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A Novel Radio Resource Management Solution in Beyond 3G Scenarios

L. Giupponi(1), R. Agusti(1), J. Pérez-Romero(1), O. Sallent(1), J. Luo(2)

(1) Universitat Politècnica de Catalunya (UPC)

(2) Siemens AG, Germany

Abstract

This paper presents an approach to Joint Radio Resource Management based on a Fuzzy Neural methodology in order to operate in a heterogeneous network scenario including cellular and wireless local area network radio access technologies. Simulation results show that the Reinforcement Learning mechanisms introduced in the proposed JRRM methodology allow guaranteeing the QoS requirements. Also, the proposed framework is able to take into consideration different operator policies as well as considering different subjective criteria by means of a multiple decision making mechanism, such as balancing the traffic among the RATs or giving more priority to one RAT in front of another one.

Furthermore, the vision considered in E2R (End-to-end Reconfigurability) Project is retained and the interactions with Dynamic Network Planning and Management and Dynamic Spectrum Management functionalities are detailed.

***Index Terms*— Fuzzy Neural, Joint Radio Resource Management, System Beyond 3G, Reconfigurability.**

1. Introduction

The problem faced by a wireless network operator is to offer a system where the network usage is maximized for a given set of QoS requirements. In the framework of 2G mobile systems (e.g. GSM), the network planning is key. However, in the framework of 3G mobile systems the situation is significantly different because of several reasons. Firstly, in WCDMA based systems there is not a constant value for the maximum available capacity, since it is tightly coupled to the amount of interference in the air interface. Secondly, the multiservice scenario drops for some services the constant delay requirement and, consequently, opens the ability to exploit RRM (Radio Resource Management) functions to guarantee a certain target QoS [1]. On the other hand, the perspective of Beyond 3G systems is that of heterogeneous networks, in which a proper interworking among RATs (Radio Access Technologies) is required, so a new dimension in the radio resource management problem is introduced. Joint Radio Resource Management (JRRM) is the envisaged process to manage dynamically the allocation and de-allocation of radio resources (e.g. time slots, codes, frequency carriers, etc.) within a single or between different radio access systems for the fixed spectrum bands allocated to each of these systems. With JRRM a more efficient usage of the radio resources will follow thanks to the trunking gain resulting from the consideration of the total pool of resources in all the RATs as a whole.

By exploiting the various RATs in addition to the different bands and hierarchical cell deployment for each RAT, both users and operators can benefit from the particular advantages each RAT offers at a given point of the time and space. In addition to that, load sharing would allow an efficient usage of resources and multi-homing capabilities could provide parallel bearers in different RATs, so as the particularities of each RAT could even be better exploited [16].

JRRM functions are implemented in the form of algorithms, which are not subject of standardization as such. Nevertheless, measurements and parameters that can be useful at JRRM are well identified.

In this context, this paper presents a general framework for JRRM development accompanied by a specific JRRM solution in order to provide more insight into the problem. The considered solution is based on Fuzzy-Neural mechanisms, which allow taking into account radio network considerations, user preferences and operator preferences in JRRM decisions. In this sense, the approach is flexible and the same framework may provide suitable solutions for both long term and short term technology evolutions. In addition to RAT selection decision, bit rate allocation is also feasible. Further, the proposed scheme will be placed in the context of a fully Beyond 3G Reconfigurable system by identifying the main interactions with relevant functional elements as well as the requirements and constraints arising in this framework. In particular, the vision considered in E2R (End-to-end Reconfigurability) Project [2] will be retained, and the interactions with Dynamic Network Planning and Management and Dynamic Spectrum Management functionalities will be further detailed.

2. JRRM framework

JRRM problem is complex and admits many possible solutions. Nevertheless, there is not an absolute optimal solution due to the multiplicity of possible criteria to consider, the constraints imposed by RATs characteristics, coupling architecture, implementation approach, user's and operator's preferences, etc. Consequently, a given JRRM strategy may result suitable in a specific framework and time-frame while not fitting another technology evolution stage and/or network constraints.

The inputs available for JRRM decisions are mainly:

- RATs deployed, bandwidth available for each RAT and scenario configuration (i.e. base station maximum transmitted power level, code sequences available in case of WCDMA based RATs, etc.)
- Interworking level of RATs in terms of very tight coupling, tight coupling, loose coupling, open coupling, etc.
- Measurements coming from the different RATs (e.g. load levels) as well as measurements coming from the User Equipments (UEs), such as the received power levels, the path loss or the Ec/Io (chip energy over noise and interference spectral density) in case of WCDMA based RATs.
- Terminal capabilities, e.g., the multi-band multi-mode terminal or multi-mode single band terminal
- Techno-economical aspects, including operator policies, which may prevail the use of certain RATs in front of others for different reasons (e.g. commercial strategies, radio network ownership, etc.) as well as subscriber profiles and user preferences (e.g. considering QoS versus cost).
- Service scalability and different priorities of the context inside of a service (e.g. the scalable video coding)

The task executed by the JRRM (managing radio resources of interworking RATs or frequency layers) include:

- Selection of RATs (Joint admission control)
- Vertical Handover (intersystem handover)
- Diagonal Handover (handover between RATs and also with dynamic frequency reallocation)
- Joint Scheduling: the scheduler could even work over multiple RAT/frequency layers, e.g., HSDPA with two frequency layers supporting RMH
- Joint Power control between interfering RATs. This does not apply to the inner-loop power control but to the outer-loop.

In turn, the Local RRM undertakes local resource allocation:

- Local admission control (RAT profile based, user preference based, terminal profile based)
- Horizontal Handover

- Outer-loop power control
- Flow control
- Load control
- Congestion control
- Power control within a RAT, including outer loop as well as inner loop power control
- Local packet scheduling
- Allocation of RAT specific resources, e.g., Channelization codes in CDMA, time slot in TDMA system, subcarriers in OFDMA system
- Other functions: e.g., cross layer functions

For some functions, the boundary between JRRM and local RRM is becoming blurred. Even very low OSI layer ARRM (Advanced RRM) functions might contain the JRRM component and local RRM components, e.g., power control, scheduling.

A special case is the distributed JRRM: in this case, the JRRM entity, e.g., Common RNC is absent, however the interworking among local RRM entities can also take over the JRRM functionalities [17].

3. A case study based on Fuzzy Neural approach

In order to envisage proper JRRM algorithm frameworks, it is important to consider that the variety of JRRM inputs belonging to different RATs will provide in general imprecise and very dissimilar information. As a result of that, since the fuzzy logic-based methodology has been proved to be good at explaining how to reach suitable decisions from such type of information [3][4][5], the framework for JRRM strategies development proposed here considers this approach. On the other side, the use of neural networks, which are good at recognizing patterns by means of learning procedures, can also be considered by tuning the fuzzy membership functions properly, thus developing hybrid solutions incorporating both fuzzy and neural methodologies [6][7].

The proposed framework for JRRM algorithm implementation based on Fuzzy-Neural mechanisms consists of three main blocks: Fuzzy based Decision, Reinforcement Learning and Multiple Objective Decision Making [8][9]. The inputs to the algorithms are a set of linguistic variables LVi, corresponding to different measurements. Also, techno-economical criteria in the form of user preferences (UP) and operator preferences (OP) are inputs of the algorithm.

The Fuzzy Based Decision, Reinforcement Learning and Multiple Objective Decision Making algorithms are executed every time a new user asks for admission in the system and during the user session. It assures the dynamical allocation and de-allocation of radio resources in the scenario and the selection of the most suitable RAT, while keeping the desired QoS requirements of all admitted users. Initial evaluations of the proposed JRRM approach were carried out in simplified scenarios [10][11]. This paper extends these prior works by further proving the concepts of the JRRM Fuzzy-Neural algorithm in a multicell scenario.

Results will prove the suitability and flexibility of the proposed approach in terms of:

- Capability to guarantee a certain QoS objective
- Capability to implement load balancing principles among diverse RATs
- Capability to implement user and operator's preferences on the RAT selection and dynamic processes.

3.1 Simulation model

Initial evaluations of the proposed JRRM approach were carried out in simplified scenarios, i.e. considering only three concentrically cells (one UMTS, one GERAN and one WLAN). In order to further prove the concepts of the JRRM Fuzzy Neural algorithm, a multicell scenario, with a seven cell deployment, including 4 UMTS base stations, 2 GERAN base stations and one WLAN access point has been envisaged as illustrated in Fig. 1. Each cell is characterized by a given coverage area and its corresponding RAT. The considered scenario consists of circular cells, with radii R1, R2 and R3, defining WLAN, UMTS and GERAN dominant areas respectively.

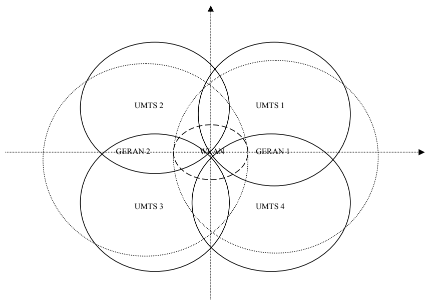

Fig. 1. Considered multi-cell scenario

In this scenario, both the RAT and the cell need to be selected for each user during the execution of the JRRM algorithms. To this end, a two steps procedure has been considered in order to decouple the cell selection from the RAT selection and bandwidth allocation processes, as outlined in Fig. 2. It is assumed that the JRRM procedure is executed for each user after having selected a combination of cells from the available RATs, i.e. a UMTS cell, a GERAN cell and a WLAN access point. The rationale behind this split of functionalities is to have a limited number of inputs in the fuzzy-based decision procedure, thus obtaining a more scalable JRRM procedure.
Firstly, a combination of three cells built around the three considered RATs is selected. To this end, a Fuzzy controller is considered, and applied to all the possible combinations of cells. As an example, the considered scenario consists of 8 combinations of cells. A Fuzzy controller is applied to each combination, thus generating a FSD (Fuzzy Selected Decision) value as output, which is obtained as the maximum of the FSD values corresponding to UMTS, GERAN and WLAN for this combination. Then, the FSD is taken as the indicator of appropriateness of the combination and, consequently, the chosen combination will be that providing the highest FSD. It is worth noting that in a given deployment scenario, some combinations could be disregarded in advance if the corresponding cells do not overlap, thus reducing the number of computations so that the scalability can prevail.

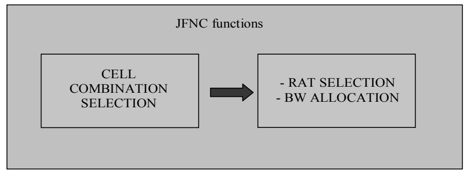

Fig. 2 Functions of the Joint Fuzzy Neural Controller

A Signal Strength criterion could also be considered in order to select a combination of cells, i.e. selecting the cells with the highest signal strenght of each RAT. However this choice would provide poorer performance, since a Fuzzy criterion is able to take into account more information in the selection, like the load existing in each cell.
The RAT selection and bit rate allocation are implemented by means of a Fuzzy Based decision, reinforcement learning and multiple decision making algorithms and constitute the final JRRM step once a particular combination selection has been retained. The Fuzzy Based decision algorithm consists of a 5-layered Fuzzy controller: Layer 2 is in charge of performing the fuzzification procedure, layer 3 implements the inference engine according to a defined Fuzzy Rule base, whereas layer 4 performs the defuzzication procedure by means of the centre-of-area method [9]. In addition to this, layers 1 and 5 manage the input/output functionalities. This process is carried out at the admission control phase and also along the active users' sessions, thus checking whether a horizontal or vertical handover is required.
With respect to performance measurements, the concept of service non-satisfaction is considered. A user is "*Non satisfied*" if, at least, one of the following situations occurs:
- The fuzzy system assigns to it an amount of bandwidth lower than the desired one according to its contract
- The user is in the "outage" state, which means that the received power does not satisfy the sensitivity criterion, which is defined differently for each of the RATs as detailed in [11].
In order to properly capture the performance of the system, the following measurements are also considered to complement the "non-satisfaction" probability:

- *Blocking probability*. A user is blocked if at the session start the JRRM algorithm assigns to the user a bandwidth of 0 kb/s.
- *Dropping probability*. A user is dropped if, after changing the current cell combination that is being considered in the bandwidth allocation for a given user, the JRRM algorithm assigns to the user a bandwidth of 0 kb/s, which means that a horizontal or a vertical handover failure has occurred.

A mobility model with users moving according to a random walk model inside the coverage area is adopted with a randomly assigned mobile speed (MS) between 0 and 50 km/h and a randomly chosen direction. The propagation model considered for UMTS and GERAN is given by L=128,1+37,6 log d (km) [12], which assumes that the frequency band is similar for both systems. For WLAN the propagation losses inside the hotspot are modelled by L= 20 log d(m)+40 [13]. The beginning and the end of the user's activity periods are defined according to a Poisson scheme with an average of 6 calls per hour and user and average call duration of 180 seconds. The users moving around the scenario belong to the traffic class described in Table I.

TABLE I
TRAFFIC CLASS

	Maximum Rate	Desired Rate ≥
UMTS	384 Kbps	192 Kbps
GERAN	96 Kbps	40 Kbps

Results are presented for the uplink direction, and the considered possible bit rates for the different RATs are:

For UMTS: 32 kb/s, 48 kb/s, 64 kb/s, 80 kb/s, 96 kb/s, 112 kb/s, 128 kb/s, 192 kb/s, 256 kb/s, 320 kb/s, 384 kb/s. A single UTRAN FDD carrier is considered. The maximum allowed uplink load factor is 0.75.

For GERAN: 32 kb/s, 48 kb/s, 64 kb/s, 80 kb/s, 96 kb/s. It is assumed that four carriers are available in each GERAN cell for GPRS users, with coding scheme CS-4 [14], thus having a maximum bit rate in the cell of 640 kb/s.

For WLAN it is considered that the total bandwidth available (11 Mb/s) is equally distributed among the WLAN users (i.e. the higher the number of users the lower the bandwidth per user will be) [15]. It is also assumed that no more WLAN users are accepted when the bandwidth per user is less or equal than 384 kb/s. A single access point is considered. It is worth mentioning that CFP (Contention free period) mechanisms allow that different users share a WLAN channel simply scheduling the transmissions on top of the MAC, which justifies the assumption that the same bit rate per user is considered [15].

Other parameters used in the simulations for UMTS are: (Eb/No) =3dB is the target requirement, PN=-106 dBm the receiver thermal noise power, W=3.84Mc/s the chip rate and the maximum available power in UMTS is 21 dBm. Cell radii of 150 m for WLAN, 650 m for UMTS and 1 km for GERAN are retained. Also the sensitivity level for GERAN is -87 dBm and for WLAN it is -93 dBm.

The Fuzzy-Neural algorithm is activated every 100 ms for the simulation purposes in order to re-allocate bandwidths and/or RATs to the currently admitted users as well as to include new users, so that the allocated resources can be changed dynamically.

In the following subsections, the different aspects of the proposed JRRM algorithm that have an influence over the final performance will be analysed on a step by step basis, in order to better clarify the relevant role played by each one.

3.2 Reinforcement Learning in a multi-cell scenario

The reinforcement learning mechanism allows to set the average value of an objective and measurable performance indicator to a target value. In particular, the non-satisfaction probability $P_I(t)$, is retained here as target performance indicator. The target rate P* can be set to any desired value (i.e. P*=1, 3, 10 %) and the system is able to keep this value during the whole simulation time, as it is shown in Fig. 3 for three different values of P*.

Furthermore, during the simulation time in the example of Fig. 3, the Fuzzy-Neural system has to cope with two sharp traffic variations.

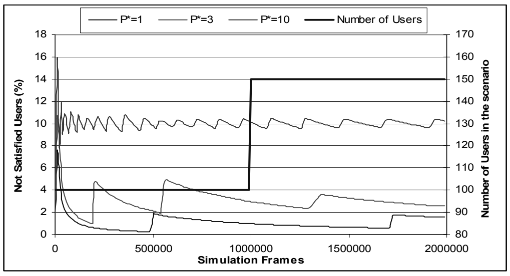

Fig. 3 Evolution of the non-satisfaction probability

At simulation start, the whole system switches from a situation in which no mobile is located in the scenario to another one, where 100 users are moving around the scenario and demanding service. In addition to this, at simulation frame 1000000, 50 more users join the scenario. Notice that, at the beginning of the simulation, a transient period after which the Fuzzy-Neural system converges to the desired QoS condition is necessary, whereas, in correspondence with the second artificial traffic change, the users are unaware of this sudden change and only concerned with the contracted QoS in terms of dissatisfaction.

3.3 Load Balancing Capabilities

The proposed approach allows the operator to select different sets of inference rules according to specific operator policies or business models to match the particular operational needs. In order to prove that the policy stated by inference rules (IR) can modify the traffic distribution in the scenario, a new scenario characterized by 9 carriers in GPRS in order to offer a similar bandwidth than in UMTS is considered. In this scenario three sets of inference rules will be considered. The first one (reference inference rules), gives a higher priority to the UMTS selection, the second one (modified inference rules) gives a higher priority to the GERAN selection while the third one (balanced inference rules) aims at balancing the traffic among UMTS and GERAN RATs. Fig. 4 shows the aggregate bandwidth allocated in each UTRAN and GERAN base station. It can be noticed that the traffic load per RAT and cell varies according to the different policies.

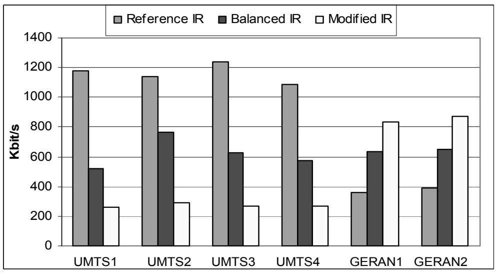

Fig. 4 Result of different Inference Rules policies

Then, an operator could balance the traffic in the network or give more impact to a particular RAT, preserving the same performances in terms of Not Satisfied users, and keeping the Blocking and Dropping probabilities to nearly comparable rates (not shown here for the sake of brevity).

3.4 Setting Operator and User Preferences

A very similar effect to the modification of the inference rules can be obtained by applying the multiple objective decision making [10]. This fact has been illustrated in the following simulations, which assume 50 users moving around a scenario with 4 GERAN carriers in each cell. Reference Inference rules are considered. In the following simulation, the criteria taken into account by the decision maker are three: the FSD value (the only one considered up to now), the Operator Preference (OP) and the User Demand (UD). It is assumed that both the users and the operator prefer the GERAN choice according to the following membership values: OP_{UMTS}=0.1, OP_{GERAN}=0.9, OP_{WLAN}=0.1and UD_{UMTS}=0.1, UD_{GERAN}=0.9, UD_{WLAN}=0.1.
In addition, a number is assigned to each criterion indicative of its importance in the decision (see [10] for details on how to establish the importance between criteria). Specifically, the UP and OP criteria are three times more important than the FSD criterion. In turn, UP and OP have the same relative importance between them. In practice, the relative importance between different criteria can be changed dynamically in a rather slow way and the membership values would depend on the user profile and the operator business models.

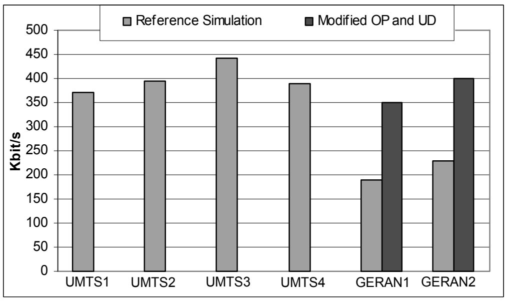

Fig. 5 Impact of OP and UP criteria in the traffic distribution

Fig. 5 shows that with this new configuration GERAN bandwidth assignment has grown whereas UMTS has never been selected. On the other hand, there is no loss in performance in terms of blocking and dropping probabilities. It is worth mentioning that the non satisfaction probability in both cases achieves the convergence to the target value of 10%.

3.5 Comparison with other JRRM approaches

In order to compare the performances of the proposed Fuzzy Neural algorithm against other approaches, three alternative algorithms are considered.
The first alternative algorithm does not take into account the JRRM concept, and it is denoted as Non-JRRM, (NJRRM). The users will be attached to a RAT which is randomly chosen among the ones in which the mobile measures a signal strength (SS) higher than its sensitivity. The second approach takes into consideration the JRRM concept in the following terms: among the cells to which the user could be attached to according to a Signal Strength criterion, the least loaded RAT will be chosen. Then, the criterion is denoted as Load-based JRRM (LJRRM). Finally, the third approach selects the RAT in which the mobile measures the lowest path loss, and it is denoted as Path-Loss-based JRRM algorithm (PLJRRM). In all the three cases, once the RAT has been selected, the bandwidth assigned to each user is the minimum bandwidth considered in the scenario in order to let the users being satisfied (i.e 192 kb/s in UMTS, and 48 kb/s for GERAN).
In Fig. 6 and Fig. 7 the comparison of performances obtained through the execution of the three algorithms is shown as a function of the number of users moving around the scenario. A target non-satisfaction probability of 1% is considered in order to compare the blocking and dropping performances. The results clearly show the benefits offered by the Fuzzy-Neural JRRM proposed in front of the other three alternatives. Even though in NJRRM, LJRRM and PLJRRM the admitted users are always satisfied, because the allocated bit rate is always the desired one, this is at the expense of a very high increase in both the dropping and blocking probability.
On the other hand, the Fuzzy-Neural JRRM algorithm allows keeping the non- satisfaction probability to the desired value (i.e. 1%) achieving at the same time much lower dropping and blocking probabilities.

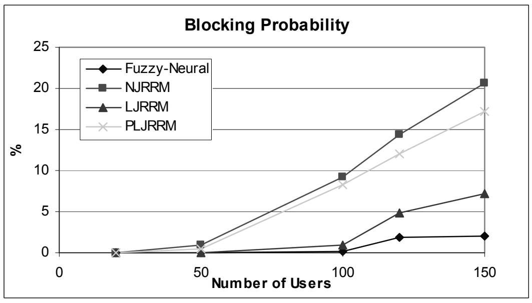

Fig. 6 Performance comparison of the different implementations in terms of blocking

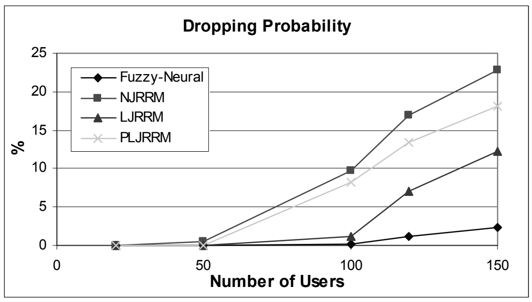

Fig. 7 Performance comparison of the different implementations in terms of dropping

4. Fuzzy Neural JRRM in E2R Framework

End-to-End Reconfigurability (E2R) project [2] targets to devise, develop and trial architectural design of reconfigurable devices and supporting system functions to offer an expanded set of operational choices to the users, applications and service providers, operators and regulators in the context of heterogeneous mobile radio systems. Clearly, reconfigurability is a key enabler to fully exploit the benefits of a Joint Radio Resource Management strategy and, consequently, JRRM approaches should be consistent with reconfigurability perspectives.

In E2R context, a Functional Architecture is identified and continues to be further elaborated [18]. As stated there, the ARRM (Advanced Radio Resource Management) works in the inner-loop of the overall functional architecture. Conceptually, the ARRM includes the Radio Resource Management for a single RAT and Joint radio resource management for interworking RATs. Besides the functions introduced specified by the local radio resource management for a single RAT, the JRRM is defined as a set of networks' or cell layers' controlling mechanisms that supports intelligent admission of calls and sessions; distribution of traffic, power and the variances of them, thereby aiming at an optimised usage of radio resource and maximized system capacity. JRRM mechanisms work over multiple radio networks or cell layers with the necessary support of reconfigurable/multi-mode terminals. JRRM is operated in a network which consists of several subnetworks or cell layers of a single radio network. In particular, the main JRRM functions are the Joint admission control (JOSAC), the Handover (either Horizontal or Vertical), the Joint load control (JOLDC) and the Joint Scheduling (JOSCH).

The proposed Fuzzy-Neural JRRM relates to the overall Functional Architecture as depicted in Fig. 8.

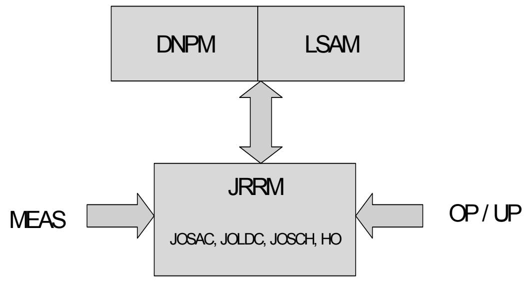

Fig. 8 Required information for JRRM function module and its interworking with other functional modules in a reconfigurable system (MEAS stands for: measurements)

The inputs of the algorithm come, on one hand, from the DNPM/LSAM (Dynamic Network Planning and Management / Local Spectrum Allocation Module), which detail the network layout, corresponding RATs and frequency bands for each site. Further inputs state the operator and users' preferences, profile as well as the measurements (i.e. signal strength, cell load, etc.).
The JRRM provides feedback in the form of KPI to the DNPM. These KPI should trigger re-planning of the area and/or request for additional spectrum in the case that a performance degradation is reported by JRRM. The identified KPI are:

- Not Satisfaction probability
- Blocking probability
- Dropping probability

The Fuzzy Neural module undertakes the following functions:

- JOSAC, as long as a new call/session request arriving at the JRRM can be accepted or not. An acceptance is characterized by a certain RAT and cell together with an allocated bandwidth. A rejection is characterized because the JRRM allocates a bandwidth equal to zero [16][17].
- JOLDC, as long as the activation of the Fuzzy-Neural machine selects a cell, RAT and bandwidth taking into account the load conditions in the overall scenario. In this sense, congestion control actions are inherently included in the Fuzzy decisions. For example, in case a cell is overloaded, this is considered in the JRRM algorithm and

may lead for some users to change to a different RAT or to decrease the allocated bit rate, then releasing congestion[16][17].

- Handover (horizontal and vertical), as long as the activation of the Fuzzy Neural machine may imply a change of cell with continuity in RAT (i.e. horizontal handover) or a change of RAT (i.e. vertical handover). It is worth noting that handover is also inherently coupled with JOLDC, so that JRRM decisions may take advantage of handover mechanisms to prevent and/or solve congestion situations. In case horizontal handover is controlled at lower level by the legacy RRM entities, an implementation of the cell combination selection based on signal strength would be de facto applied.
- JOSCH, as long as the activation of the Fuzzy-Neural machine may imply a change of the allocated bandwidth per user. Then, a packet scheduling mechanism would try to provide the assigned bandwidth resources concurrently from simultaneously connected RATs to the end users [16][17].

In the following section, some key outputs and inputs for neural module are detailed.

4.1 Effective Inputs to the Fuzzy Neural Module

In [17], we have identified the affecting factors for JRRM performance. They are: service profile (packet/circuit switch services, scalability etc.), terminal profile (multi-mode with single band or multi-band capabilities), network profile (network constellation, spectrum arrangement and inter-operability), user profile (preference of RAT) and channel status information (available bandwidth and fading situation). Due to the high complexity of the radio context that a reconfigurable system has to encounter, we proposed two modules in the fuzzy machine: one is the implementation of the rules; another one is the local system state memory (local database).

Based on the pre-knowledge out from our aforementioned principles according to the interrelationship between the factors and the potential JRRM performance, the fuzzy logic machine can work more effectively. For each available principle by knowing the input profiles, a subspace of the whole search space can be identified. The more principles available according to the given factors, the smaller the resulted subspace is. It then implies a much faster search methodology [17].

4.2 Effective Outputs to the Fuzzy Neural Module

According to the traffic pattern, user terminal profile and network constellation in terms of the operated spectrum and co-existing RATs, the Fuzzy-Neural model selects the most appropriate modes of JRRM, such as radio access through a single RAT or radio access through multiple RATs simultaneously.

Another output is to interface the network management function [18]. The overall performance of the KPIs will be periodically reported back to the performance manager in the OMC (Operation and Maintenance Controller) which gets in charge of the network planning and management (DNPM). Whenever the network is under a bad condition resulting in a set of bad KPI, the OMC is informed by the Fuzzy Neural Logic module for further optimization. The results can be an increment of frequency layer, reconfiguration of base station to another air interface or antenna tilt.
Throughout the control loop of Fuzzy Neural network, Fuzzification causes loss of information, which gives even higher demand for the accuracy given by the later decision making engine. If the layers for the MLP (multi-layer perceptron) and number of neutrons are sufficient in providing needed granularity and accuracy, detailed radio resource (e.g., transport block size, quantum size for scheduler, power segments, number of codes) in each scheduling time can also be the outputs of the Fuzzy Neural logic module. Otherwise, the Fuzzy Neural logic module is only used for policy settings added onto the classical JRRM functions, e.g.,

selection of RATs, selection of JRRM modes, i.e., JOSAC or JOSCH.

4.3 Practical Feasibility

With respect to the numerical complexity of the proposed algorithm, it should be mentioned that the number of operations in the procedure is low enough to ensure operation in real time by means of software approaches. In that sense, the required operations should be considered at the following two levels:

- In order to achieve the fuzzy-based decision with respect to the RAT and bandwidth allocation the type of operations to be performed are essentially comparisons and sums. Also a small number of multiplications and divisions are required. As a result of that, the number of operations to achieve a decision per user is in the order of 5000, which turns into a requirement of about 100µs per user on a single state-of-the-art general-purpose processor (e.g. 2 GHz). Then, real time operation is feasible even with a high number of users, since the time constraints are typically fixed at the radio frame-time scale (e.g. in the order of several milliseconds).
- With respect to the reinforcement learning algorithm, the effect is the modification of the parameters of the membership functions at layer 2 and layer 5 used by the fuzzy-based decision procedure according to the system evolution. Since this modification occurs at the long-term, it does not pose constraints for real-time operation. In fact, the evolution of the parameter changes can be done offline with respect to the real time reconfiguration.

5. Conclusion and Future Work

A Fuzzy Neural JRRM strategy for a multi-cell and multi-RAT scenario including UMTS, GERAN and WLAN Radio Access Technologies has been proposed. The algorithm operates in two steps in order to select the most suitable RAT and cell that each mobile should be attached to. The first step selects a combination of three cells built around the three considered Radio Access Technologies. To this end, a Fuzzy-based approach is more effective than a signal strength criterion. During the second step, the proposed JRRM selects the most appropriate RAT among the three considered, and allocates a granted bit rate to each user. The role of each element of the discussed Fuzzy-Neural system has been described in detail. Furthermore, the proposed algorithm allows implementing different operator policies as well as technical and subjective criteria, such as the operator and user preferences when performing the RAT selection, by means of appropriate inference rules and a multiple decision mechanism. Moreover, a reinforcement learning mechanism is used in order to tune the considered membership functions, allowing the system to keep a defined QoS parameter to a contracted value. In particular, the proposed JRRM algorithm is able to keep the Non Satisfaction probability to a target value under different varying conditions in terms of traffic, mobility, propagation, etc. Finally, the proposed algorithm has been compared with three alternative JRRM algorithms, showing that the discussed framework is able to keep a desired value of user non-satisfaction probability while at the same time having low values of dropping and blocking probabilities.

In the future work, we will integrate the fuzzy neural network both for JRRM and network reconfiguration processes. In the radio subsystem, the traffic splitting over multiple RATs simultaneously will also be taken into account for further investigations. In addition, the interworking between neural fuzzy logic JRRM and network reconfiguration will also be studied.

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