Deliverable FI3-D1.1.6
Study on Cognitive Resource Management for Multi-access Networks

Helena Rivas

Petteri Mannersalo

TIVIT Future Internet Programme
(TIVIT FI)

Phase 3: 1.4.2011 – 30.4.2012

Tivit, Strategisen huippuosaamisen keskittymän tutkimusohjelma

Rahoituspäätös 1171/10, 30.12.2010, Dnro 2790/31/2010

www.futureinternet.fi

www.tivit.fi

This work was supported by TEKES as part of the Future Internet programme of TIVIT (Finnish Strategic Centre for Science, Technology and Innovation in the field of ICT).

Executive summary / Internal release

Title: Study on Cognitive Resource Management for Multi-access Networks

Content: This technical report describes an expert system solution optimizing which access points a multi-interface wireless device should connect. The access point classification is performed by applying a cascade fuzzy logic approach. The decisions are based on information on the status of the network, used services and the device itself.

Impact: The developed solution is implemented within the FI3 showcase application. In general it allows more efficient usage of resources and improves the QoE.

Contact info: Helena Rivas (helena.rivas@vtt.fi) and Petteri Mannersalo (petteri.mannersalo@vtt.fi)

1 Introduction

Within the future internet program, cross-layer metrics and dynamic decision mechanisms for network access selection based on different criteria, like energy-efficiency, cost, delay, capacity, security, etc., have been developed. The possible optimization algorithms include, e.g., self-organized maps, fuzzy logic, game theory and genetic algorithms. In this paper, we present a network selection fuzzy logic (NSFL) approach for multi-access devices.

The overall scenario consists of wireless devices equipped with multiples interfaces which can be used at the same time and may support different technologies (WLAN, 3G and LTE). The devices run a content delivery application, which in this case is a multi-access capable BitTorrent supporting localization of data. The setting is showed in Figure 1. The ultimate goal is an end-to-end load balancing solution, where the load balancing decisions are made co-operatively both at the network and at the service level. Additionally, each end user tries to optimize his/her QoE. In this document, we focus on the network selection from the access point perspective without collaboration with the service level mechanisms. The main idea is that the interfaces of the multi-access mobile device are connected to the most suitable network based on the information on available services as well as statuses of the access points and the devices themselves.

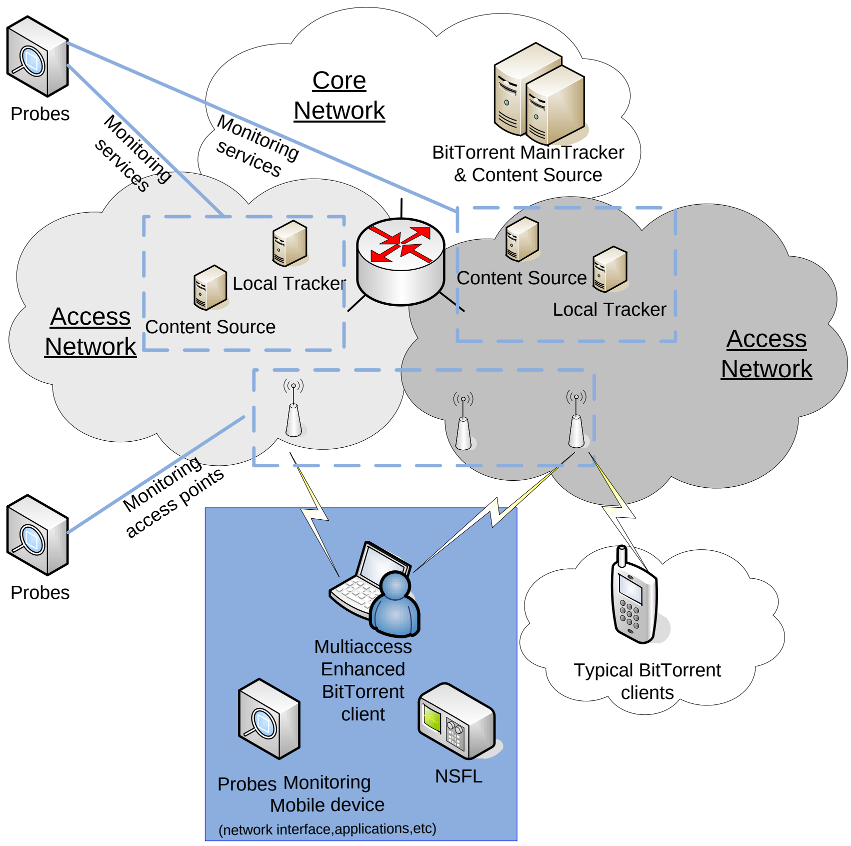

Figure 1: Multi-access scenario

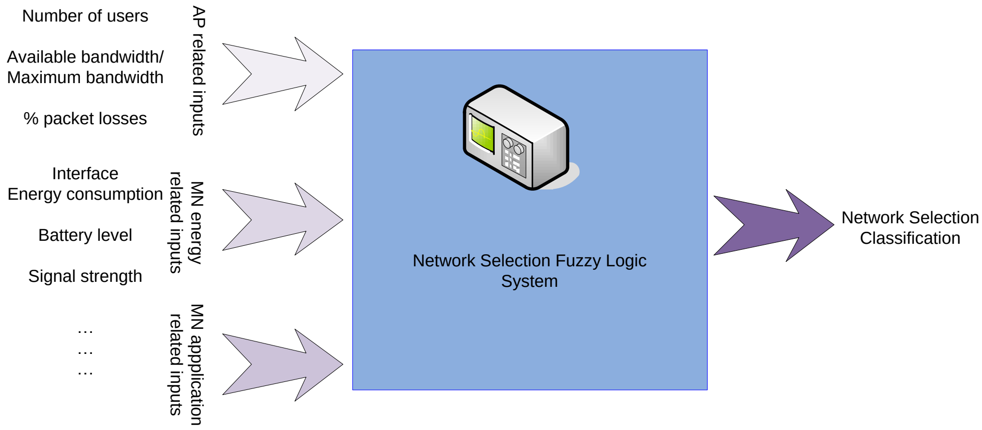

Figure 2: Network Selection Fuzzy Logic System

The probes monitoring the APs, mobile devices and services send the information to NSFL which ranks the access points per mobile device. An example is shown in Figure 2. We take into consideration not only the congestion of the access points, but also energy consumption of the interfaces and application related inputs. The decision modules, located either at the access or client level, receive the AP classification updates from NSFL. Since the NSFL implementation does not keep track of the previous states of the APs, the decision modules need to keep a history of previous states to avoid pingpong effects. Based on the information received from NSFL, a handover recommendation or forcing may be triggered.

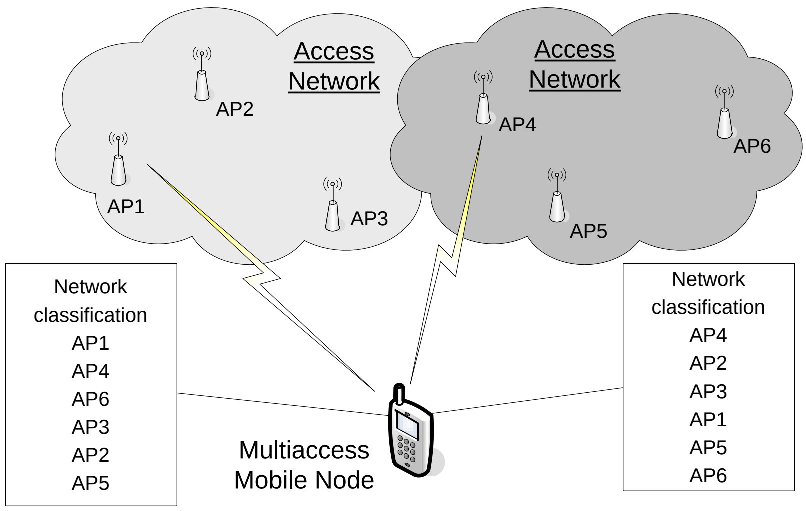

Figure 3: NSFL classification

Figure 3 shows the basic idea of the approach. Based on the NSFL outcome, each interface of a multi-access mobile node (MN) is associated with a ranking of possible AP connections. Then the decision module may suggest or force to use certain interface(s) and decide which AP to connect. If the NFSL instance and decision module co-locate inside a mobile device, the following pseudo-code could be used for access selection:

```
For each network interface ni available in the mobile node do
        l_ap = ordered list of Aps
        For each AP ap in range
                Run NSFL(ni,ap)
                Add ap to l_ap
        End
Interface ni connect to first AP in l_ap
End
```

In this case after obtaining an ordered list of APs per interface, we choose to connect to the best AP from that list. Note that if there are additional preferences or policies by the user or the network providers, these requirements need by included in the access selection algorithm.

2 NFSL: Network Selection Fuzzy Logic

We have implemented a Mamdani-type [Mamdani] Cascade Fuzzy Inference System, where an input space is mapped into an output space based on if-then-rules. The implementation details are given below

2.1 Input variables

In order to apply fuzzy logic, we need to define membership functions that map input value to its appropriate membership. In this work, the network classification is based on inputs related to the APs, energy consumption and application specific variables. In all cases, a triangular membership function is used (see e.g. Figure 4).

AP related inputs variables:

For evaluating an access point we choose three main parameters: number of users associated to it, ratio between available bandwidth and maximum bandwidth and the percentage of packet losses. With these parameters we expect get an overall view on the load of the AP.

For each of the input variables, we define the membership functions. For example Figure 4 shows the membership functions for the number of users associated with the AP.

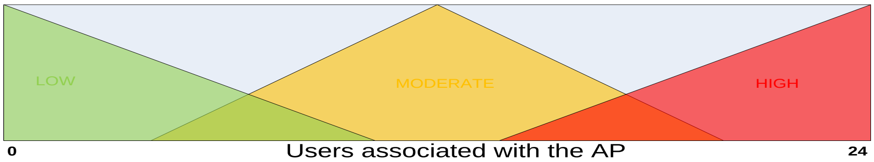

Figure 4: Membership function for numbers of users per AP.

We define triangular membership functions for the different levels (LOW, MODERATE, and HIGH) for all three input variables.

MN related inputs variables:

As energy consumption is quite important factor for small mobile devices, we have taken into consideration the energy consumption of the network interface, the battery levels of the MN and also the signal strength to AP. For these three variables triangular membership functions were defined for the different levels (LOW, MODERATE, and HIGH).

Application related input variables:

Many parameters can be chosen depending on the applications running on the MN. In this paper, we have focused on a multi-access BitTorrent client scenario. In this case, the ratio between (local) seeds and peers in the network can be considered as an indicator of the goodness of the access point.

2.2 Output variables

AP related output variable:

The output parameter in this case is an indicator of how loaded is the AP. For this we define five levels (VERY_BAD, BAD, REGULAR, GOOD, and VERY_GOOD) and used again triangular membership functions.

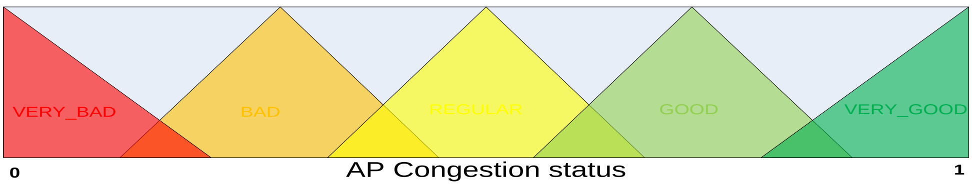

Figure 5: Membership function for AP congestion status

MN related output variable:

The output parameter in this case is an indicator of how good is to connect to determined network through some network interface. A triangular membership function for each of five levels (VERY_BAD, BAD, REGULAR, GOOD, and VERY_GOOD) was defined for this output variable.

Network classification output variable:

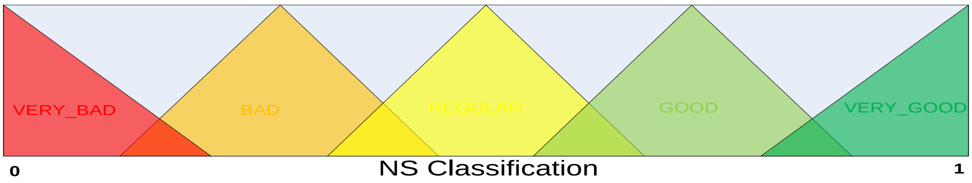

Figure 6: Membership function for Network Selection Classification

Finally the fuzzy logic algorithm returns a value between 0 and 1 indicating the goodness of the network selected. Being 1 the best possible classification result.

2.3 Rules

The set of rules are defined based on the knowledge about the input parameters.

2.4 Output

The different FIS modules use Mamdani based rules for computing the output.

2.5 Cascade classification

Due to the great number of input parameters in our system and the difficulty of defining the fuzzy rules for NSFL we opted to have a modular solution. NSFL consist of a cascade of different FIS to get to the final classification of the network. See Figure 7.

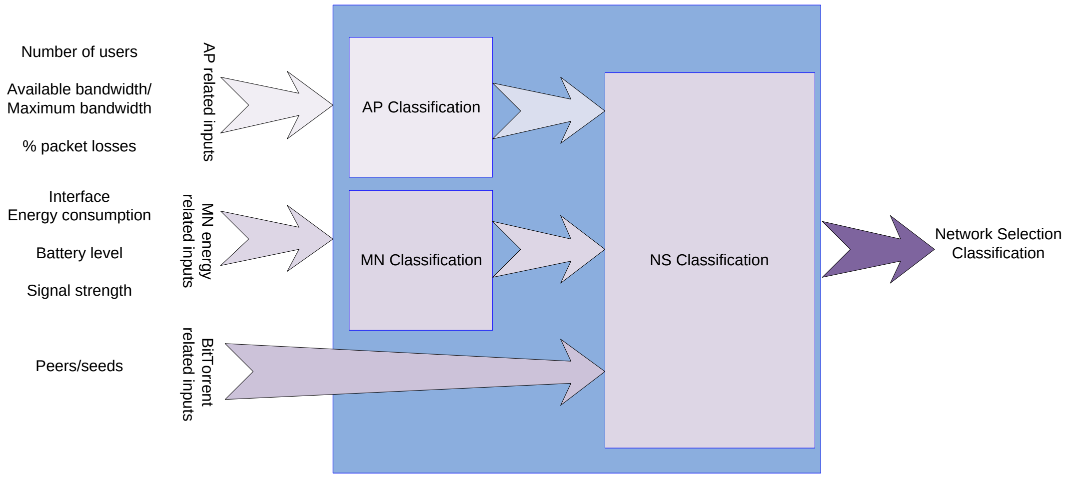

Figure 7: Cascade classification.

2.6 Fuzzy Inference process

The fuzzy inference process consists of five parts: fuzzification of the input variables, application of the fuzzy operator (AND or OR) in the antecedent, implication from the antecedent to the consequent, aggregation of the consequents across the rules, and defuzzification. An example is showcased in Figure 8.

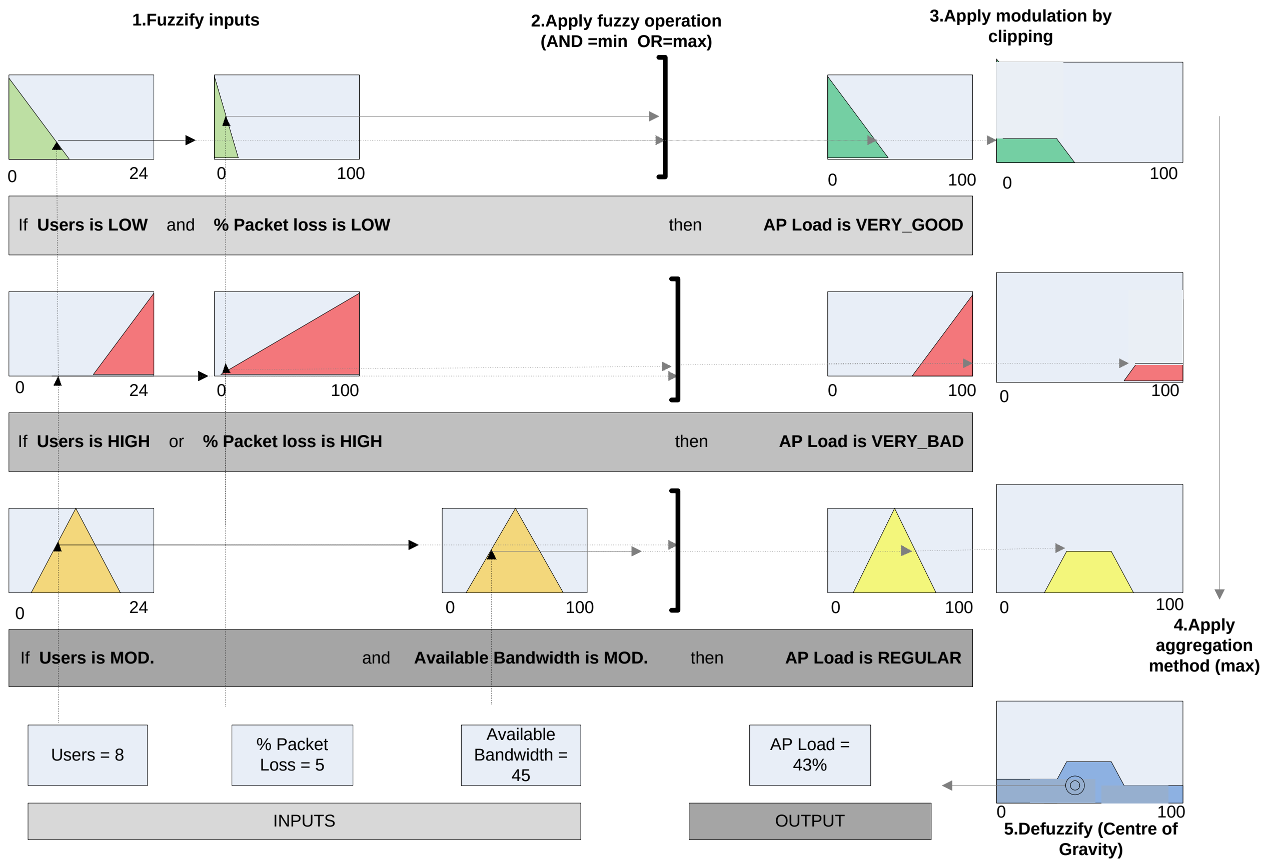

Figure 8: Fuzzy inference process.

3 Implementation

The NFSL approach has been implemented in the Future Internet showcase to demonstrate how the cognitive solutions can be applied in the context of multipath/multi-interface communications. In order to enable communication between the different entities, a Distributed Decision Engine (DDE) [dde] framework has been used. It not only defines a common interface for different information producers, algorithms and configuration enforcement points at different levels to exchange information, but also provides a caching and a filtering functionality for messages to be delivered among different entities. The framework is shown in Figure 9 and the details of a proof-of-concept implementation are depicted in Figure 10.

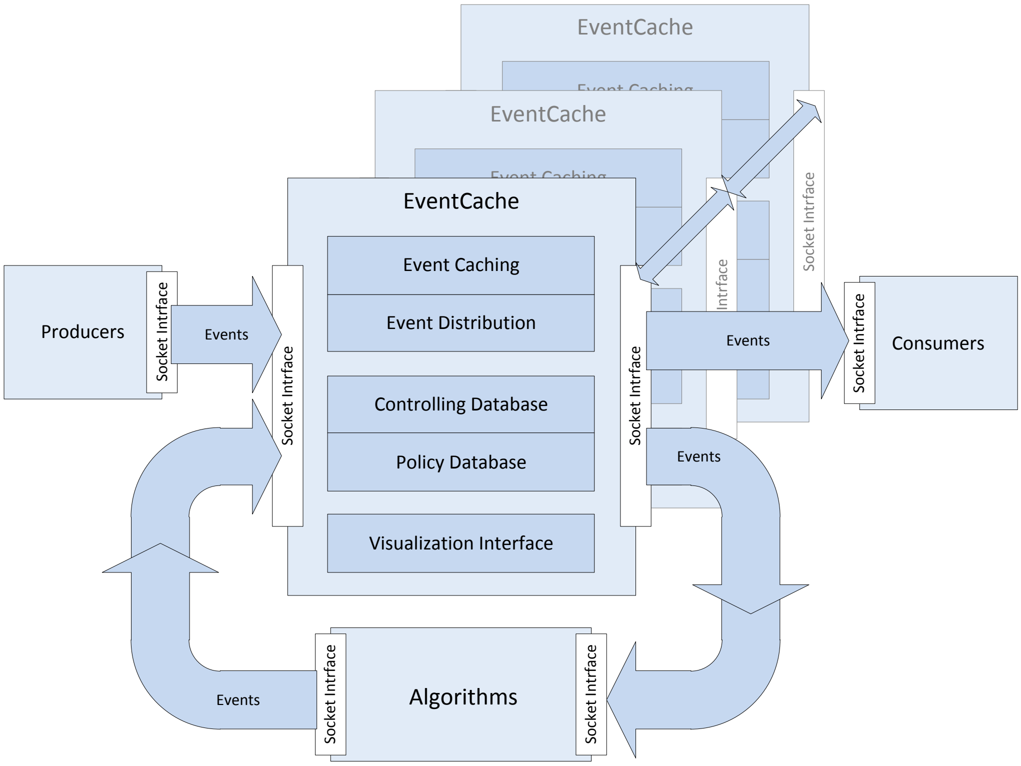

Figure 9: Distributed Decision Engine (DDE).

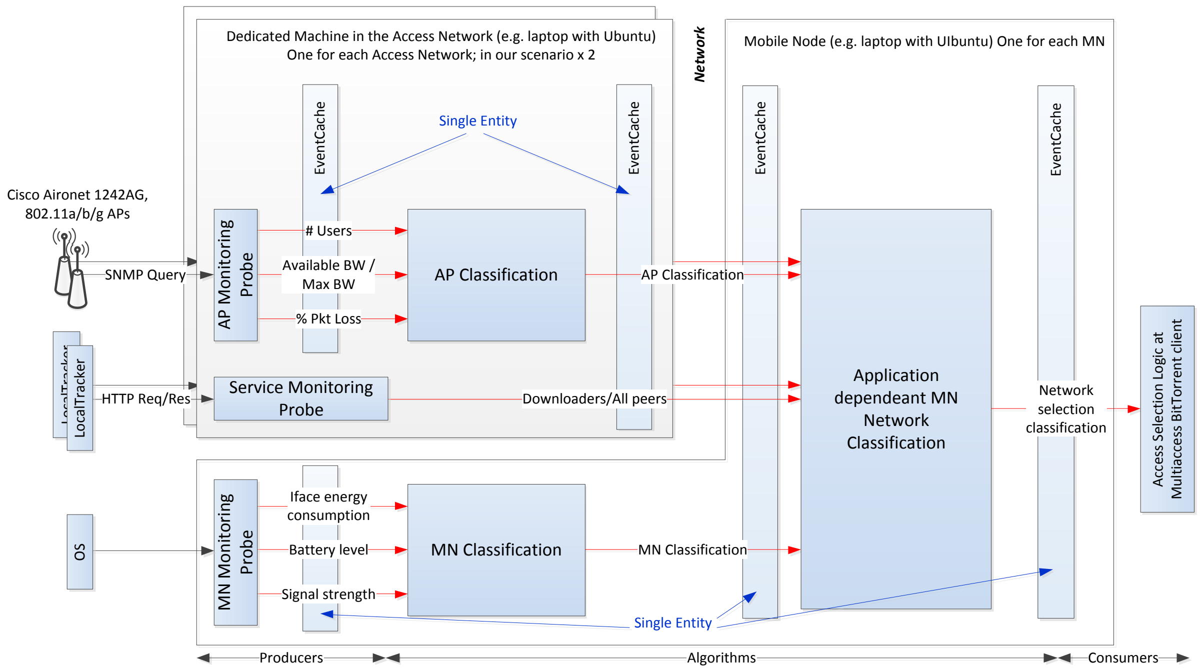

Figure 10: Proof-of-concept implementation

The fuzzy logic algorithm for NFSL has been developed using C++ implementation of FuzzyLite library v.1.03 [fuzzylite]. Default setting has been used for defining the fuzzy system.

T-Norm: FuzzyAndMin	Defuzzifier: CoGDefuzzifier
S-Norm: FuzzyOrMax	Algorithm: TriangulationAlgorithm
Modulation: FuzzyModClip	Number of samples:100
Aggregation: FuzzyOrMax	

4 Concluding remarks

The network access selection is a long studied problem and several different approaches have been applied. There exist several different solutions and there is no unique optimal solution as the performance strongly depends on the use case. For example, we have also studied neural network based AP classification using self-organizing maps (SOM) in quite similar setting. However, since SOM based approach requires long training whenever the system is changed noticeable, we have opted for fuzzy logic based solutions which are better suited for highly dynamic situations with distributed decision making. NFSL approach does not necessarily result in the optimal performance, but it is easily implementable and after the suitable parameter values are found the observed performance measured, e.g., in terms of QoE is quite good.

5 References

[mamdani] E.H. Mamdani and S. Assilian, "An experiment in linguistic synthesis with a fuzzy logic controller," International Journal of Man-Machine Studies, Vol. 7, No. 1, pp. 1-13, 1975.

[fuzzylite] FuzzyLite: A fuzzy Logic Library written in C++. Developed by Juan Rada Vilela http://code.google.com/p/fuzzy-lite/

[dde] J. Mäkelä, M. Luoto, T. Sutinen and K. Pentikousis, "Distributed information service architecture for overlapping multi-access networks." International journal of Multimedia Tools and Applications, Springer 2011.

[nes] S. Horsmanheimo, J. Eskelinen, and H. Kokkoniemi-Tarkkanen: "NES - Network Expert System for Heterogeneous Networks", In Proceedings of the 17th International Conference on Telecommunications 2010 (ICT-2010), April 2010, Doha, Qatar. http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=05478789