Research Inventy: International Journal of Engineering And Science
Vol.10, Issue 8 (August 2020), PP 18-27
Issn (e): 2278-4721, Issn (p):2319-6483, www.researchinventy.com

Selecting the number of HSS and MME units of a LTE network under uncertainty

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Abstract:*Most research efforts treating 4G/LTE mobile networks focus on the terrestrial access network, while the design of the network core has only been scarcelytouched in the literature. Sizing the core requires the knowlegde of how many subscribers the network will serve. If the network intends to function for several years in the future, is a common practice to extrapolate thenewtork number of subscribers and to treat this estimate as a deterministic quantity when doing the sizing. This is the case even though many things can arise that make this estimate far off the real number of subscribers the network sees when it goes into operation.Similarly, other parameters required when sizing a network, such as the number of connected subscribers at peak time, are uncertain when designing the network, as they depend on the subscribers' usage patternsand change over the years. This work adopts a Decision Analytic perspective to put forward a method to size the network's Home Subscriber System and Mobility Management Entity units. The method distinguishes itself in treating the number of subscribers and the fraction of them connected at peak time as uncertain, and using utility functions to measure the preference of the decision maker for different results.*

Keywords:*Decision Analysis, Wireless Network, Uncertanty*

Date of Submission: 06-08-2020 Date of Acceptance: 19-08-2020

I. INTRODUCTION

The 4G/LTE mobile network has become the dominant architecture of wireless networks in practically all countries (Figure 1). The architecture can be split into a terrestrial access network, that comprises the so called e-NodeB, that are the antennas producing the radio electric waves that are received by the mobile devices (mainly cellular phones) and the Evolved Packet Core (EPC) which comprises several different types of equipment that link the IP of the provider to the e-Nodes B.

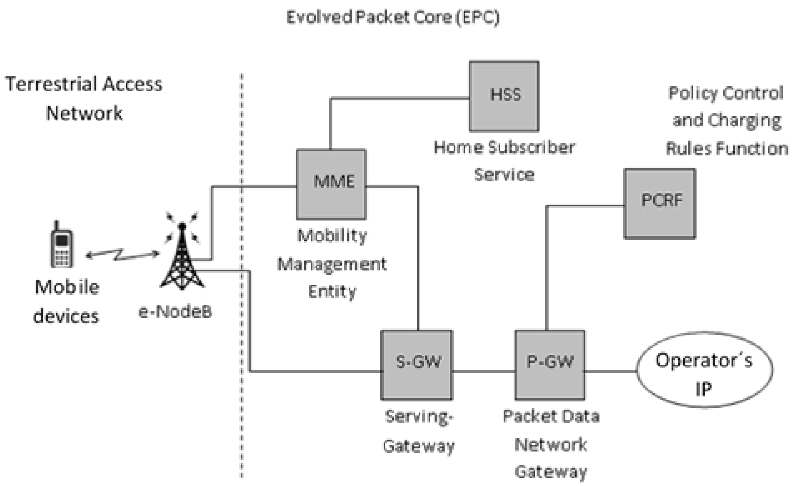


Figure 1. Schematic representation of a wireless data network

A brief description of the functionalities of the different type of equipment making-up the EPC follows:

- **Mobility Management Entity (MME)**: It coordinates the plane signaling control function, including mobility and security functions of devices and terminals that connect over the LTE network. Also, it executes e-node B message distribution to initiate connection, standby status control, logic interface control, encryption, and signaling integrity protection (Magnus Olsson, 2013)
- **Serving Gateway (S-GW)**: the serving GW terminates the S1-U user plane interfaces to eNBs, and is the anchor for intra-LTE mobility, as well as (optionally) for mobility between GSM/GPRS, WCDMA/HSPA and LTE. The S-GW also stores in buffers downlink IP packets destined to terminals that happen to be in idle mode.
- **Packet Data Network Gateway (P-GW)**: This is the point of interconnection to external IP networks through the SGi interface. PS-GW includes functionality for IP address assignment, loading, packet filtering, and policy-based control of user-specific IP flows. PS-GW also has a key role in QoS support for end-user IP services.
- **Home Subscriber Server (HSS)**: HSS manages user data and related user management logic for users accessing through LTE RAN. Subscription data includes credentials for authentication and authorization access. The HSS also supports mobility management within LTE, as well between LTE and other access networks.
- **Policy and Charging Rules function (PCRF)**: Provides flow-based charging (including online credit control), it also controls different flow-based load management policies and functionalities, ending in an interface called Rx. It includes support for service authorization and Quality of Service (QoS) rules for knowing what treatment a given IP flow will receive on the network (i.e. contains policy control decisions)

Most research efforts that can be found on the design of 4G/LTE mobile networks have focused on the terrestrial access network (e.g. specifying the number, capacity, and location of B-nodes to minimize signal interference). On the other hand, the design of Core networks such as the Evolved Packet Core (EPC) of these networks is much less researched.

The sizing of a wireless data transmission network (i.e. deciding the number of units of each equipment type) requires the knowledge of how many users (i.e. subscribers) the network is planning to serve. If the network intends to be functional for several years into the future, is common practice to extrapolate the number of subscribers from past data, and the value so obtained is regarded as deterministic when substituted in the network sizing equations (Alfin Hikmaturokhman, 2018; Prados-Garzón, 2018; Arsany Basta, 2019). This is the case even though many things can arise that make this estimation to be far off the real number of subscribers the network sees when it finally goes into operation.

Similarly, other parameters required when sizing a network, such as the number of connected subscribers at peak time, are viewed as deterministic, even though they depend on the subscribers' service usage pattern that is likely to change over the years. This work puts forward a to size two types of equipment in wireless networks: the Home Subscriber System (HSS) and Mobility Management Entity (MME) that regards the number of subscribers and the fraction of subscribers connected in peak time as random variables, and represented by probability distributions.

It starts by analyzing the possibilities of uncertain variables, that is, the values they can take. Through the equipment capacity equations, a possibility in the uncertain variables entails a certain possible design. By sweeping the range of possible value of the uncertainties, the set of designs that are to be considered is identified. The task is to select one of the designs for the given problem.

The next step is to determine the consequences. A consequence is what happens when, for a fixed design, each uncertain variables take a given value. This step also identifies aspects of the consequences that are important for the decision-maker. Finally, the uncertain variables probability distributions are discretized so to be incorporated into decision trees to obtain the probability distribution of consequences for different designs. With these probability distributions, a value model is needed to select the recommended design.

II. PROPOSED METHODOLOGY

2.1 Design equations

This work focuses on two elements of the EPC in an LTE: the Home Subscriber Server (HSS) and Mobility Management Entity (MME). The sizing equations permit the calculation of how many elements of each type the network requires(Tabbane, 2018). The number of HSS (N_{HSS}) is calculated based on the number of subscribers N_A of the network and the capacity of an HSS unit (C_{HSS}) as in equation 1

$$N_{HSS} = \left[\!\left[\frac{N_A}{C_{HSS}}\right]\!\right] \quad (1)$$

Where the notation $[[x]]$ indicates "the integer greater than or equal to x". The number of MME units depends on the number of connections from subscribers, changes between active/inactive, and procedures. These quantities depend on the proportion of subscribers connected at peak time (P_{AU}) and usage parameters per connected user: k_A number of attachments, $k_{ID/AC}$ number of connections and disconnections and number of processes k_{PROC}. If C_{SAU}, $C_{ID/AC}$ and C_{PROC} are, respectively, the capacity of a MME regarding the number of simultaneously connected users, the connections/disconnections and procedures, then the required number of MME, N_{MME} is

$$N_{MME} = Max\left\{\left[\!\left[\frac{k_A \times P_{AU} \times N_A}{C_{SAU}}\right]\!\right], \left[\!\left[\frac{k_{ID/AC} \times P_{AU} \times N_A}{3600 \times C_{ID/AC}}\right]\!\right], \left[\!\left[\frac{k_{PROC} \times P_{AU} \times N_A}{3600 \times C_{PROC}}\right]\!\right]\right\} \quad (2)$$

If N_A and $P_{AU}$are taken as deterministic quantities (known with certainty), the number of HSS and MME in a given network is calculated by simply plugging their values into equations 1 and 2.

2.2 Why uncertainty should be taken into account when sizing the network

Here the number of network subscribers (N_A) and the proportion of these simultaneously connected at peak time (P_{AU}) are taken as uncertain variables. The first variable refers to the number of clients the network will have once it starts offering its wireless connection service, and is estimated using population parameters. However, the real number of subscribers is only revealed once the network starts operating, because different factors, as the appearance of competitors or changes in population dynamics, can make their actual value different from the projected one. Similarly, the maximum fraction of connected users can vary as network usage habits change. Therefore, there is no guarantee that the future value of the variables will match the forecast. The reality is that N_A and P_{AU} are variables whose true value is unknown when designing the network.

2.3 Steps of the procedure

The proposed steps to build a model to select the number of MME and HSS in a network, under uncertainty of the number of subscribers and the proportion of them who simultaneously connect to the network are shown below. These steps derive from a decision analysis persepective (Howard, 1988) to the decision.

1. Possibility Analysis: Which values can the uncertain variables take?
2. Analysis of alternatives: Given the possibilities, which alternatives are to be considered for the problem?
3. Consequence analysis: What happens, if an alternative is chosen and the uncertain variables take a given set of values?
4. Probability analysis: It consists of choosing probability distributions adequate for what is known about the uncertain variables.
5. Calculation of consequences: For each alternative, the probability distributions of uncertain variables are translated into probability distributions of the consequences.
6. Selection of an alternative: Based on the probability distributions of the consequences, the best alternative can be selected. This can be done in two ways: Invoking dominance criteria between alternatives or, if a dominance analysis does not generate a preferred alternative, constructing a value model must be constructed that represents the decision-up's preferences over different values of the consequences.
7. The following are the steps applied to selecting the number of HSS and MME computers in a data transmission network.

III. APPLICATION TO A CASE STUDY

The detailedapplication of the methodology toanhypotethical case study is now shown.

3.1 Analysis of possibilities

For this example, we take the possibilities of N_A to range between 0 and 40'000'000 while those of P_{AU} do so between 0 to 1.

3.2 Anaysis of alternatives

The parameters of equation (1) are fixed to C_{HSS}=24’300’090, while those of equation (2) are set to C_{SAU}=13’000’050, $C_{ID/AC}$=185’185, C_{PROC}=213’675, k_A=1, $k_{ID/AC}$=50 and k_{PROC}=53.6. Varying $N_A$and P_{AU} respectively, from 0 to 40’000’000 and from 0 to 1, and using equations (1) and (2) to calculate N_{HSS} and N_{MME}, the (N_A, P_{AU}) space can be divided into five different zones, each representing the required number of N_{HSS} and N_{MME}, as shown in figure 2.

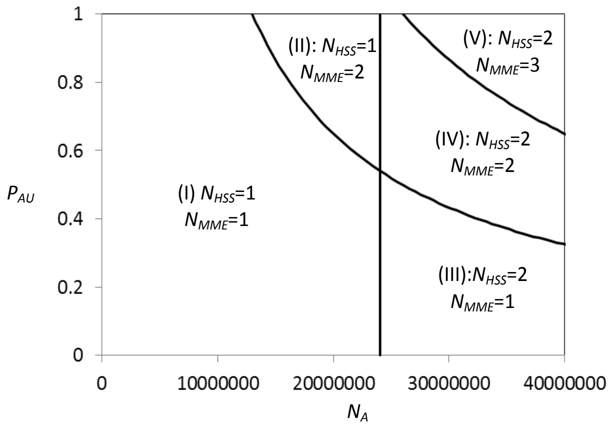


Figure 2. Alternative designs of the problem

For example, if the pair (N_A, P_{AU}) lies in the zone marked with (III) in Figure 2, then the network would include two equipment of type HSS and one MME. It is seen that the possibilities and sizing equations imply five alternative designs: Design I: 1 HSS and 1 MME; Design II: 1 HSS and 2 MME, Design III: 2 HSS and 1 MME; Design IV: 2 HSS and 2 MEE y Design V: 2 HSS and 3 MME.

3.3 Anaysis of consequences

If the real, true (deterministic) value of (N_A ,P_{AU}) were known, the area of Figure 2 in which said value lies would indicate the appropriate design. However when the wireless network is being planned, N_A and P_{AU} are uncertain, so the problem becomes one of decision-making under risk.

To define the consequences, the question that should be answered is: What happens if a certain design (I or V) is selected and the uncertain variables N_A and P_{AU} take a particular value? There are three possible results

- The proposed design is adequate: that is, the actual values of N_A and P_{AU} fall into the area of Figure 2 covered by said design.
- The design is too large: The actual values of N_A and P_{AU} fall outside the area of Figure 2 covered by the selected design, and are located in a zone of Figure 2 corresponding to a smaller (with fewer HSS or MME) design. In this case, the selected design is said to be over-sized.
- The design is too small: the actual values of N_A and P_{AU} fall outside the area of Figure 2 encompassed by the selected design, and fall in a zone of Figure 2 satisfied by a larger (with more HSS or MME units) design. When the selected design is too conservative, two undesirable effects may arise:
  - The network has fewer subscribers than those that it could have had if a bigger design was selected. This is measured by a variable called “number of lost subscribers” denoted by N_{LS}.
  - The proportion of subscribers needing to connect at peak time is higher than the maximum proportion of subscribers that the selected design can provide. This is measured by the variable “number of unconnected subscribers”, denoted by N_{US}.

Let us consider some design X, that has $N_{HSS}{}^X$ units of HSS and $N_{MME}{}^X$ units of MME equipment. The maximum number of subscribers of this design is:

$$N_{A,MAX}{}^X = C_{HSS} \times N_{HSS}{}^X \quad (3)$$

The connection capability of this design, measured by the maximum proportion of subscribers that can connect simultaneously $P_{AU,MAX}{}^X$, depends on the number of subscribers to the network, which is the smallest of N_A and $N_{A,MAX}{}^X$ through equation 4 below

$$P_{AU,MAX}^X = min\left\{\frac{N_{MME}^X \times C_{SAU}}{k_A \times min\left(N_{A,MAX}^X, N_A\right)}, \frac{3600 \times C_{ID/AC} \times N_{MME}^X}{k_{ID/AC} \times min\left(N_{A,MAX}^X, N_A\right)}, \frac{3600 \times C_{PROC} \times N_{MME}^X}{k_{PROC} \times min\left(N_{A,MAX}^X, N_A\right)}\right\} \quad (4)$$

The oversizing of a design, it defined with respect to the number of units of HSS and MME equipment that suffice to serve a set of values N_A y P_{AU}. This “just adequate” number of HSS and MME, called $N_{HSS}{}^J$ and $N_{MME}{}^J$are calculated as

$$N_{HSS}^J = \left[\!\left[\frac{N_A}{C_{HSS}}\right]\!\right] \quad (5)$$

$$N_{MME}^{J} = Max\left\{\begin{array}{c}\left[\!\left[\frac{k_A \times P_{AU} \times min\,(N_A, N_{A,MAX}^X)}{C_{SAU}}\right]\!\right], \\ \left[\!\left[\frac{k_{ID/AC} \times P_{AU} \times min\,(N_A, N_{A,MAX}^X)}{3600 \times C_{ID/AC}}\right]\!\right], \left[\!\left[\frac{k_{PROC} \times P_{AU} \times min\,(N_A, N_{A,MAX}^X)}{3600 \times C_{PROC}}\right]\!\right]\end{array}\right\} \quad (6)$$

Note that the "just adequate" value for the number of MME units, N_{MME}^{J}, depends on N_A, $P_{AU}$and alsoN_{AMAX}^{X}. This happens because the required MME units depends on the actual subscriber number, which is the minimum of N_A and N_{AMAX}^{X}.

The number of lost subscribers is calculated as

N_{LS}=max{0, N_A-$N_{A,MAX}^{X}$} (7)

If P_{AU}>$P_{AU,MAX}^{X}$ the number of unconnected subscribers is calculated as

N_{US}=(P_{AU}-$P_{AU,MAX}^{X}$)× min(N_A,$N_{A,MAX}^{X}$) (8)

Finally the over-sizing on HHS (OS_{HSS}) and on MME equipment (OS_{MME}) are calculated as

OS_{HSS}=max(0, N_{HSS}^{X}-N_{HSS}^{J}) (9)

OS_{MME}=max(0, N_{MME}^{X}-N_{MME}^{J}) (10)

3.4 Analysis of probabilities

Knowledge of the uncertain variables of the N_A and P_{AU} is described by a joint probability density distribution $f(N_A,P_{AU})$. If the variables are independent then this distribution is the product of marginal distributions of each variable

f(N_A,P_{AU})= $f_{NA}(N_A)$×$f_{PAU}(P_{AU})$ (11)

To facilitate calculations, continuous distributions are converted to discrete distributions (Clemen, 1996). If X is a continuous uncertain variable, it's probability distribution on a certain range is approximated by a discrete distribution composed of a finite set of evenly spaced possibilities x^0, x^1,....,x^N covering the desired range and a probability mass function p^0, p^1,...,p^N such as P(X=x^i)=p^i. The distance $\Delta x=(x^N-x^0)/N$ is the distance between consecutive values of the discretized distribution (Figure 3).

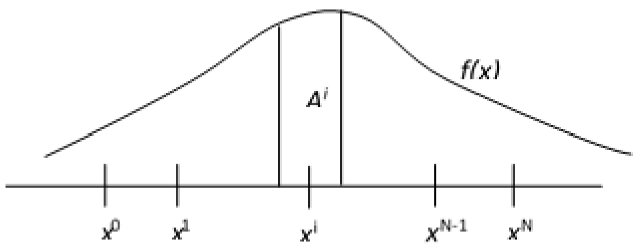


Figure 3. Discretization of continuous probability distribution

For i=0,…,N the area A^i is calculated as

$$A^i = \int_{x^i-0.5\Delta x}^{x^i+0.5\Delta x} f(x)\,dx \quad (12)$$

The probability mass function p_i (i=0,…,N) is calculated as

$$p_i = \frac{A^i}{\sum_i A^i} \quad (13)$$

The probability distributions of N_A andP_{AU} were discretized over eleven values N_A^i, $P_{AU}^i$with$i$=1,…10. The marginal discretized probability distributions of N_A and P_{AU} are p_{NA}^i=P(N_A=N_A^i) y p_{PAU}^i=P(P_{AU}=P_{AU}^i). If N_A and P_{AU} are taken as probabilistically independent, the joint probability of these variables are $p_{NA,PAU}^{(i,j)}$=P(N_A=N_A^i, P_{AU}=P_{AU}^j)=p_{NA}^i×p_{PAU}^j. Two cases are treated regarding the knowledge of N_A and P_{AU}:

- **Maximum uncertainty**: In this case, N_A and P_{AU} are uniformly distributed between, respectively, 0 and 40'000'000 and 0 to 1. The figure below shows the discretized probability distribution of this case

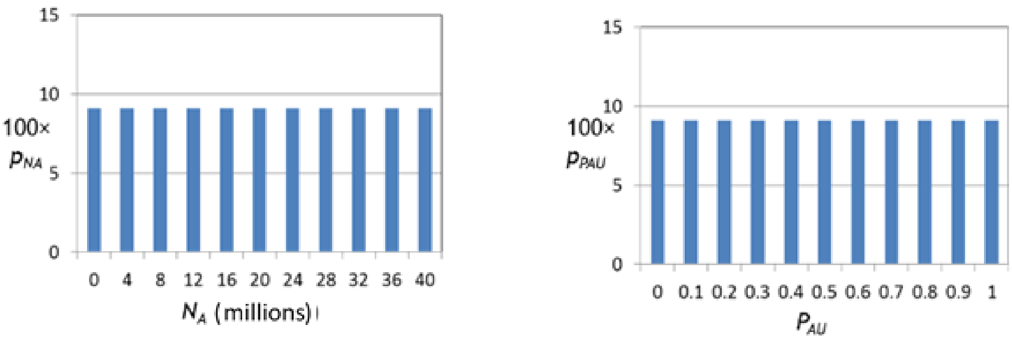


Figure 4. Maximum uncertainty on N_A and P_{AU}

- **Reduced uncertainty:** For this case, $N_A$is normally distributed with mean of 20’000’000 and standard deviation of 12’000’000, while P_{AU} is normally distributed with mean 0.7 and standard deviation of 0.3. The discretized versions of these distributions are shown below.

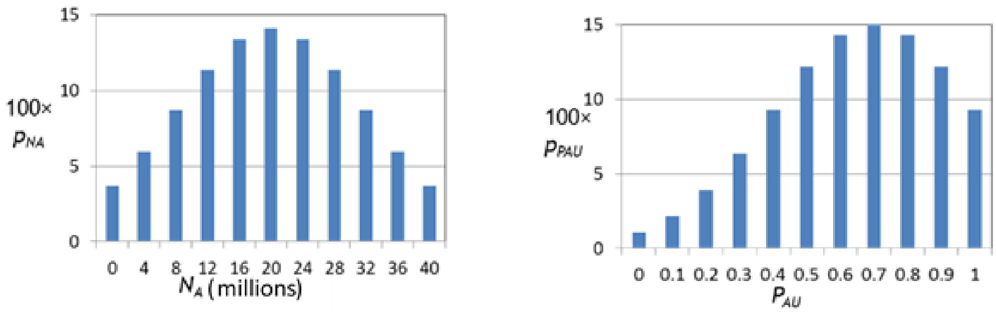


Figure 5. Reduced uncertainty probability distributions

3.5 Consequences probability distribution calculation

Having discretized probability distributions, the probability distribution of the consequence metrics can be evaluated using decision trees (Gilboa, 2011) such as the one shown below.

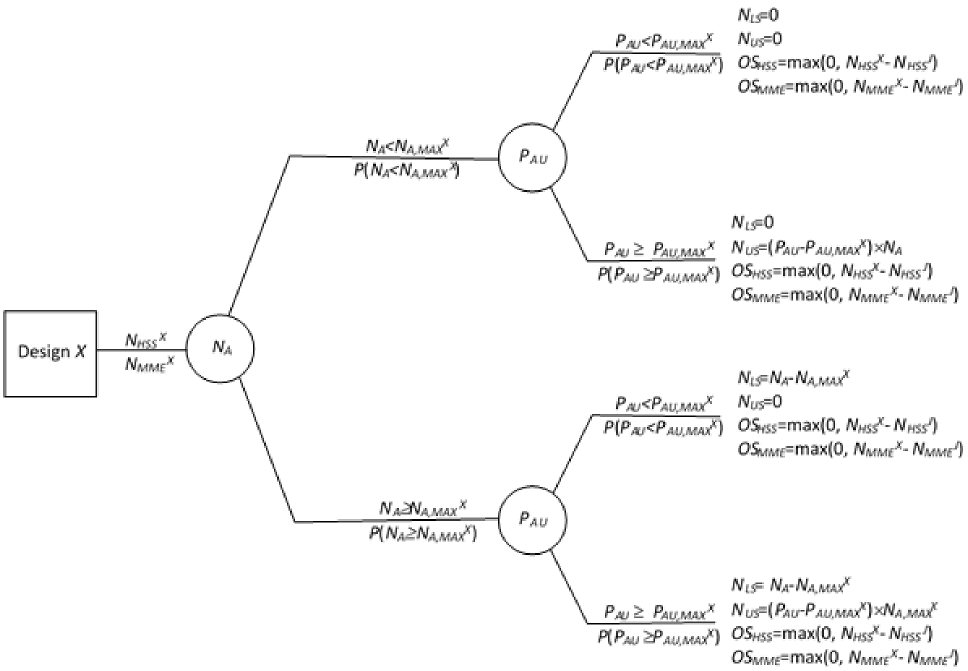
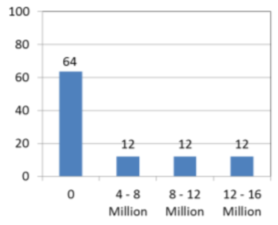
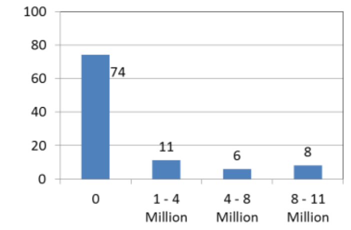
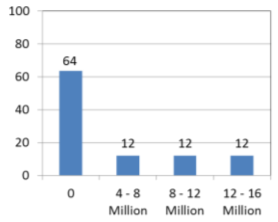
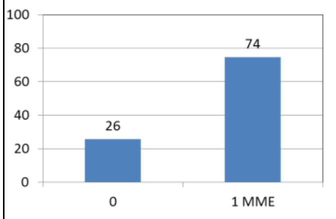
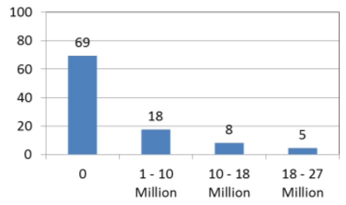
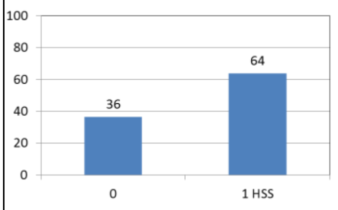


Figure 6. Decision tree for calculating consequences probability distributions

The tree starts from the left, with the selection of one design, which involves selecting a number N_{HSS}^{X} and N_{MME}^{X} of units of HSS and MME devices. Uncertain variables N_A and P_{AU} are represented as uncertainty nodes, and the number of lost subscribers N_{LS} and unconnected subscribers N_{US} depend on the comparison between N_A and P_{AU} and the design maximum capacities $N_{A,MAX}^{X}$ and $P_{AU,MAX}^{X}$. Design oversize depends on the relationship between the number of equipment of the selected design and the "just adequate" values N_{HSS}^{J} and N_{MME}^{J}.

The following table shows a summary of the probability distributions of N_{SL}, N_{US} and Oversizing for the case of maximum uncertainty. In each plot, the y-axis shows probability (as percentage) for the range of values of shown in the x-axis.

Table 1. Probability distributions (in %) for number of lost subscribers, number of unconnected subscribers and design oversizing: case of maximum uncertainty on N_A and P_{AU}

<table>
<tr><td></td><td>Number of Lost Subscribers</td><td>Number of un-connected subscribers</td><td>Oversizing</td></tr>
<tr><td>Design</td><td>N_{LS}</td><td>N_{US}</td><td>OS_{HSS}, OS_{MME}</td></tr>
<tr><td>I: 1 HSS, 1 MME</td><td>
</td><td>
</td><td>None</td></tr>
<tr><td>II: 1 HSS, 2 MME</td><td>
</td><td>None</td><td>
</td></tr>
<tr><td>III: 2 HSS, 1 MME</td><td>None</td><td>
</td><td>
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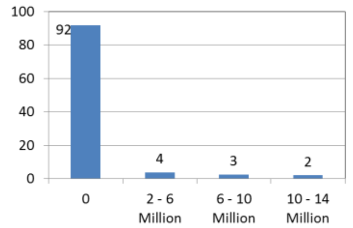
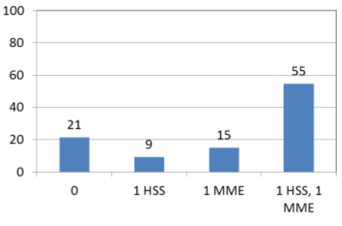
<tr><td>IV: 2 HSS, 2 MME</td><td>None</td><td>
</td><td>
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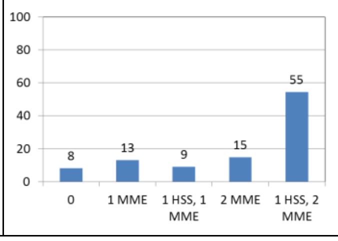
<tr><td>V: 2 HSS, 3 MME</td><td>None</td><td>None</td><td>
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</table>

Each design performance, expressed as a probability distribution of the consequences, can be read from this table. For example, from the plots of Design I, it can be seen that it design has a 64% probability of having no lost subscribers, and a 12% probability each of having between 4-8 million, 8-12 million or 12-16 million lost subscribers. The second chart of Design I show a 74% probability of having no unconnected subscribers and a 11% probability of producing between 1-4 million unconnected subscribers. Being the smallest design, Design I has no probability of being oversized. Similarly, Design II 64% of not losing any subscriber, and, having 2 MME devices, is certain not to have unconnected subscribers. However, the probability of Design 2 to be oversized in 1 MME is 74%. The most equipped design, Design V, is certain not to lose subscribers or leaving them unconnected, however, it only has a 8% probability of not being oversized and a 55% probability of being oversized by 1 HSS unit and 2 MME units.
The results for the case of reduced uncertainty are shown in the table below, the graphs interpretation is similar to that of Table 1.

Table 2. Probability distributions (in %) for number of lost subscribers, number of unconnected subscribers and design oversizing: case of reduced uncertainty on N_A and P_{AU}

<table>
<tr><td></td><td>Number of lost subscribers</td><td>Number of unconnected subscribers</td><td>Oversizing</td></tr>
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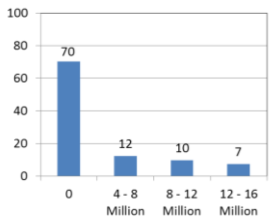
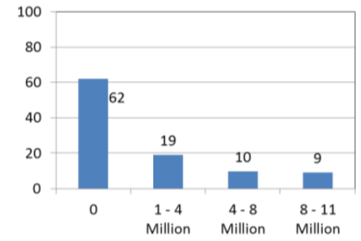
<tr><td>I: 1 HSS, 1 MME</td><td>
</td><td>
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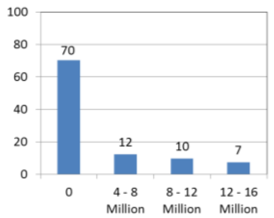
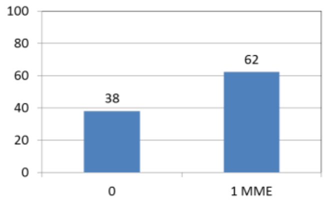
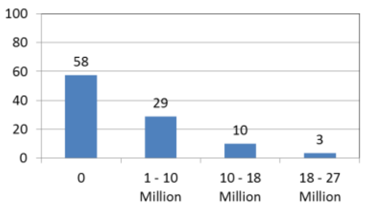
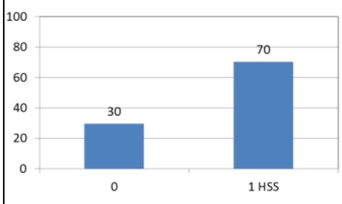
<tr><td>II: 1 HSS, 2 MME</td><td>
</td><td>None</td><td>
</td></tr>
<tr><td>III: 2 HSS, 1 MME</td><td>None</td><td>
</td><td>
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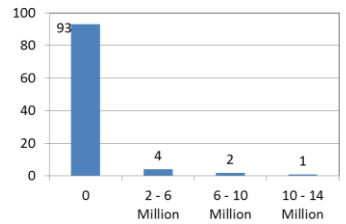
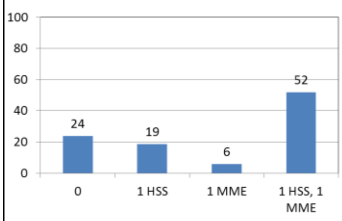
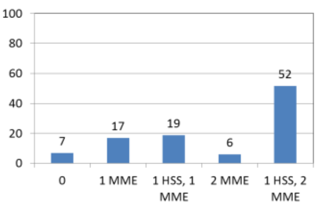
<tr><td>IV: 2 HSS, 2 MME</td><td>None</td><td>
</td><td>
</td></tr>
<tr><td>V: 2 HSS, 3 MME</td><td>None</td><td>None</td><td>
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</table>

3.6 Alternative selection

From the probability distributions of the consequences (number of lost subscribers N_{LS}, number of unconnected subscribers N_{US} and oversizing) the best design should be selected. This requires constructing a value model that gives a quantitative metric for the decision maker´s preferences for different values of the consequences. A value model is built from judgments of the importance that the decision maker attaches to each consequence level relative to the different levels of the other consequences.

So to avoid the construction of a complete value model, and still be able to make the selection of the best design, we set three objectives and their respective metrics according to:

- Objective 1 (O1): Maximize the quality of service to subscribers, meaning that all subscribers intending to connect at peak time can do so. This variable is measured by the probability that the number of unconnected subscribers is cero or P(N_{US}=0).
- Objective 2 (O2): Maximize the number of subscribers on the network, taking as a metric the probability that the number of lost subscribers is cero P(N_{LS}=0).
- Objective 3 (O3): Minimize the size of the equipment in the network, which is measured by the probability that the design is the smallest for the given requirement, or that the over-sizing is zero, or P(Oversizing=0).

The preference is given by an utiliy function

$$U=k_{US}\times U_{US}+ U_{LS}\times U_{LS}+k_{OS}\times U_{OS} \quad (14)$$

Where U_X ($X=US$, LS or OS) are utility functions giving a cero value for the worst result and one for the best result in the relevant consequence. These utilities are defined linearly as

$$U_{US}=\frac{P(N_{US}=0)-P(N_{US}=0)^-}{P(N_{US}=0)^+-P(N_{US}=0)^-} \quad (15)$$

$$U_{LS}=\frac{P(N_{LS}=0)-P(N_{LS}=0)^-}{P(N_{LS}=0)^+-P(N_{LS}=0)^-} \quad (16)$$

$$U_{OS}=\frac{P(Oversize=0)-P(Oversize=0)^-}{P(Oversize=0)^+-P(Oversize=0)^-} \quad (17)$$

Where the superscripts (+) and (-) indicate, respectively, the maximum and minimum values of the relevant variable. The weights k_{US}, k_{LS}, and k_{OS} parameters are positive values that add up to one, and indicate the relative importance given to, respectively, the number of unconnected subscribers, number of lost subscribers and design oversize.

The figure below shows the preferred design for the case of maximum uncertainty on N_A and P_{AU} as the parameters of the value function (k's) are varied between 0 and 1. We note that much of the space is occupied by the smallest (Design I) and the largest designs (Design V). The first is preferable when emphasizing the likelihood of not incurring in oversizing (near the origin of the figure), while design V is preferred when there is concern about not having lost subscribers or not leaving subscribers offline.

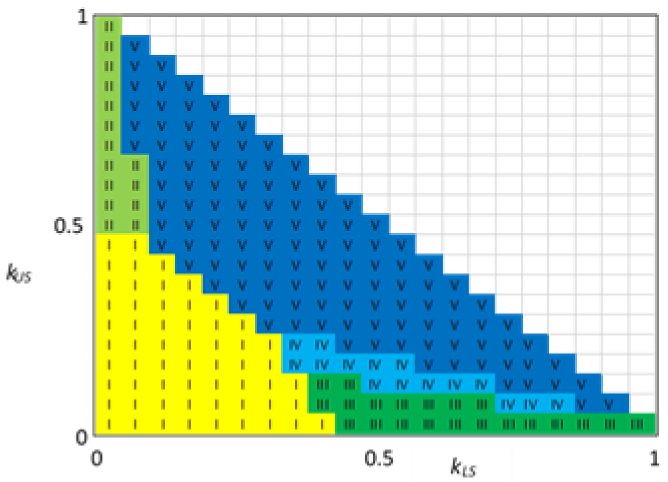

Figure 7. Preferred design selection, maximum uncertainty on N_A and P_{AU}

For the case of reduced uncertainty on N_A and P_{AU}, the chosen designs as the weights ot the utility función vary are shown below. The reduction of uncertainty gives greater area to medium-sized designs (Designs II, III and IV)

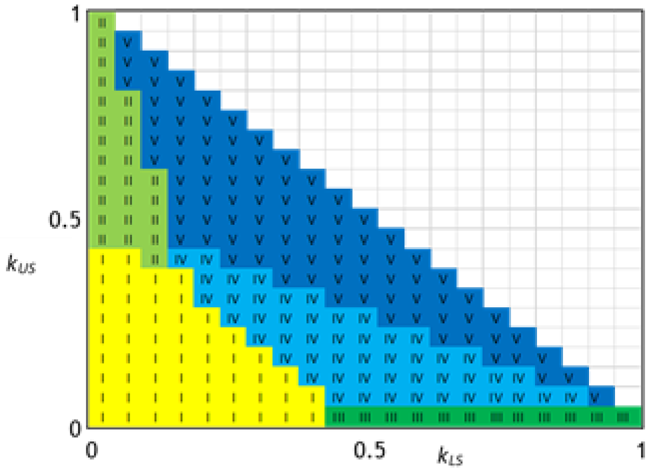

Figure 8. Preferred design selection, maximum uncertainty on N_A and P_{AU}

IV. CONCLUSION

Decision Analysis is a discipline aiming to help decision makers facing difficult decisions. One of the most common source of decision difficulty is uncertainty: not knowing for sure what will happen if a given alternative is followed. While network core design in seldom viewed as a problem affected by uncertainty, some critical parameters of the sizing equations can only beestimated at the design phase. Being estimates,they are uncertain quantities, and their uncertainty should be considered when sizing the network.

This work applies Decision Analysis to put forward a method to size two types of equipment in the network core: the Home Subscriber System (HSS) and Mobility Management Entity (MME). The number of subscribers and the maximum fraction of subscribers simultaneously connected are treated as uncertain quantities and a utility function is used to represent the network owner's preferences, allowing the selection of the preffered design. The steps of the methodology are presented, and a detailed application of the method is shown using anhypotethical design problem.

Conflict of interest
There is no conflict to disclose.

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Francisco Javier Casanova Ramírez, et. al. "Selecting the number of HSS and MME units of a LTE network under uncertainty." *International Journal of Engineering and Science*, vol. 10, no. 08, 2020, pp. 18-27.