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***Abstract*—Traffic offloading in Long Term Evolution (LTE) networks is a key process in cellular networks so a mobile device chooses one of the available femtocells. In the last few years, several network selection methods have been proposed based on multiple attribute decision making (MADM) techniques for traffic offloading in LTE. The Analytic Network Process (ANP) is an MADM method that has been barely studied for network selection in cellular networks; ANP configures the decision making problem as a network of attributes in order to derive priority scales of individual judgments. We propose in this paper NetANPI (Network selection ANP-based mechanism with Ideal network comparison), which is an ANP decision making mechanism for traffic offloading in LTE. We show its effectiveness by contrasting it with MADM methods proposed in the literature as AHP, ELECTRE, TOPSIS, GRA, and SAW. We also introduce a mechanism to rank the MADM algorithm using utility theory. Our results show that NetANPI outperforms the most used MADM mechanism for the interactive and conversational traffic classes.**

Keywords – Traffic Offloading; MADM Mechanisms; LTE (Long Term Evolution)

I. Introduction

One of the most relevant goals of LTE cellular networks is to provide QoS (Quality of Service) to a large number of users, while at the same time offering a wide coverage. Such goal is difficult to achieve due to physical reasons in a cellular cell, since as the number of users grows the achievable throughput per user decreases. One of the most popular techniques to solve such problem is *traffic offloading* via femtocells, which consists in deriving traffic from a macrocell with a wide coverage range (hundreds of meters) to femtocells. In contrast, such femtocells have a reduced coverage range (tens of meters) but they can provide good QoS parameters to a small number of users.

In the near future, it is expected that the number of femtocells will considerably grow, which will naturally result in frequent coverage overlapping. As a consequence, it is of key importance to account with efficient handover mechanisms, also called *network selection* mechanisms, so the mobile device may choose one of the available femtocells. Multiple Attribute Decision Making (MADM) mechanisms have been widely used to solve the network selection problem. Such mechanisms allow to choose one of the available alternatives according to multiple, and perhaps, conflicting criteria as their input [1].

The Analytic Network Process (ANP) is an MADM mechanism that has been very little explored to solve the network selection problem. ANP allows to see the scenario as a network of attributes, where nodes may be an alternative, a criterion, a sub-criterion, or even groups of criteria. ANP compares each network node with the other nodes connected to it via a pairwise comparison, building a super-matrix. The final result is a ranking vector of alternatives, which results in a very efficient method to choose a network, as we will see. Thus, in this paper we propose an ANP-based method for network selection that we call NetANPI.

NetANPI characterizes each alternative (femtocell) by four different performance parameters: Packet Loss (PL), Average Throughput (AT), Delay per Packet (DP), and Network Occupancy representing the available Resource Blocks (RB) in a femtocell. Besides comparing among different alternatives, NetANPI also allows to compare each network with an ideal case. Based on the four traffic classes defined by the 3GPP TS 23.107 standard (streaming, background, conversational, and interactive), NetANPI allows for user heterogeneity with different QoS requirements.

To evaluate the performance of NetANPI, we run numerical simulations comparing NetANPI with the most used MADM mechanisms for network selection found in the literature. Then, we introduce a method to rank MADM methods, which is based on utility theory. Our results show that NetANPI outperforms the other methods for the cases of interactive and conversational traffic classes.

This paper is organized as follows, Section II presents the background and related work. Section III describes our proposed NetANPI mechanism for network selection. Section IV details how we use a utility theoretical network selection algorithm to rank different MADM algorithms. Section V presents the performance comparison and results, and finally Section VI draws some concluding remarks.

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II. Background and related work

In this section, we describe how traffic offloading is done in LTE networks and how it applies to the network selection problem. We also describe briefly some related work on network selection.

A. Traffic Offloading in LTE

With the vast increase of mobile applications, traffic over cellular networks has grown exponentially in the last few years [2]. Such phenomenon comes along with a corresponding increase in network congestion, which directly impacts the QoS provided to users. Traffic offloading via femtocells has become one of the most used techniques to solve such problem. This technique refers to offloading the traffic from a macrocell to femtocells. In LTE networks, a macrocell is an eNB (evolved Node B) with a wide coverage range and femtocells are indoor base stations with a low coverage range. In this way, the QoS provided to users may be kept within acceptable levels since a femtocell supports a small number of users with good QoS parameters.

Figure 1 illustrates the LTE femtocell/macrocell network architecture. There are two subsystems, the Core Network or Evolved Packet Core (EPC), and the Radio Access Network (RAN). Each femtocell is connected to the EPC by a broadband/Internet network and the macrocell has a direct link to the Mobility Management Entity (MME) in the EPC. Our main interest in this work is on the RAN since macrocell and femtocells are located in this subsystem. As we can observe, the macrocell coverage overlaps with that of femtocells, and there is a large number of overlapped femtocells, thus the traffic offloading technique is needed. There are two ways to perform traffic offloading: the user-centric approach and the network-centric approach. In the former, the user makes the decision and in the latter it is the network that makes it. In this paper, we follow the first approach. Thus, the network selection procedure is performed by the user to handoff from the macrocell to one of the available femtocells. Network selection in this context consists in choosing the best femtocell based on its performance parameters.

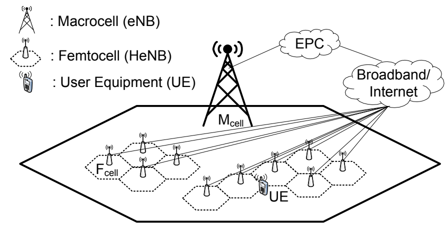

Figure 1. LTE femtocell/macrocell network architecture.

B. Related work on MADM network selection mechanisms

Extensive research has been done on network selection mechanisms. The main efforts have been done on vertical handoff between wireless networks, where a diverse set of mathematical approaches to model this problem have been proposed. Among the most important ones we may find utility theory, multiple attribute decision making (MADM), fuzzy logic, combinatorial optimization, Markov chain models, and recently game theory [1,3,4]. One of the contributions applying MADM methods to the network selection problem is that of Stevens-Navarro and Wong in [5]. They compare four different mechanisms namely MEW, SAW, TOPSIS and GRA, to conclude that GRA shows better performance regarding the background traffic class. In [6], Vaca and Ramos propose an algorithm considering the uncertainty during the decision making process. In [7], Ramirez and Ramos present a hierarchical decision scheme based on the Analytic Hierarchy Process (AHP). Later in [8], the same authors present a strong comparison between various MADM algorithms showing their advantages and disadvantages for network selection.

An evolution of the AHP method is the ANP general framework presented in [9]. We may find in the literature very few contributions applying ANP to the network selection problem. In this paper, we show that using ANP may be a very attractive solution for that purpose since it allows to see the scenario as a network of attributes; such capability has been barely studied in previous work regarding ANP [10,11].

III. ANP and the network selection problem

The Analytic Network Process is a general framework to derive relative priority scales of individual judgments, or absolute numbers from actual measurements. Such individual judgments represent the relative influence of one or more elements over the other(s) in a pairwise comparison with respect to an underlying control criterion [9]. ANP configures the problem of decision making as a network of attributes, where nodes may be an alternative, a criterion, a sub-criterion, or even criteria groups. Each node is contrasted with the nodes connected to it through a pairwise comparison to build a super-matrix, where the final result is a ranking vector of the networks [9].

In this paper we propose NetANPI, which is an ANP mechanism considering the influence of the alternatives on criteria. Besides comparing among different network alternatives, NetANPI also allows to compare each network with itself. This fact may sound weird because it is difficult to say that a network exhibits better throughput than latency, for example, but it may be achieved if the network is compared with an ideal one. This comparison includes a new ranking in the decision making mechanism in order to make it more robust. To achieve such evaluation, we adapt a well know ELECTRE (ELimination Et Choix Traduisant la REalité) version presented in [8] that takes into account the comparison of networks with an ideal network. In Table I, we list the parameters to carry out this comparison. Unlike other MADM methods, ANP is able to build groups of criteria. NetANPI groups three QoS parameters into one cluster, while occupancy is considered separately. This is because both clusters have a different nature. On one hand, the former refers to the link's quality perceived by the user at the instant when the decision is made. On the other hand, the latter refers to the

Table I
COMPARISON WITH IDEAL NETWORK PARAMETERS.

	Conversational		**Streaming**		**Background**		**Interactive**	
	Ideal	Weight	Ideal	Weight	Ideal	Weight	Ideal	Weight
AT	200 Kb/s	0.175	3 Mb/s	0.45	1 Mb/s	0.33	500 Kb/s	0.15
DP	100 ms	0.65	300 ms	0.30	300 ms	0.33	75 ms	0.75
PL	$10^{-2}\%$	0.175	$10^{-2}\%$	0.25	$10^{-6}\%$	0.33	$10^{-4}\%$	0.15

Table II
3GPP TS 23.107 APPLICATION CLASSES.

Traffic Class	**Example**	**QoS Requirements**
Conversational	VoIP	Low delay, preserve delay variation.
Streaming	Video streaming	Minimum throughput and delay levels
Interactive	Gaming	Very low level of delay, preserve time variation.
Background	e-mail	Preserve payload content

Table III
NETANPI QOS PAIRWISE COMPARISON.

	Conversational			**Streaming**			**Background**			**Interactive**		
	AT	DP	PL	AT	DP	PL	AT	DP	PL	AT	DP	PL
AT	1	$\frac{1}{4}$	1	1	2	2	1	1	1	1	$\frac{1}{6}$	1
DP	4	1	4	$\frac{1}{2}$	1	1	1	1	1	6	1	6
PL	1	$\frac{1}{4}$	1	$\frac{1}{2}$	1	1	1	1	1	1	$\frac{1}{6}$	1

number of users with respect to the total network capacity, such occupancy is used to predict if the network handover may cause congestion or not.

A diagram for NetANPI is presented in Figure 2; as we can see, there is a preference relation among the options (available networks) and the QoS criteria, that is how we graphically represent the comparison of each network with itself.

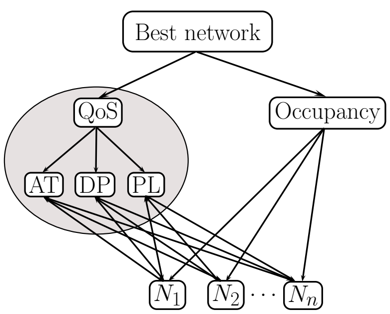

Figure 2. Diagram of NetANPI.

A. Selection criteria and application classes

We consider the four different traffic classes defined in the TS 23.107 3GPP standard, each with its corresponding QoS requirements. Such characterization is presented in Table II. We represent each candidate network by three different QoS parameters along with network occupancy.

Network Occupancy (NO) is defined as the percent of Resource Blocks (RB) available in each network at the instant when the decision is made. The *Average Throughput* (AT) is the achievable average throughput per user in the network, while the *Delay per Packet* (DP) represents the end-to-end delay. Finally, *Packet Loss* (PL) is defined as the packet loss rate in the network.

B. Pairwise comparison of NetANPI

As we have described, the structure of NetANPI is composed of two types of criteria: network occupancy and the QoS parameters. This is why we need to make two pairwise comparisons for each traffic class, one for the QoS cluster and the other one for QoS and occupancy. In Table III, we present the first comparison matrices. In the second comparison, we choose a relation of two-to-one.

Weights selection is purely subjective; however, it is based on the QoS requirements for each application class defined in the TS 23.107 3GPP standard. For instance, the interactive class is very restrictive regarding delay; that is why the relation between such criterion and the rest is of six-to-one. A similar case occurs for the case of the conversational class, but in this case the relation is of four-to-one since this class is less restrictive than the previous one. The converse case is the background traffic class since in this case there is no preference among criteria. Finally, we generate the corresponding super-matrix from priority vectors, which are obtained by analyzing the eigenvalues from both, the pairwise comparison and the comparison with an ideal network. The structure of the super-matrix is shown in Figure 3.

Each box of the supermatrix in Figure 3 corresponds to an eigenvalue analysis made according to the pairwise comparison described above. For example, the green boxes represent the priority vector of the QoS eigenvalue analysis made for each alternative. The final priority vector will appear in the red boxes once Equation (1) is applied. This procedure is similar to obtaining the steady state of a Markov Chain, i.e.:

$$W^{\lim} = \lim_{k \to \infty} W^k, \quad (1)$$

where W is the supermatrix.

IV. UTILITY THEORY FOR NETWORK SELECTION

Utility theory was developed by Von Newman and Morgenstern [12]. It has been used very often in microeconomics to characterize the ability of a good or service to satisfy a human need. In this context, utility theory normally uses utility functions to express numerically such level of satisfaction. Different users may have different levels of satisfaction for the same good or service depending on their corresponding

Table IV
UTILITY FUNCTIONS PARAMETERS.

	AT			PD			PL			NO		
	x_α	x_β	ζ	x_α	x_β	ζ	x_α	x_β	ζ	3 x_α	x_β	ζ
Conversational	65 Kb/s	200 Kb/s	3	100 ms	250 ms	9	$10^{-4}\%$	$2\times10^{-2}\%$	3	0%	75%	3
Streaming	500 Kb/s	3 Mb/s	7	200 ms	300 ms	3	$10^{-6}\%$	$10^{-4}\%$	5	0%	75%	3
Background	100 Kb/s	1Mb/s	3	300 ms	350 ms	5	$10^{-6}\%$	$10^{-4}\%$	3	0%	75%	3
Interactive	100 Kb/s	500 Kb/s	5	65 ms	75 ms	12	$10^{-4}\%$	$10^{-2}\%$	3	0%	75%	3

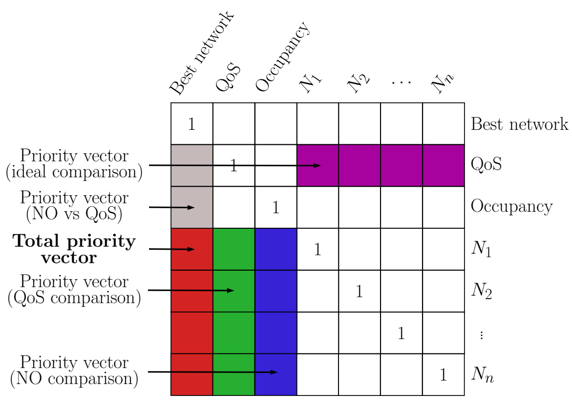

Figure 3. Supermatrix of NetANPI

preferences; individual preferences are taken into account differently for each user regarding utility functions.

In our context, users with different preferences are replaced by different classes of applications with different requirements for each QoS parameter. There are two types of utility functions, single-criterion and multiple-criterion. In this paper, we consider the sigmoidal utility functions presented in [12] for an upward x criterion such that $x_\alpha \le x \le x_\beta < \infty$; they are defined as follows:

$$u(x) = \begin{cases} 0 & \text{if} \quad x < x_\alpha \\ \frac{\left(\frac{x-x_\alpha}{x_m-x_\alpha}\right)^\zeta}{1+\left(\frac{x-x_\alpha}{x_m-x_\alpha}\right)^\zeta} & \text{if} \quad x_\alpha \le x \le x_m \\ 1-\frac{\left(\frac{x_\beta-x}{x_\beta-x_m}\right)^\gamma}{1+\left(\frac{x_\beta-x}{x_\beta-x_m}\right)^\gamma} & \text{if} \quad x_m < x \le x_\beta \\ 1 & \text{if} \quad x > x_\beta. \end{cases} \tag{2}$$

Where γ and ζ are tuned steepness parameters, which express the elasticity of the criterion; they are defined by:

$$\gamma = \frac{\zeta(x_\beta - x_m)}{x_m - x_\alpha} \qquad \zeta \ge \max\{\frac{2(x_m - x_\alpha)}{x_\beta - x_m}, 2\}. \tag{3}$$

A large value of ζ models an elastic application; i.e., a small variation would affect drastically the application's performance. Regarding the downward parameters, the utility function is $1 - u(x)$.

We define a different utility function for each parameter and each class of application (see Table IV for details). The decision is made as follows: we evaluate the utility function over each network parameter, then we add the corresponding utilities obtained in each network. These values form a ranking vector of the networks, the largest value in this vector indicates the decision point that will be used to compare the MADM mechanisms.

The values of x_α and x_β characterize different types of applications for LTE networks. The variable ζ is chosen according to the TS 23.107 3GPP standard, and assumes different values according to the class of application [13]. The interactive class is inelastic for the delay parameter, the real-time voice and video applications are inelastic regarding their demand for bandwidth. Browsing and e-mail are perfectly elastic on delay requirements [14,15]. This is why the interactive class takes $\zeta = 12$, while for the background class there is no inelastic parameter, and so all the values for $\zeta = 3$.

V. PERFORMANCE ANALYSIS

We present in this section the simulation scenario and describe the results we obtain.

A. Simulation scenario

Our aim in this work is to compare the most cited MADM mechanisms in the literature for the network selection problem with our NetANPI mechanism so as to show the effectiveness of our proposal. To do so, we implement numerically the following mechanisms: NetANPI, AHP, ANP (not contrasting it with an ideal network), TOPSIS, ELECTRE, SAW, and GRA. The simulations are run for a set from 2 to 20 different network alternatives. We execute 300,000 simulations for each decision making (see Table V), where the network parameters are generated from a normal distribution characterized by μ and σ indicated in Table VI and chosen in a way that corresponds to standard values for LTE networks.

Since all the MADM mechanisms evaluated consider subjectivity in the decision process, determining which of them is the best for a particular type of application is not straightforward. Thus, we propose a way to rank the evaluated mechanisms that is based on utility theory. Basically, we implement the sorting utility algorithm proposed in [12] and described in Section IV. Then, we compute the euclidean distance in Equation (4) between the points selected by the MADM methods with the point selected by the utility theory sorting mechanism. The method with the largest euclidean distance is

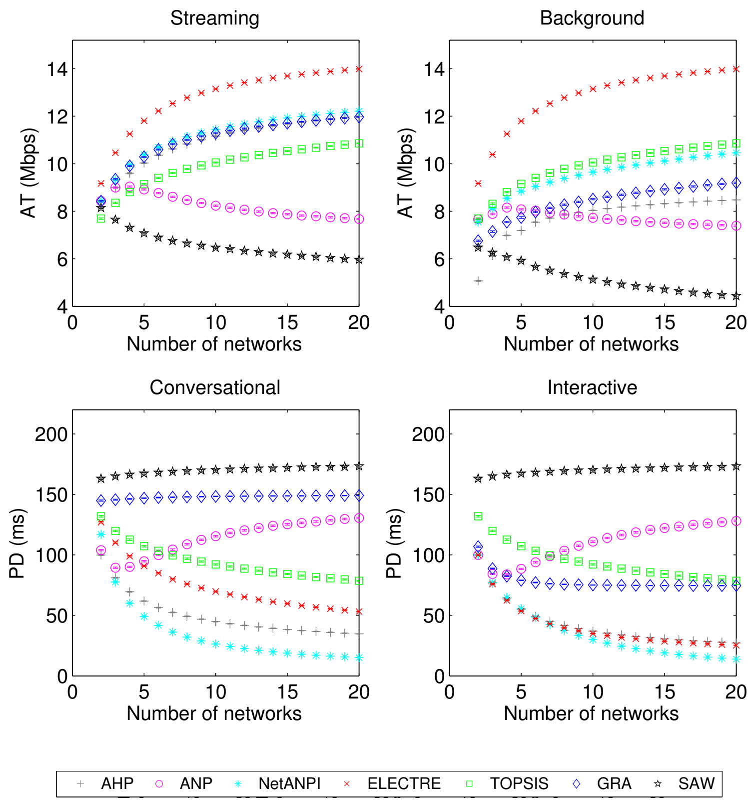

Figure 4. Performance comparison.

Table V
SIMULATION PARAMETERS.

Parameter	Value
Number of alternatives at each decision point	$2, 3, \ldots, 20$
Number simulation per decision point	$300,000$
Reference decision method	Sigmoidal utility function
MADM Mechanisms	NetANPI, AHP, ANP, GRA, SAW TOPSIS, ELECTRE
Selection criteria	NO, AT, PD, PL

Table VI
NETWORK PARAMETERS.

Parameter	Minimum value ($\mu - 2\sigma$)	Maximum value ($\mu + 2\sigma$)
NO	0%	100%
AT	1 b/s	15 Mb/s
PD	1 μs	350 ms
PL	10^{-7}%	20%

the worst one for each case. Therefore, the euclidean distance is given by:

$$d_E(P,Q) = \sqrt{\sum_{i=1}^{n}(p_i - q_i)^2}, \quad (4)$$

where $P = (p_1, p_2, \ldots, p_n)$ and $Q = (q_1, q_2, \ldots, q_n)$ are the euclidean points in the n-dimensional euclidean space.

B. Results

Figure 4 shows plots representing the most relevant parameters for each class of application: delay for the conversational and interactive classes, and throughput for the streaming and background classes. For each plot, we consider 95% confidence intervals. On one hand, we see how NetANPI outperforms the other mechanisms on delay regarding the conversational and interactive application classes. On the other hand, regarding the streaming and background application classes, ELECTRE outperforms the other mechanisms followed closely by NetANPI. These results suggest that NetANPI is an excellent candidate to be used as a mechanism for network selection.

The comparisons we make consider only one parameter at a time and they depend on the subjectivity when assigning weights. Thus, as we said above, in order to reduce such subjectivity we compare the euclidean distance with our utility theoretical method. Thus, we see in Figure 5 that NetANPI exhibits the best performance for the interactive and conversational application classes. For the streaming and background classes, the baseline ANP mechanism shows the best performance. As we may see, AHP, ANP, and NetANPI improve their performance as the number of options increases.

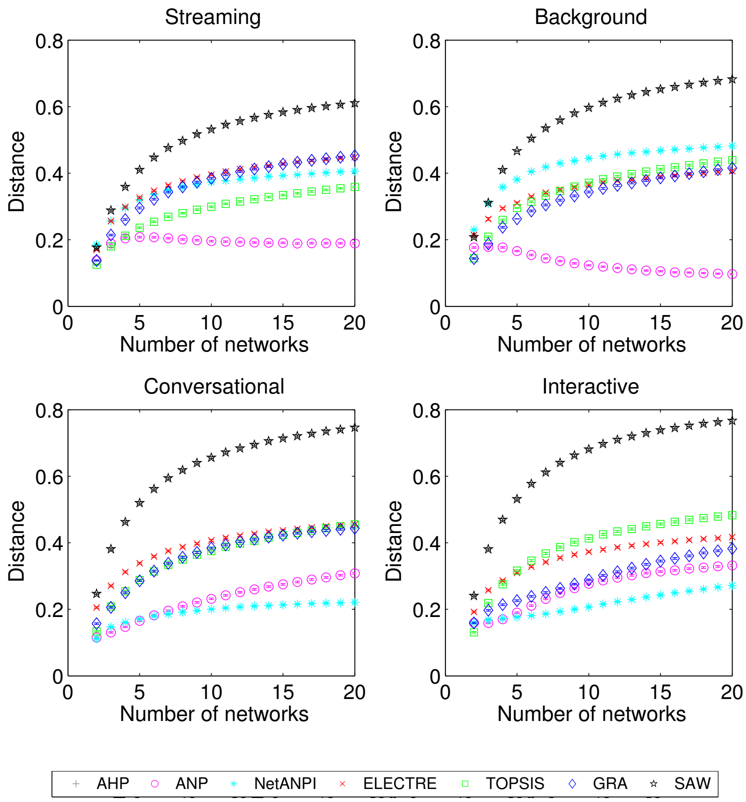

Figure 5. Distance comparison.

Besides, in all cases the distance increases proportionately along with the number of options.

VI. Conclusions

In this paper we proposed NetANPI, which is an MADM mechanism based on the Analytic Network Process taking into account the contrast of available networks with their ideal counterpart. We also proposed a mechanism to rank different network selection methods on a utility theoretical way. We executed numerical simulations to compare the most cited MADM mechanisms in the literature in order to show the effectiveness of our proposed NetANPI method when selecting an available network. NetANPI showed the best performance on delay among the other mechanisms regarding the conversational and interactive traffic classes. Equivalently, our utility theoretical approach confirmed that NetANPI is very well suited for such type of application classes.

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