Multi-hop Extensions to Heterogeneous Access Network Selection

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Abstract. This paper evaluates an access selection architecture able to handle heterogeneous technologies. We establish a generic access selection algorithm, which assigns different weights to the constraints established by both the network and the terminal. In addition, we improve the traditional operation by allowing multi-hop extensions, by means of which an end-user may reach an Access Element (i.e. base station) through other nodes willing to relay traffic. The results show that the multi-hop extensions are beneficial, not only from the point of view of the end-user, but also from the perspective of the network operator, since they allow an increase on the overall network throughput.

Keywords: Heterogeneous Access Networks, Multi-hop extensions.

1 Introduction and Related Work

Near future wireless communications will be characterized by being highly heterogeneous, not only regarding the involved technologies, but also considering the number of operators which will manage the different networks. In such scenarios, the end-user would have a much wider choice than today. This has gathered the interest from both the scientific community and the relevant standardization bodies. In fact, this has brought about several research challenges which have been covered just partially, and thus it is worth considering them.

Thanks to the recent proliferation of different radio access technologies, together with the advances on electronic miniaturization, it is nowadays becoming more common to have devices able to communicate over different technologies. In parallel, due to the rise of the number of network operators, as well as the increasing requirements from the end-user services, it is clear that some sort of cooperation between networks might be required.

Although this line of research has attracted much interest, most of the existing works are focused on a subset of the whole problematic, without looking at it with a holistic view. A first point which becomes fundamental is the abstraction of the subjacent resources, so that they could be managed on a homogenous and uniform way (see, e.g. [1], [2], [3], [4]). In this aspect, it is also worth highlighting the effort being made by the IEEE 802.21 group, which is currently defining a framework to ease the handover processes between networks, on an independent way from the subjacent technology (Media Independent Handover Services).

The current "almost-static" access selection which is used by most of the current technologies and networks would most likely become insufficient in the future; in fact, it will be required to change the current access, based on various parameters, such as the end-user preferences (policies) or the current situation of the network (in terms of e.g. load). Due to this new challenge, an entity able to collect, classify and deliver those events, which might eventually evolve into an access change (see [5]), is needed.

Another aspect which is common to all the different proposals which have been done within this line of research is a smart entity, able to process all the available information, providing the user with the best possible access any time. This component has received different names, such as MRRM [6], [7], CRRM [8], JRRM or CARM [9], although all of them share the same basic characteristics and functionalities.

There exist a number of works which can be embraced within this framework. In [10], the authors present an architecture to perform access selection within heterogeneous network environments. Other focus on particular technologies, like [11], [12], [13], which mostly analyse the integration between WLAN and 3G, studying different mobility schemes; furthermore, [14] discusses the benefits of employing different metrics to determine the optimum access, although they do not consider the possibility of changing one access once it has been selected. The approach followed by the AROMA project should be also highlighted [15], since it follows the guidelines proposed by the 3GPP [17] group and it focuses on the integration of UMTS and WLAN technologies. We must say that this paper does not aim at proposing a novel architecture, but it extends previous works since it carries out a thorough analysis of access selection algorithms which could be brought about by such frameworks.

Hence, we will use a simulation-based approach to evaluate the access selection architecture developed within the Mobilia collaborative project [16]. A generic algorithm has been designed, able to assign different weights to the constraints established by either the network or the end-user terminal. Furthermore, one of the distinctive features of the analysis is that we extend the more traditional approach, by means of multi-hop extensions, as long as the end-users have the opportunity to reach a base station by means of other entities willing to relay traffic.

The paper is structured as follows: Section 2 presents the algorithm which will be evaluated. Section 3 introduces the configuration and parameters of the proprietary simulator which has been developed to carry out this analysis, whose results are reported in Section 4. Finally, Section 5 concludes the paper, advocating some items for future work.

2   Access Selection Algorithm

This section presents the access selection algorithm which will be evaluated, taking into consideration the constraints of both the network and the end-users, *Network Constraints (nc)* and *Terminal Constraints (tc)*, respectively. A different weighting factor will be applied to each of these parameters and, finally, the
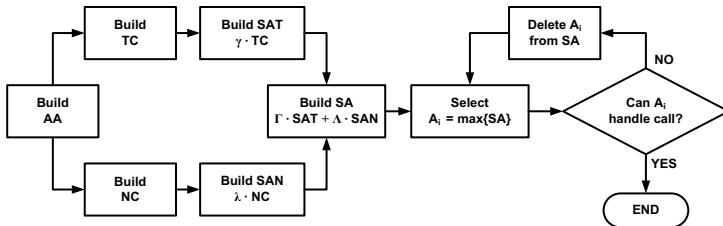
Fig. 1. Access Selection Algorithm

preferences of both entities will be combined, selecting the access alternative which maximizes the resulting cost function. Particularly, a linear combination of the constraints will be used so as to evaluate each of the elements detected by the terminal, as it is shown in (1), where A_j refers to the suitability of access j to the user.

$$A_j = \Gamma \sum_{i=0}^{N} \gamma_i tc_i^{(j)} + \Lambda \sum_{i=0}^{M} \lambda_i nc_i^{(j)} \tag{1}$$

In the previous expression, Γ refers to the overall weight which is given to the terminal (end-user) preferences, while Λ modulates those aspects which affect the network. Furthermore, a different weight is applied to each of the parameters (γ_i for the different terminal constraints and λ_i for the network ones), which will be used so as to adjust each of the jth access constraints, ($tc_i^{(j)}$ and $nc_i^{(j)}$, respectively). Thus, N is the overall number of constraints handled by the terminal, while M refers to the constraints handled by the network. The value of A_j lies between 0 and 1, provided that the values of all the different weights are properly selected.

In this sense, Figure 1 depicts the access selection algorithm. As can be seen, it starts with the establishment of the Available Accesses (AA) set. It embraces all the Access Elements to which the end-user has a possibility to connect. On a traditional system, this set will contain those base stations covering the position of the end-user; however, we also account for the possibility of connecting with an Access Element by means of a multi-hop path, if there are some nodes willing to relay traffic. Starting from this set, both the network and the terminal build their corresponding constraint matrixes (**NC** and **TC**, respectively), where each of the columns comprises the constraints which are being applied to each of the T elements of the AA; they apply those matrixes to build their corresponding Selected Accesses (SAN and SAT).

$$\mathbf{TC} = \begin{bmatrix} tc_1^{(1)} & tc_1^{(2)} & \cdots & tc_1^{(T)} \\ tc_2^{(1)} & tc_2^{(2)} & \cdots & tc_2^{(T)} \\ \vdots & \vdots & \ddots & \vdots \\ tc_N^{(1)} & tc_N^{(2)} & \cdots & tc_N^{(T)} \end{bmatrix} \qquad \mathbf{NC} = \begin{bmatrix} nc_1^{(1)} & nc_1^{(2)} & \cdots & nc_1^{(T)} \\ nc_2^{(1)} & nc_2^{(2)} & \cdots & nc_2^{(T)} \\ \vdots & \vdots & \ddots & \vdots \\ nc_M^{(1)} & nc_M^{(2)} & \cdots & nc_M^{(T)} \end{bmatrix} \tag{2}$$

When both matrixes are multiplied with the vectors containing the weights that are given to each of the constraints, $\overline{\gamma} = [\gamma_1 \cdots \gamma_N]$ for the terminal and $\overline{\lambda} = [\lambda_1 \cdots \lambda_N]$ for the network and, furthermore, they are modulated by the parameters which provide a relative weight to each of the involved entities, the overall Selected Access (SA) is established, as shown in 3, which is just the matrix version of the expression previously presented.

$$\mathbf{SA} = \Gamma \ (\overline{\gamma} \cdot \mathbf{TC}) + \Lambda \ (\overline{\lambda} \cdot \mathbf{NC}) \tag{3}$$

The next step is therefore to sort the SA vector, selecting the element which has the higher value, provided that the corresponding base station has enough resources to satisfy the service. If such is not the case, the corresponding set is iterated, until an element able to handle the request is found.

As can be seen, the algorithm is generic and flexible enough and, thus, adding new constraints and/or modifying the weights given to the existing ones does not require relevant modifications.

3   Simulator Configuration

The scenario which will be used during the analysis entails a relatively large number of access alternatives, and we will assume that all terminals within the area of analysis are equipped with three radio access technologies (RAT) and, thus, they would be able to connect to any base station, provided that they are within their coverage area. In order to measure the different capacities which might be requested by the different services and to be able to assign resources accordingly, a generic capacity unit (*Traffic Unit, TU*) will be used during the analysis so as to characterize both the services requirements as well as the capacity of the different base stations. Table 1 summarizes the characteristics of the three RATs which have been employed during the analysis. As can be seen, both RAT-1 and RAT-3 aim at emulating the characteristics of typical WLAN technologies, while RAT-2 could be related with a legacy cellular access technology, with a much broader coverage area and higher capacity. We assume an ideal (i.e. disk-radius) channel model, although, as will be later explained, we modulate the *'link quality'* based on the distance between the end-user and the base station.

Table 1. Access technologies used during the access selection mechanism evaluation

RAT	Coverage (m)	Number of Cells	Capacity per Cell (TU)
1	80	30	5
2	600	4	30
3	60	20	5

Since there might be some end-users not willing to participate in the multi-hop extensions (this might impose, e.g. a higher energy consumption), we will assume that only half of them (i.e. 50% are relaying traffic); furthermore, considering the characteristics of the RATs they are equipped with, only RAT-1 is employed in the forwarding procedures. At the time of writing, the use of multi-hop communications with cellular technologies is far more difficult.

Nodes move according to the *Random Waypoint* mobility model within the area under analysis, which is assumed to be squared, with 1000 m side. In this sense, an end-user would select a random direction, a speed uniformly distributed between 2 and 3 m/s and a movement time, also uniform in the interval $[100, 120]$ s. Each time a node reaches the final destination of its current movement, it stays for a *pause* time at that position, also randomly selected in $[5, 10]$ s. Furthermore, whenever an end-user reaches any of the four edges of the simulation area, a reflection mechanism is applied, continuing its movement afterwards.

The last aspect which needs to be considered is the way nodes generate traffic. In order to better analyze the performance of the algorithms, we will assume a high load within the network. Traffic will be generated according to the *Poisson* model; each end-user can be seen as an independent traffic source, with two different services, which we assumed cannot be requested simultaneously. Table 2 shows the characteristics of these two services, where λ is the average number of calls per minute and μ^{-1} is the average duration of a call (in seconds).

Finally, we also need to identify which are the particular constraints which will be taken into consideration while building the SA. In the case of the end-user, two different aspects will be considered.

Table 2. Characteristics of the services used during the access selection algorithm evaluation

Service	λ (min^{-1})	μ^{-1} (s)	Capacity (TU)
1	0.6	120	1
2	0.6	80	3

– **Quality (tc_1).** It represents the quality of the link between the terminal and the Access Element. It is scaled, so as to always take a value between 0 and 1, thus emulating the information which shall be provided by an abstraction entity (which is a focal part of any access selection architecture, as it was discussed in Section 1). In this case, it is calculated from the relative distance to the base station (taking into account the particular coverage of the corresponding RAT), reaching the maximum value (1) when the position of the terminal is the same as the the base station one, and 0 when it is placed just at the coverage area border[1]. It is worth mentioning that, for the case

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[1] We know that this is a simplification, but our goal is to have a bounded value between 0 and 1 for the sake of the proposed algorithm; introducing more realistic channel models would not have a strong impact, provided that this interval is respected.

of multi-hop routes, the lowest quality of the path has been taken at the overall quality of the access alternative, although this assumption can be easily adapted.

– **Handover (tc_2).** This parameter represents the preference that any end-user might have of keeping the communication with the current access and, whenever necessary of trying to prioritize those base stations which have the same technology as the currently active one. In order to reflect this, we use three different values for this parameter: $tc_2 = \{0, 0.5, 1\}$, whenever the current service is moved to a completely different base station, to an access alternative with the same RAT as the current one, or when it is not moved at all, respectively. This constraint aims at emulating the desire of the end-users to minimize the delay in which they incur during a handover procedure.

On the other hand, the network will certainly have other interests to look at, and the two following constraints will be applied.

– **Load (nc_1).** It might be the most relevant parameter from the perspective of the network when establishing the *Selected Accesses.* The goal is to balance the load of the different base stations, and therefore it uses the relative remaining capacity for each of them, so that when all resources are available, 1 is assigned to this parameter, while a 0 implies that a base station does not have any available capacity.
– **Handover (nc_1).** This constraint, which is pretty similar to the corresponding one at the terminal side, is used so as to model the interest that the network might have to maintain the connections at the same base stations as much as possible, so as not to incur in the cost associated to the handover procedures. It will use the same values as the ones which were established for the terminal.

4   Discussion of Results

The main goal of this first study is to analyze different combinations of the corresponding weights, so as to allow us establishing their best configuration. Afterwards, these combinations could be challenged over different scenarios (increased number of users, different setup of Access Elements, etc). Hence, we do not assume any *prior* assumption about the values which the weights should have, rather we aim at finding sensible choices for them.

The following parameters will be analyzed.

– **Reject probability.** It refers to those requests which were not handled by the network.
– **Anomalous termination.** It considers those calls that, albeit having started correctly, did not end properly, due to the fact that there were not available resources on the potential new base stations during a handover process to satisfy their capacity needs.
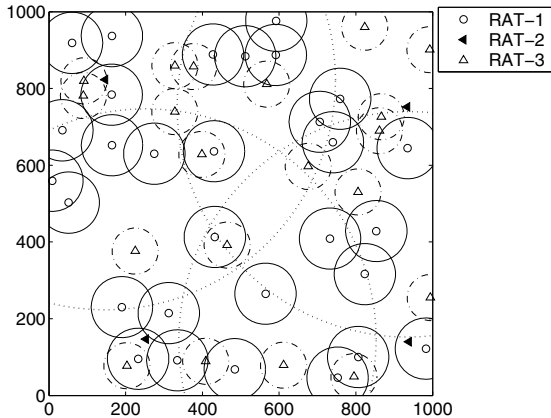
Fig. 2. Base station deployment

- **Average number of handovers per service.** We will differentiate between those involving base stations of the same RAT (Intra-RAT) as well as those which happen between different RATs (Inter-RAT).
- **Relative load.** This parameter allows analyzing how well the load was distributed between the different network Access Elements, since it is defined as the relative available capacity.
- **Overall network load.** It can be used so as to study the performance (or throughput) which can be obtained, by using the different access selection strategies.

In all cases, we have used the same network deployment, in which the base stations were randomly deployed (ensuring a minimum distance between two of the same kind). The particular deployment which was used (shown in Figure 2) ensures enough overlapping, while the four RAT-2 base stations cover the whole simulation area. Each of the scenarios is simulated 20 times, presenting the average results, so as to ensure tight confidence intervals.

4.1   Terminal Centric Strategy

In this case, we assume that it is the terminal the entity with the overall responsibility when deciding on the Access Element to connect to, and thus $\Gamma = 1$ and $\Lambda = 0$. Under these circumstances, we will study the influence of using different weight combinations (γ_i). Since we are using only two parameters and $\sum_i \gamma_i = 1$, we can yield that $\gamma_1 = 1 - \gamma_2$.

Figure 3 shows both the reject probability and the percentage of calls that did not end properly. We can see that both of them are much more relevant for the second service, due to the fact that it requires a higher capacity. We can also see that there is not a remarkable influence of the particular configuration of the weights, since the probabilities are almost stable for the various values of γ_i

(a) 1 hop   (b) 2 hops   (c) 3 hops


(d) 1 hop   (e) 2 hops   (f) 3 hops
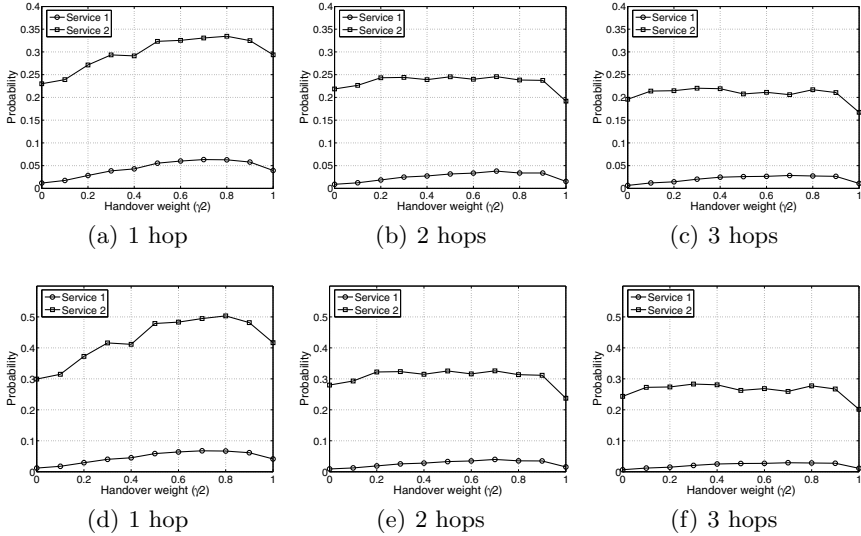
Fig. 3. Reject (top) and anomalous termination (bottom) probabilities with the *Terminal Centric* strategy

which have been used. Last, but not least, multi-hop extensions bring about an important improvement from the point of view of the *quality of service* perceived by the end-users, as both probabilities decreases as we augment the maximum number of hops which can be used to reach a base station (around 10 % for the reject probability a and almost 20 % for the anomalous termination); we also see that this influence is less relevant when going from 2 to 3 hops (close to 5 % for both parameters).

Figure 4 shows the average number of handovers per service and the relative load per RAT. From the point of view of the handover events, it is clear that as long as we increase γ_2 (weight given by the terminals to the constraint of maintaining the same base station), the average number of handovers decreases. There is a slight change of tendency close to $\gamma_2 = 1$, which is due to the fact that in this case there will be more connections with a poor quality (close to the cell border, which eventually will require a handover soon. In this case we only present the results which were obtained for a single-hop, since there was not much difference for the other two configurations. We see that the number of handovers for the second service is lower, which could have been expected, since the average duration of this service is shorter. Regarding the relative load, the first thing to highlight is that RAT-2 base stations are the more loaded ones, since their coverage is much broader than the other two. When we increase the number of hops we can see how the load is better balanced, since thanks to the multi-hop routes there might be more chances to reach one of the base stations with RAT-1 or RAT-2 (around 10 % increase).

(a) Service 1

(b) Service 2

(c) 1 hop

(d) 2 hops
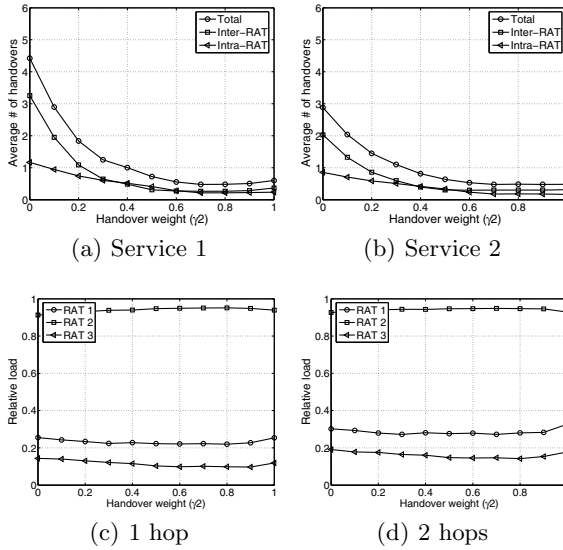
Fig. 4. Average number of handovers (top) and load balancing (bottom) with the *Terminal Centric* strategy
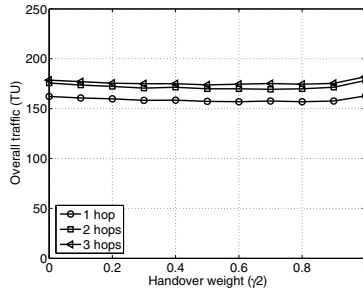

Fig. 5. Overall network throughput with the *Terminal Centric* strategy

Finally, Figure 5 shows that the overall network performance increases when we enable the multi-hop extensions. This is a very relevant result, since it yields an additional benefit of multi-hop topologies, from the point of view of the operators. Traditionally, most of the benefits of the these network extensions (enhanced coverage, better performance) were more closely related to the end-user, but Figure shows that the operator would also obtain benefit from them.

4.2 Network Centric

In this case, we give all the responsibility of the decision process to the network and thus, Λ takes a value of 1, and Γ is 0. Under these circumstances, we analyze
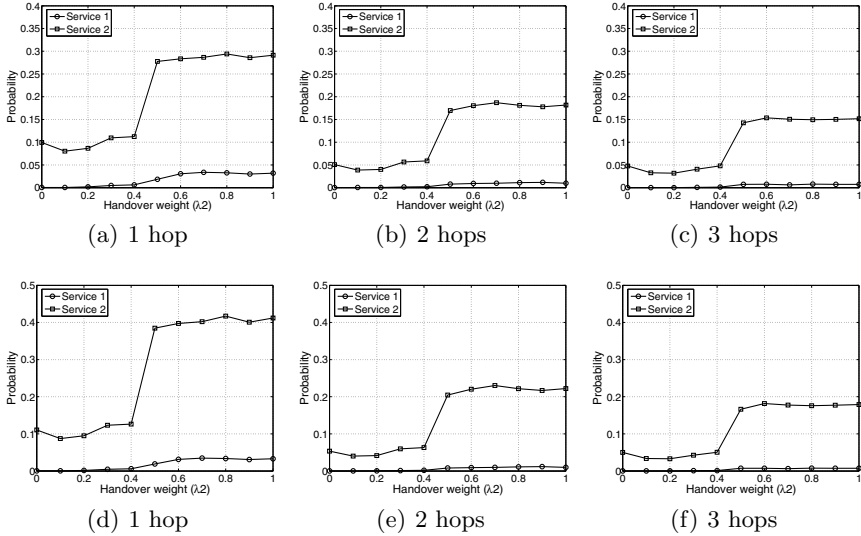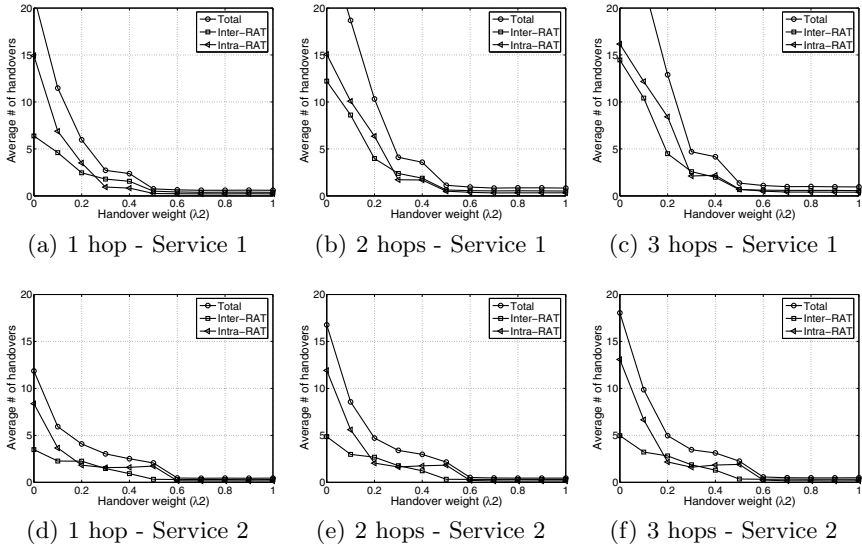
Fig. 6. Reject (top) and anomalous termination (bottom) probabilities with the *Network Centric* strategy

which is the consequence of tweaking the access selection strategy, by varying the weight of the two constraints, λ_i; again, it is clear that $\lambda_1 = 1 - \lambda_2$.

Figure 6 shows the reject and anomalous termination probabilities; in this case we can also see the benefits of the multi-hop extensions, since both probabilities are heavily reduced when increasing the maximum number of hops which can be used to reach a base station (10 % and 20 %, respectively, when increasing from 1 to 2 hops, and $\tilde{5}$ % when allowing up to three hops). For instance, we can see that both probabilities almost reaches 0 for the first service when three hops are allowed to reach an Access Element. Besides, the effect of the multi-hop extensions are more clear in this case; this is a direct consequence of the load balancing procedure which is used by the base stations, which maintains a bunch of available resources in the network. In fact, this improvement is even more remarkable, when we increase the weight given to the load balancing constraint. Finally, and opposed to the Terminal Centric approach, the figures show that there is a strong influence on the particular configuration of the access selection strategy (values λ_1 and λ_2) in the obtained results. In all the analyzed cases, we can clearly distinguish two areas, with a relevant penalization on the QoS perceived by the end-users when λ_2 is higher than 0.4; however, both metrics stay quite stable in the two resulting intervals.

On the other hand, Figure 7 shows the average number of handovers which are executed per service for the different configurations of the *Network Centric* strategy. The first aspect to be highlighted is the values obtained for the lowest values of λ_2, for which we can see a high number of handovers taking place. The reason behind this aspect is that, in these circumstances, the main (and almost

(a) 1 hop - Service 1   (b) 2 hops - Service 1   (c) 3 hops - Service 1

(d) 1 hop - Service 2   (e) 2 hops - Service 2   (f) 3 hops - Service 2

**Fig. 7.** Average number of handovers for the *Network Centric* strategy

unique) goal of the access selection strategy is to balance the load between all the base stations, and thus it is sensible thinking that there might be some *ping-pong* effect, shifting the communications between base stations almost continually. As soon as the weight that the network gives to keeping the calls on the same base station takes a sufficiently large value (0.4), the number of handovers heavily decreases and, from that moment, it is maintained on a reasonably low values, independently of the configuration of the access selection strategy. Regarding the influence of the maximum number of hops which can be used, we perceive a light increase of the average number of handovers when increasing route lengths, but the difference is almost negligible for values of λ_2 higher than 0.4, as it was also observed for the *Terminal Centric* strategy.

Taking into account that this was one of the main objectives of the *Network Centric* access selection strategy, the values which are observed in Figure 8, which shows the relative load per RAT, could have been anticipated. In this case, traffic is much fairer distributed between the different types of base stations which conform the scenario under analysis. The two previously identified intervals are again easily identified in the figures, being the boundary once more around $\lambda_2 = 0.4$, as it happened with the previously studied parameters. However, the aspect which more clearly appears this time is that the effect of increasing the number of hops which can be used to reach a base station has a strong influence, as we can see a notable enhancement of the occupancy of both RAT-1 and RAT-3, especially when we increase from one to two hops (around 10 %).

Finally, Figure 9 shows the improvement from the point of view of the overall network throughput. Again, we see that the multi-hop extensions can provide a

(a) 1 hop   (b) 2 hops   (c) 3 hops
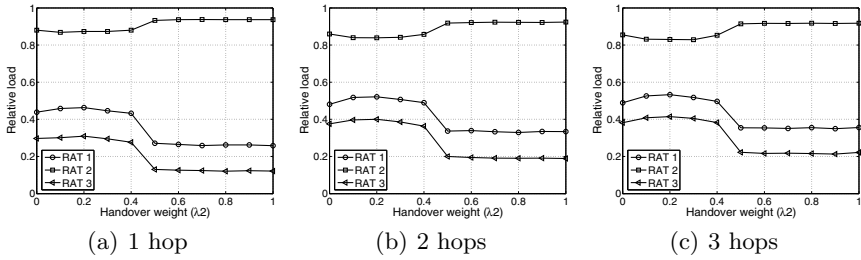
Fig. 8. Relative RAT load with the *Network Centric* strategy
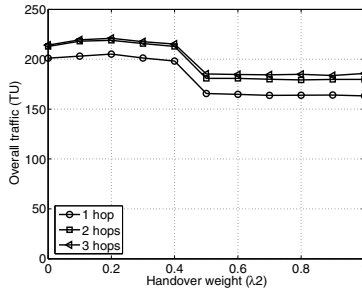
Fig. 9. Overall network throughput with the *Network Centric* strategy

significant revenue increase to the operators and that, in this case, the overall throughput is higher than in the *Terminal Centric* strategy, as could have been expected, since the goal of the network should be to maximize the overall load.

5   Conclusions

By using a generic access selection algorithm we have evaluated the performance of different access selection strategies. We have analyzed two complementary approaches, one centered at the end-user terminal and the other one centered at the network. For the two of them, different configurations, based on various parameters, have been used. The obtained results could help to establish an optimum configuration for the access selection strategy.

Furthermore, we have seen that the use of multi-hop extensions may bring about different benefits, not only to the end-users, but also to network operators, since they will facilitate an increase on the overall network throughput.

In the future we will analyze other access selection strategies, combining the preferences of the terminals and the network, as well as adding more constraints into the picture. In addition, we will compare the results by running the access selection algorithm with the optimum values, using Optimization Techniques to find these benchmarks.

Another item which is left for future work is to account for more realistic channel models, according to the specific considered technology and to analyze the drawbacks of the multi-hop extensions (e.g interference).

Acknowledgements

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