, \frac{g_{ie3}^U}{b_e}, \frac{g_{ie4}^U}{b_e}, v_{ie}^U\right)\right] \tag{15}$$

$$\tilde{g}'_{ie} = \left[\left(\frac{c_e}{g_{ie4}^L}, \frac{c_e}{g_{ie3}^L}, \frac{c_e}{g_{ie2}^L}, \frac{c_e}{g_{ie1}^L}, v_{ie}^L\right), \left(\frac{c_e}{g_{ie4}^U}, \frac{c_e}{g_{ie3}^U}, \frac{c_e}{g_{ie2}^U}, \frac{c_e}{g_{ie1}^U}, v_{ie}^U\right)\right] \tag{16}$$

c) Construction of the weighted normalized decision matrix: The weighted normalized decision matrix is constructed by multiplying each element of the normalized decision matrix $\tilde{g}'_{ie}$ with the respective weight w_e according to the formula 17.

$$\begin{aligned} \tilde{u}_{ie} = &\left[\left(g'^L_{ie1} \cdot w_e, g'^L_{ie2} \cdot w_e, g'^L_{ie3} \cdot w_e, g'^L_{ie4} \cdot w_e, v'^L_{ie}\right),\right. \\ &\left.\left(g'^U_{ie1} \cdot w_e, g'^U_{ie2} \cdot w_e, g'^U_{ie3} \cdot w_e, g'^U_{ie4} \cdot w_e, v^U_{ie}\right)\right] \end{aligned} \tag{17}$$

d) Determination of the positive and negative ideal solution: The positive ideal solution is defined in 18, where $\bigwedge_i \equiv \max_i$ in case $e \in \Gamma_b$ and $\bigwedge_i \equiv \min_i$ in case $e \in \Gamma_c$. Correspondingly, the negative ideal solution is defined in 19, where $\bigvee_i \equiv \min_i$ in case $e \in \Gamma_b$ and $\bigvee_i \equiv \max_i$ in case $e \in \Gamma_c$.

$$\begin{aligned} \tilde{G}^+ &= \left[\left(g_{ie1}^{+L}, g_{ie2}^{+L}, g_{ie3}^{+L}, g_{ie4}^{+L}, v_{ie}^{+L}\right), \left(g_{ie1}^{+U}, g_{ie2}^{+U}, g_{ie3}^{+U}, g_{ie4}^{+U}, v_{ie}^{+U}\right)\right] \\ &= \left[\left(\bigwedge_i u_{ie1}^L, \bigwedge_i u_{ie2}^L, \bigwedge_i u_{ie3}^L, \bigwedge_i u_{ie4}^L, v_{ie}^L\right),\right. \\ &\quad \left.\left(\bigwedge_i u_{ie1}^U, \bigwedge_i u_{ie2}^U, \bigwedge_i u_{ie3}^U, \bigwedge_i u_{ie4}^U, v_{ie}^U\right)\right] \end{aligned} \tag{18}$$

$$\begin{aligned} \tilde{G}^- &= \left[\left(g_{ie1}^{-L}, g_{ie2}^{-L}, g_{ie3}^{-L}, g_{ie4}^{-L}, v_{ie}^{-L}\right), \left(g_{ie1}^{-U}, g_{ie2}^{-U}, g_{ie3}^{-U}, g_{ie4}^{-U}, v_{ie}^{-U}\right)\right] \\ &= \left[\left(\bigvee_i u_{ie1}^L, \bigvee_i u_{ie2}^L, \bigvee_i u_{ie3}^L, \bigvee_i u_{ie4}^L, v_{ie}^L\right),\right. \\ &\quad \left.\left(\bigvee_i u_{ie1}^U, \bigvee_i u_{ie2}^U, \bigvee_i u_{ie3}^U, \bigvee_i u_{ie4}^U, v_{ie}^U\right)\right] \end{aligned} \tag{19}$$

e) Measurement of the distance of each alternative from the ideal solutions: The distances of each alternative from the positive ideal solution are evaluated using formulas 20 and 21. Likewise the distances of each alternative from the negative ideal solution are estimated using formulas 22 and 23.

$$p_{i1}^{+} = \sum_{e=1}^{n} \left\{ \frac{1}{4} \left[\left(u_{ie1}^{L} - g_{ie1}^{+L} \right)^2 + \left(u_{ie2}^{L} - g_{ie2}^{+L} \right)^2 + \left(u_{ie3}^{L} - g_{ie3}^{+L} \right)^2 + \left(u_{ie4}^{L} - g_{ie4}^{+L} \right)^2 \right] \right\}^{\frac{1}{2}} \tag{20}$$

$$p_{i2}^{+} = \sum_{e=1}^{n} \left\{ \frac{1}{4} \left[\left(u_{ie1}^{U} - g_{ie1}^{+U} \right)^2 + \left(u_{ie2}^{U} - g_{ie2}^{+U} \right)^2 + \left(u_{ie3}^{U} - g_{ie3}^{+U} \right)^2 + \left(u_{ie4}^{U} - g_{ie4}^{+U} \right)^2 \right] \right\}^{\frac{1}{2}} \tag{21}$$

$$p_{i1}^{-} = \sum_{e=1}^{n} \left\{ \frac{1}{4} \left[\left(u_{ie1}^{L} - g_{ie1}^{-L} \right)^2 + \left(u_{ie2}^{L} - g_{ie2}^{-L} \right)^2 + \left(u_{ie3}^{L} - g_{ie3}^{-L} \right)^2 + \left(u_{ie4}^{L} - g_{ie4}^{-L} \right)^2 \right] \right\}^{\frac{1}{2}} \tag{22}$$

$$p_{i2}^{-} = \sum_{e=1}^{n} \left\{ \frac{1}{4} \left[\left(u_{ie1}^{U} - g_{ie1}^{-U} \right)^2 + \left(u_{ie2}^{U} - g_{ie2}^{-U} \right)^2 + \left(u_{ie3}^{U} - g_{ie3}^{-U} \right)^2 + \left(u_{ie4}^{U} - g_{ie4}^{-U} \right)^2 \right] \right\}^{\frac{1}{2}} \tag{23}$$

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

f) Calculation of the relative closeness: The relative closeness of the distances from the ideal solutions are calculated using formula 24 and 25. Subsequently, the compound relative closeness is obtained using formula 26.

$$RC_{i1} = \frac{p_{i1}^{-}}{p_{i1}^{+} + p_{i1}^{-}} \tag{24}$$

$$RC_{i2} = \frac{p_{i2}^{-}}{p_{i2}^{+} + p_{i2}^{-}} \tag{25}$$

$$RC_{i} = \frac{RC_{i1} + RC_{i2}}{2} \tag{26}$$

g) Alternatives ranking: The alternative networks are ranked according to their RC_i values, while the best alternative is that with the higher RC_i value.

III. Simulation Setup and Results

In our experiments, the 5G-VCC topology presented in figure 1 is simulated. A mobility trace indicating the map of the Syntagma square in Athens along with road traffic data has been created using the Open Street Map (OSM) software [20]. Then, the mobility trace has been used as input in the Simulator of Urban Mobility (SUMO) simulator [21] allowing the production of a realistic mobility pattern for the simulated vehicles. Furthermore, the network topology is being built upon the map, using the Network Simulator 3 (NS3) simulator [22]. It includes a heterogeneous access network environment and a Cloud infrastructure. The access network environment includes 1 LTE Macrocell, 4 LTE Femtocells, 1 WiMAX Macrocell and 4 WAVE RSUs. Additionally, the Cloud infrastructure includes a set of Virtual Machines (VMs) providing Driver Assistance (DA), Passengers Entertainment and Information (PeNI) and Medical (MED) services. DA services include Navigation Assistance (NAV) and Parking Assistance (PRK) services. Accordingly, PEnI services include Conversational Video (CV), Voice over IP (VoIP), Buffered Streaming (BS) and Web Browsing (WB) services. Finally, MED services include Live Healthcare Video (LHVideo) [7], Medical Images (MedImages) [8], Health Monitoring (HMonitoring) [9] and Clinical Data Transmission (CData) [10] services. Furthermore, a Software Defined Network (SDN) controller provides centralized control of the entire system.

TABLE II: Linguistic terms and the corresponding interval-valued trapezoidal fuzzy numbers used for the criteria attributes.

Linguistic term	**Interval-valued trapezoidal fuzzy number**
Absolutely Poor (AP)	[(0.0, 0.0, 0.0, 0.0, 0.9), (0.0, 0.0, 0.0, 0.0, 1.0)]
Very Poor (VP)	[(0.01, 0.02, 0.03, 0.07, 0.9), (0.0, 0.01, 0.05, 0.08, 1.0)]
Poor (P)	[(0.04, 0.1, 0.18, 0.23, 0.9), (0.02, 0.08, 0.2, 0.25, 1.0)]
Medium Poor (MP)	[(0.17, 0.22, 0.36, 0.42, 0.9), (0.14, 0.18, 0.38, 0.45, 1.0)]
Medium (M)	[(0.32, 0.41, 0.58, 0.65, 0.9), (0.28, 0.38, 0.6, 0.7, 1.0)]
Medium Good (MG)	[(0.58, 0.63, 0.8, 0.86, 0.9), (0.5, 0.6, 0.9, 0.92, 1.0)]
Good (G)	[(0.72, 0.78, 0.92, 0.97, 0.9), (0.7, 0.75, 0.95, 0.98, 1.0)]
Very Good (VG)	[(0.93, 0.98, 1.0, 1.0, 0.9), (0.9, 0.95, 1.0, 1.0, 1.0)]
Absolutely Good (AG)	[(1.0, 1.0, 1.0, 1.0, 0.9), (1.0, 1.0, 1.0, 1.0, 1.0)]

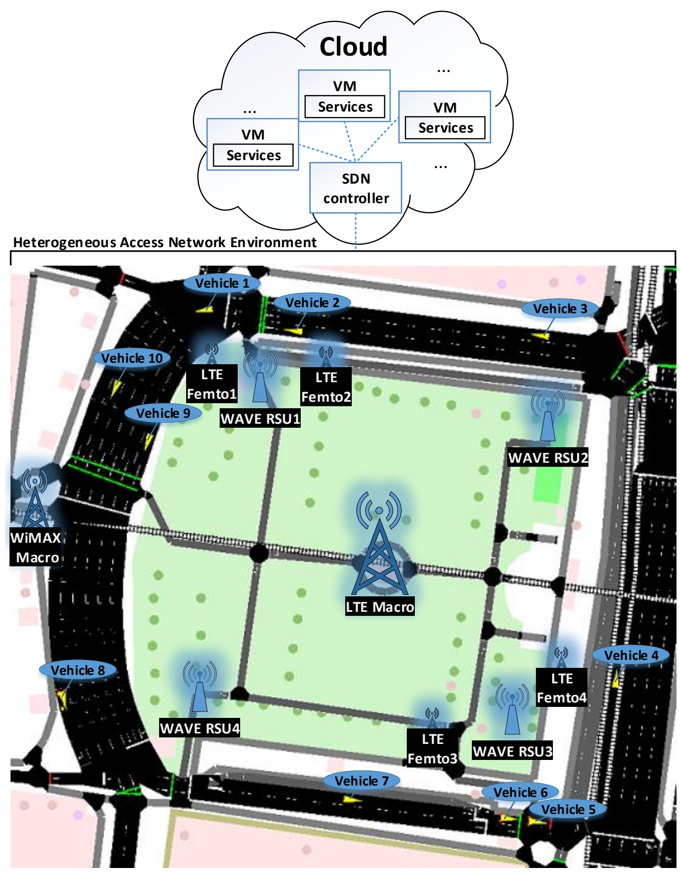

Fig. 1: The simulated topology.

Three Service Level Agreements (SLAs) are defined. Each SLA determines the available networks for each service type. SLA1 supports all the available networks while SLA3 supports the fewer networks.

Table II presents the lingustic terms and the corresponding interval-valued trapezoidal fuzzy numbers used for the criteria attributes of the available networks, while table III presents the corresponding specifications per service and SLA of each network, in terms of throughput, delay, jitter, packet loss ratio, price, security and service reliability. Service reliability

TABLE III: The available networks.

Service	SLA 1	SLA 2	SLA 3	Network	Through -put	Delay	Jitter	Packet Loss	Service Reliability	Security	Price
Navigation Assistance (NAV)	✓	✓	✓	LTE Macro	G	MG	VG	AG	VG	AG	VG
	✓	✓	✓	LTE Femto 1	VG	AG	VG	VG	AG	MG	P
	✓	✓		LTE Femto 2	AG	G	AG	G	VG	G	G
	✓			LTE Femto 3	G	MG	G	MG	G	AG	P
	✓			LTE Femto 4	AG	AG	MG	AG	G	G	AP
	✓	✓	✓	WiMAX Macro	G	AG	G	VG	AG	VG	VP
	✓	✓	✓	WAVE 1	VG	MG	VG	AG	VG	AG	G
	✓			WAVE 2	MG	MG	VG	VG	G	G	AP
	✓	✓	✓	WAVE 3	MG	MG	G	VG	MG	MG	M
	✓			WAVE 4	M	M	MG	VG	MG	MG	MP
Parking Assistance (PRK)	✓	✓	✓	LTE Macro	MG	M	G	VG	VG	AG	MP
	✓	✓	✓	LTE Femto 1	AG	AG	AG	AG	AG	VG	G
	✓	✓		LTE Femto 2	VG	AG	M	VG	AG	G	AG
	✓			LTE Femto 3	G	VG	MG	AG	VG	AG	MG
	✓			LTE Femto 4	MG	G	M	G	VG	G	G
	✓	✓	✓	WiMAX Macro	G	M	M	AG	MG	M	MP
	✓	✓	✓	WAVE 1	M	MP	MG	VG	G	G	VG
	✓			WAVE 2	MG	M	M	AG	M	M	M
	✓	✓	✓	WAVE 3	AG	G	G	AG	MG	MG	P
	✓			WAVE 4	G	M	AG	AG	MG	G	G
Conversation Video (CV)	✓	✓		LTE Macro	AG	AG	AG	VG	VG	AG	G
	✓	✓		LTE Femto 1	MP	MG	VG	AG	AG	VG	AP
	✓	✓		LTE Femto 2	G	G	MG	VG	AG	MG	M
	✓			LTE Femto 3	AG	VG	AG	G	VG	G	P
	✓			LTE Femto 4	G	VG	VG	AG	MG	AG	MG
	✓	✓		WiMAX Macro	MP	M	MG	G	G	G	MP
	✓	✓		WAVE 1	G	G	VG	VG	G	G	M
	✓			WAVE 2	MG	MG	AG	VG	G	MG	AG
	✓	✓		WAVE 3	MG	MG	G	AG	MG	VG	MP
	✓			WAVE 4	MP	MP	MG	AG	MG	G	P
Voice over IP (VoIP)	✓			LTE Macro	VG	VG	AG	AG	VG	AG	AP
	✓			LTE Femto 1	M	G	VG	VG	AG	VG	G
	✓			LTE Femto 2	G	VG	MG	AG	VG	G	MG
	✓			LTE Femto 3	MG	G	G	VG	G	MG	MP
	✓			LTE Femto 4	VG	AG	VG	AG	VG	VG	P
	✓			WiMAX Macro	M	G	MG	MG	G	G	M
	✓			WAVE 1	M	MG	AG	AG	G	G	VG
	✓			WAVE 2	MG	M	VG	AG	MG	M	M
	✓			WAVE 3	VG	AG	VG	AG	MG	VG	G
	✓			WAVE 4	G	VG	G	AG	MG	G	AG
Buffered Streaming (BS)	✓	✓		LTE Macro	G	MG	VG	AG	VG	AG	VG
	✓	✓		LTE Femto 1	VG	AG	AG	VG	AG	VG	P
	✓	✓		LTE Femto 2	AG	VG	VG	MG	MG	AG	G
	✓			LTE Femto 3	G	MG	VG	G	VG	G	M
	✓			LTE Femto 4	AG	AG	AG	VG	G	G	P
	✓	✓		WiMAX Macro	G	AG	G	VG	AG	VG	VP
	✓	✓		WAVE 1	VG	MG	VG	AG	VG	AG	G
	✓			WAVE 2	MG	MG	VG	VG	G	G	AP
	✓	✓		WAVE 3	MG	MG	G	VG	MG	MG	M
	✓			WAVE 4	M	M	MG	VG	MG	MG	MP
Web Browsing (WB)	✓	✓	✓	LTE Macro	MG	M	G	VG	VG	AG	MP
	✓	✓	✓	LTE Femto 1	AG	AG	AG	AG	AG	VG	G
	✓	✓		LTE Femto 2	G	G	M	G	G	VG	G
	✓			LTE Femto 3	AG	AG	MG	AG	VG	MG	M
	✓			LTE Femto 4	VG	G	G	VG	MG	G	MG
	✓	✓	✓	WiMAX Macro	G	VG	MG	G	M	VG	M
	✓	✓	✓	WAVE 1	M	MP	MG	VG	G	G	VG
	✓			WAVE 2	MG	M	M	AG	M	M	M
	✓	✓	✓	WAVE 3	AG	G	G	AG	MG	MG	AP
	✓			WAVE 4	G	M	AG	AG	MG	G	G
Live Healthcare Video (LHVideo)	✓	✓	✓	LTE Macro	MG	MG	G	VG	MG	VG	MP
	✓	✓	✓	LTE Femto 1	MP	MG	VG	AG	AG	VG	AP
	✓	✓		LTE Femto 2	G	VG	AG	AG	VG	G	G
	✓			LTE Femto 3	VG	AG	G	AG	G	MG	M
	✓			LTE Femto 4	MG	G	VG	G	AG	AG	G
	✓	✓	✓	WiMAX Macro	MP	M	MG	G	G	G	MP
	✓	✓	✓	WAVE 1	G	G	VG	VG	G	G	M
	✓			WAVE 2	MG	MG	AG	VG	G	MG	AG
	✓	✓	✓	WAVE 3	AG	AG	AG	AG	VG	AG	G
	✓			WAVE 4	MP	MP	MG	AG	MG	G	P
Medical Images (MedImages)	✓	✓	✓	LTE Macro	M	MG	AG	AG	G	AG	VG
	✓	✓	✓	LTE Femto 1	M	G	VG	VG	AG	VG	G
	✓	✓		LTE Femto 2	AG	AG	VG	AG	VG	AG	P
	✓			LTE Femto 3	VG	MG	G	MG	G	MG	MP
	✓			LTE Femto 4	G	G	VG	G	AG	G	MP
	✓	✓	✓	WiMAX Macro	M	G	MG	VG	G	G	M
	✓	✓	✓	WAVE 1	VG	VG	AG	AG	VG	AG	AP
	✓			WAVE 2	MG	M	VG	AG	MG	M	M
	✓	✓	✓	WAVE 3	VG	AG	VG	AG	MG	VG	G
	✓			WAVE 4	G	VG	G	AG	MG	G	MP
Health Monitoring (HMonitoring)	✓	✓	✓	LTE Macro	G	MG	VG	AG	VG	AG	VG
	✓	✓	✓	LTE Femto 1	VG	AG	AG	VG	AG	VG	P
	✓	✓		LTE Femto 2	AG	G	G	G	MG	G	VG
	✓			LTE Femto 3	VG	AG	MG	AG	MG	VG	G
	✓			LTE Femto 4	G	VG	VG	G	G	G	VG
	✓	✓	✓	WiMAX Macro	G	AG	G	VG	AG	VG	VP
	✓	✓	✓	WAVE 1	VG	MG	VG	AG	VG	AG	G
	✓			WAVE 2	MG	MG	VG	VG	G	G	AP
	✓	✓	✓	WAVE 3	MG	MG	G	VG	MG	MG	M
	✓			WAVE 4	M	M	MG	VG	MG	MG	MP
Clinical Data Transmission (CData)	✓	✓	✓	LTE Macro	MG	M	G	VG	VG	AG	MP
	✓	✓	✓	LTE Femto 1	AG	AG	AG	AG	AG	VG	P
	✓	✓		LTE Femto 2	AG	VG	MG	VG	VG	G	M
	✓			LTE Femto 3	G	AG	M	G	G	MG	M
	✓			LTE Femto 4	VG	G	G	AG	VG	AG	G
	✓	✓	✓	WiMAX Macro	G	MG	VG	G	VG	MG	AG
	✓	✓	✓	WAVE 1	M	MP	MG	VG	G	G	AG
	✓			WAVE 2	MG	M	M	AG	M	M	M
	✓	✓	✓	WAVE 3	AG	G	G	AG	MG	MG	P
	✓			WAVE 4	G	M	AG	AG	MG	G	G

TABLE IV: The simulated vehicles.

Vehicle	SLA	Vehicular Services	Patient Health Status
1	1	PRK, CV, BS, WB, LHVideo	Immediate
2	1	WB, MedImages, HMonitoring	Non-Urgent
3	1	NAV, VoIP, HMonitoring	Standard
4	1	NAV, WB, CData	Urgent
5	2	CV, LHVideo, MedImages	Non-Urgent
6	2	CV, WB, MedImages	Immediate
7	2	WB, HMonitoring	Very urgent
8	3	WB, MedImages, CData	Standard
9	3	NAV, HMonitoring, CData	Urgent
10	3	WB, MedImages, HMonitoring	Immediate

determines the ability for service constraints satisfaction and optimization of performance when a network is congested.

We consider the case where 10 vehicles with patients are moving inside the network environment and need to be connected to a network which satisfies the requirements of their services and at the same time comply with their patient health status, as well as with their respective SLA agreements. The health status of each patient is evaluated using the Manchester Triage System (MTS) [23] healthcare classification system, which defines 5 health statuses, called Non-Urgent, Standard, Urgent, Very-Urgent and Immediate. The Non-Urgent status has the lower risk about patient's life, while the Immediate status has the higher one.

During the network selection process initially the relative importance $\tilde{\omega}_{\tilde{p}s}$ of each service is considered with respect to the patient health status. Figure 2 presents the importance of each service per patient health status, as it is obtained using the TF-AANP method. As can be observed, the importance of MED services depends on the patient health status. Indicatively, when the patient health status becomes immediate, the MED services obtain higher importance than the DA and the PEnI services. Accordingly, when the patient health status becomes Non-Urgent, the relative importance of the services is quite similar. Subsequently, the TF-AANP estimates the decision weights w_e per service type and patient health status, considering the ANP network model proposed in [14]. The criteria weights per SLA for DA and PEnI services are presented in figures 3 and 4, respectively. Also, for each possible health status, the criteria weights per healthcare service for the MED services are presented in figure 5. As illustrated the weights are proportional to the constraints of each service as well as to the health status of each patient. In particular, the weight of the price criterion is low for Immediate health status, resulting in a weight value which is very close to 0. Accordingly, when the health status is evaluated as Non-Urgent, the medical risk for the patient is very low and the price criterion becomes more important.

Considering the relative importance $\tilde{\omega}_{\tilde{p}s}$ of each service and the criteria weights w_e for DA, PEnI and MED services, the final criteria weights are estimated for each vehicle with respect to the health status of onboard patients, as well as to the SLA of each vehicle (figure 6).

Ranking of the networks alternatives is performed from the TFT-ACW algorithm using the afforementioned criteria weights for each vehicle.

Subsequently, the experimental results of the TFT-ACW method are compared with the ones obtained from the TFT

TABLE V: Networks' classification in respect of TFT-ACW, TFT and FSAW results.

Networks \ Method	Vehicle 1 TFT-ACW	Vehicle 1 TFT	Vehicle 1 FSAW	Vehicle 2 TFT-ACW	Vehicle 2 TFT	Vehicle 2 FSAW	Vehicle 3 TFT-ACW	Vehicle 3 TFT	Vehicle 3 FSAW	Vehicle 4 TFT-ACW	Vehicle 4 TFT	Vehicle 4 FSAW	Vehicle 5 TFT-ACW	Vehicle 5 TFT	Vehicle 5 FSAW	Vehicle 6 TFT-ACW	Vehicle 6 TFT	Vehicle 6 FSAW	Vehicle 7 TFT-ACW	Vehicle 7 TFT	Vehicle 7 FSAW	Vehicle 8 TFT-ACW	Vehicle 8 TFT	Vehicle 8 FSAW	Vehicle 9 TFT-ACW	Vehicle 9 TFT	Vehicle 9 FSAW	Vehicle 10 TFT-ACW	Vehicle 10 TFT	Vehicle 10 FSAW
LTE Macro	4	3	3	2	2	2	**1**	**1**	**1**	2	2	**1**	2	2	**1**	2	**1**	**1**	**1**	2	2	**1**	**1**	2	2	3	4	3	2	3
LTE Femto 1	3	2	**1**	**1**	**1**	**1**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	**1**	**1**	2	**1**	**1**
LTE Femto 2	2	**1**	2	3	4	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LTE Femto 3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LTE Femto 4	-	-	-	-	-	-	-	-	-	**1**	4	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WiMAX Macro	7	7	8	6	7	7	3	3	2	4	5	3	4	4	4	4	4	4	3	3	3	3	3	3	4	2	3	4	5	5
WAVE 1	5	4	4	4	3	4	2	2	3	3	**1**	2	3	3	3	**1**	3	3	2	**1**	**1**	2	2	**1**	**1**	4	2	**1**	3	2
WAVE 2	6	6	7	8	8	8	5	5	5	6	7	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WAVE 3	**1**	5	5	5	5	6	4	4	4	7	6	6	**1**	**1**	2	3	2	2	4	4	4	4	4	4	5	5	5	5	4	4
WAVE 4	8	8	6	7	6	5	6	6	6	5	3	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

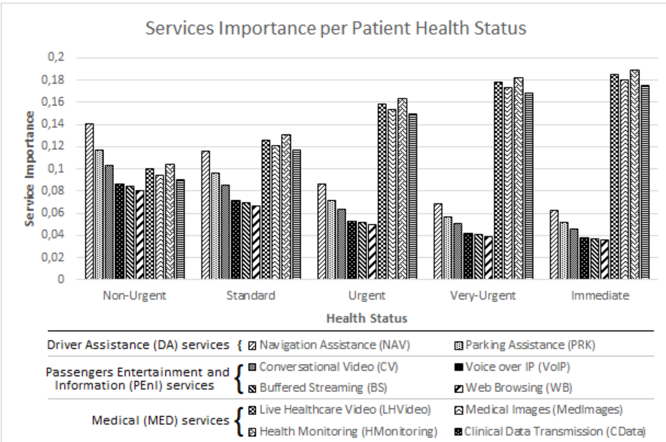

Fig. 2: The importance of each service per patient health status.

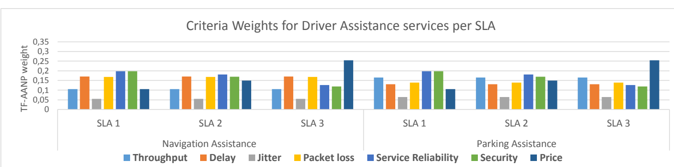

Fig. 3: The TF-AANP criteria weights for DA services per SLA.

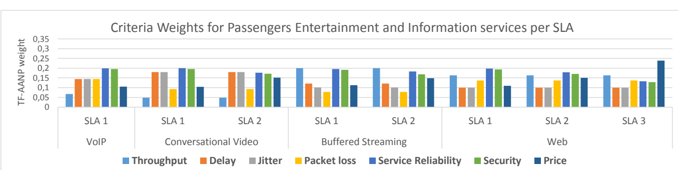

Fig. 4: The TF-AANP criteria weights for PeNI services per SLA.

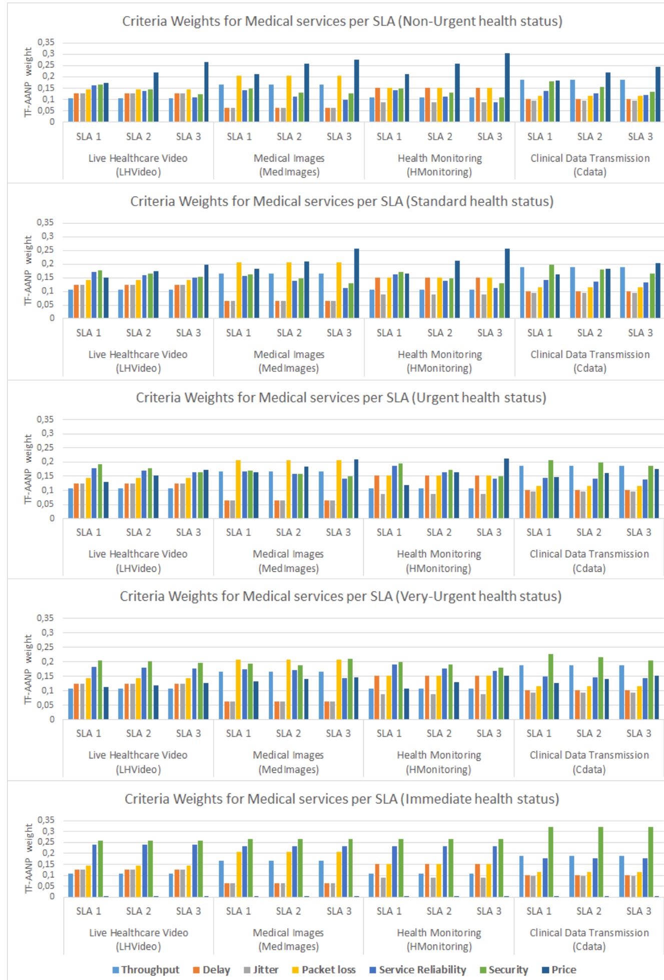

Fig. 5: The TF-AANP criteria weights for MED services per SLA and patient health status.

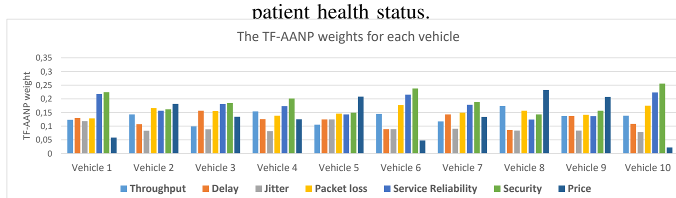

Fig. 6: The TF-AANP weights for each vehicle.

[14] and the FSAW [12] algorithms (Table V). When the patient health status is Non-Urgent (vehicles 2 and 5) or Standard (vehicles 3 and 8) the results of the TFT-ACW and the TFT are similar, due to the similar relative importance considered from the TFT-ACW for each service. However, when the patient health status gets worse, the TFT-ACW assigns higher importance to MED services and selects the most appropriate network to satisfy their strict constraints. Indicatively, in the case of vehicle 1, the TFT-ACW selects the WAVE 3 network, which provides VG for service reliability, as well as AG for throughput, delay, jitter, packet loss and security, for the LHVideo medical service. On the contrary, the results of both TFT and FSAW are negatively affected from the existence of non medical services in the vehicle 1 ignoring the immediate health status of the patient. Specifically, the TFT selects the LTE Femto 2 network, which provides worse specifications for the LHVideo service (e.g. G for throughput and VG for delay), while the FSAW selects the LTE Femto 1 network, which also provides worse specifications for the aforementioned medical service (e.g. MP for throughput and MG for delay).

IV. Conclusion

This paper proposes a network selection scheme for supporting modern vehicular services in 5G-VCC systems. The discussed scheme consists of two FMADM algorithms, namely the TF-AANP to calculate the relative importance of each service, as well as the weights of the selection criteria and the TFT-ACW to accomplish the ranking of the candidate networks. The health status of onboard patients and the SLA of each vehicle are considered, while the criteria used for network evaluation include throughput, delay, jitter, packet loss, service reliability, security and price. Performance evaluation showed that the proposed scheme outperforms existing network selection methods by satisfying the strict constraints of medical services, when the patient's health status becomes immediate and multiple types of non medical services coexist with medical services to the vehicle.

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