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Affecting Factors for Joint Radio Resource Management and a Realization in a Reconfigurable Radio System

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Abstract— This paper aims to summarize the relevant affecting factors to the performance of the *Joint Radio Resource Management* (JRRM) in a reconfigurable radio system. Such system consists of types of reconfigurable terminals and self-tuning functionalities in the *Radio Access Network* (RAN). The Terminals are classified by the capability in processing multiple *Radio Access Technologies* (RAT) simultaneously or alternatively. The network is responsible to assign a bundling of radio *Resource Units* (RU) to the involving terminals w.r.t. their services, capabilities (profiles) and the cost of using RUs.

Based on the determined affecting factors to JRRM, we propose a framework which is expected to be integrated in the future self-tuning radio network. This framework is able to identify the dominating factor among all possible inputs and perform effective decision towards a more spectrum efficiency orientated resource allocation scheme. According to the large number of possible solutions, a self-learning mechanism based on heuristic search is needed. A significant contribution implies in an efficient reconfiguration process, i.e., upon a reconfiguration, which knowledge needs to be retrieved first for the complex radio system.

***Index Terms* — Joint Radio Resource Management, Reconfigurability, Multi-mode Terminal, Fuzzy Logic**

1. INTRODUCTION

Our previous works show that JRRM for reconfigurable terminals in coupled radio networks brings significant performance gain compared to the stand-alone radio networks [1][2][3]. The performance however is affected by a number of factors which can also be based on to dimension the complex analysis.

For the analysis of interrelationships between the factors and the JRRM performance, we classify the factors into JRRM inputs and JRRM options, where the inputs consists of the characteristics of the terminals, users, services and network (profile), the options include types of JRRM mechanisms based on centralised, distributed or hybrid modes.

Based on the combination of the JRRM inputs, the most appropriate JRRM mechanism is selected and implemented to a group of users using allocated radio resource. According to the options of JRRM, there are two basic types of JRRM being of interests, namely the *Joint call/session Admission Control* (JOSAC) and *Joint Session Scheduling* (JOSCH) [1][2]. The JOSAC does not offer detailed traffic splitting to subnetworks, which only results in certain gain thanks to the traffic routing, by alternatively diverting traffic into different subnetworks. The JOSCH algorithm offers detailed traffic splitting, which gives the chance of optimal allocation of the traffic over subnetworks.

The technical contribution is structured as follows: First an overview on the possible inputs to JRRM as well as the options can be selected by it is given in Section 2. In this section, a fundamental comparison between using resource alternatively and simultaneously in the interworking subnetworks presented by different RATs is given. In section 3, interrelationships between some selected factors to the JRRM performance are specially studied. In Section 4, base on the mass inputs to JRRM which results in a huge search space for the global optimal problem, we propose a self-learning framework for an efficient JRRM mechanism. The framework needs empirical experience of those investigated factor-dependent performances for a Fuzzy-Logic based machine, in order to derive the global optimization with a faster speed.

2. Overview on the affecting factors and JRRM options

Figure 6 shows an overview on the factors as inputs to the JRRM mechanisms. The affecting factors are classified into characteristics (profiles) for the network, service, user and terminals, where the network profile is the most complicated category including information of instantaneous spectrum resource, interwork (coupling) level, existence or absence of the central *Radio Resource Controller* (RRCR) and the deployment pattern of the involving subnetworks, traffic load, etc.

The service profile includes not only the QoS requirements (Error rate and latency) of the requested services, but also the scalability and the relevant entity of the network being able to offer it. For instance, if the scalability is offered by the remote server from the JRRM controller viewpoint, the performance of JRRM is different to the case when the resource controller offers the scalability agnostically. This phenomenon is valid for both the circuit switched case and the packet switched case.

The terminal profile is from the viewpoint of reconfigurability and processing capability. Basically, the capability of *Multi Mode Single Band* (MMSB) reconfigurable terminal and the *Multi Mode Multi Band* (MMMB) reconfigurable terminal can be classified. The former only can apply JOSAC, the latter can apply both.

In the following, we analyse the JRRM performance depending on some selected factors, which are marked in bold letters in Figure 6.

3. Performance comparison w.r.t. affecting factors

3.1 MMSB v.s. MMMB terminal for circuit switched services with agnostic traffic split

If single class calls without pre-splitting are circuit switched services and they arrive to the *Radio Resource Controller* (RRCR) which controls the interworking subnetworks, there is no added capacity gain given by JOSCH compared to the performance given by JOSAC is the calls are split agnostically. However, the gains given by JOSCH will be manifested if there exist multiple call classes. As investigated in [2], the *Operation Space* (OSP) offered by JOSCH in a finite-state-machine based theoretical model is bigger than the OSP offered by JOSAC. The performance of JOSAC is therefore bounded by the JOSCH, as shown in Figure 1.

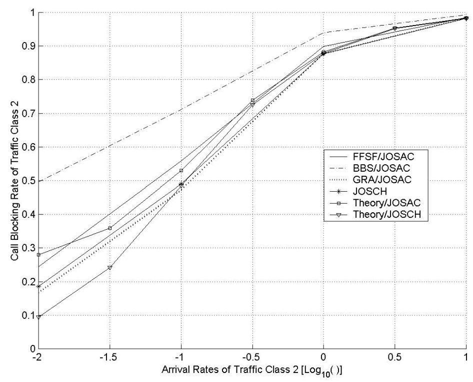

Figure 1: Performance for JOSCH and JOSAC for agnostic traffic splitting

3.2 MMSB v.s. MMMB terminal for packet switched services with agnostic traffic split

Similar as agnostic traffic splitting in Section 3.1, the JOSCH allows traffic splitting among available RATs and frequency layers. We define the multiplexing gain given by this action. The gain can be simply compared between the M/G/1-PS queuing model and the M/G/2-PS model [3] especially for the packet switched service[1].

[1] Here, it needs to be pointed out that the multiplexing gain is special for packet switched service. For circuit switched service gains is only applicable for multi-classes service which require different level of resource [3]. This gain anyway, only can be classified in the trunking gain category, due

The delay factor defined by comparing multi-user response time to the single user response time based on the M/G/1 PS and M/G/2 PS model can be compared in Figure 2. It shows a significant reduction of the response time when JOSCH is applied.

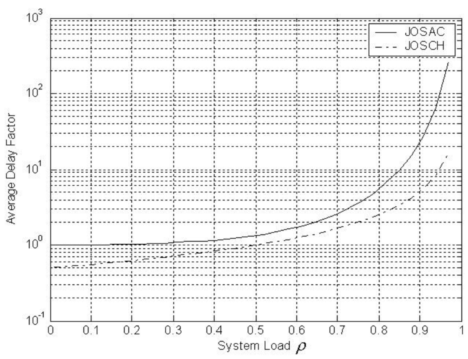

Figure 2: Delay Factor Comparison between JOSAC and JOSCH

3.3 Entity which performs traffic splitting

The scope of reconfigurability covers the Radio Access Network, the Switch subnetwork, the Core network, the O&M subnetwork. As an extension to the RRCR based agnostic traffic split defined in Section 3.1 and 3.2, the traffic splitting entities can be extended to the switching centre, e.g, SGSN, MSC and the remote service server/proxy, as depicted in Figure 3. We group the non-RRCR based traffic split into the category as a policy based one, i.e., the traffic split entity and the split pattern are policies as inputs to the JRRM mechanism.

A fundamental difference to the RRCR bases traffic splitting is the nature of traffic characteristics in terms of the inter arrival time between sub call units and the bounded traffic peak rate. In the circuit switched domain, the inter sub call units arrival time is not deterministic anymore, which helps a potential trunking gain. In the packet switched domain, the sub traffic streams result in bounded peak rates, so that the equivalent number of servers also increases.

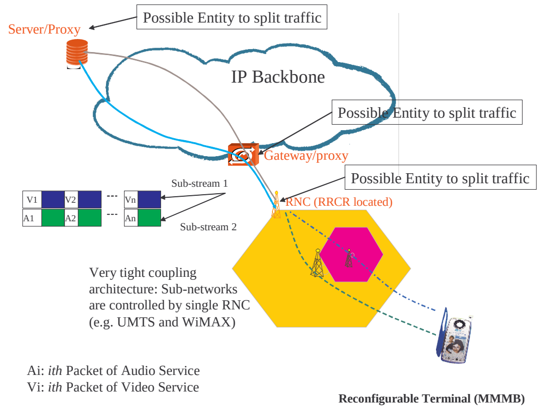

Figure 3: Traffic Splitting Entities

We give an example in the circuit switched domain. Based on the definition of policy based traffic split, where the call units are split at the remote server, the inter sub call unit arrival time is assumed as exponential distributed. In order to have a fair comparison between the JOSCH and JOSAC approaches, we need to firstly obtain the mapping between the targeting call blocking probabilities. If a sub call unit is blocked, there must be one call unit is blocked in the JOSAC case. In the case with two subnetworks, if two sub call units are blocked, it can be two call units or only one call unit blocked, as depicted in Figure 7. The relationship between the targeting call blocking rates for JOSAC and JOSCH is calculated as: $p_B = \frac{1}{2}\left(3p_b - p_b^{\ 2}\right)$, where p_B is the call blocking rate in the JOSAC level, the p_b is the call blocking rate in the JOSCH level. The detailed derivation of the mapping procedure and the performance are included in [3]. The relative capacity gain given by JOSAC and JOSCH compared to the non JRRM implemented system is shown in Figure 4. The trunking gain is not straightforward only by splitting the traffic units. For higher capacity system or services requires lower QoS (higher call blocking rate), the policy based traffic split does not provide better performance than JOSAC for circuit switched services.

to the added operational space for high throughput requirement service class.

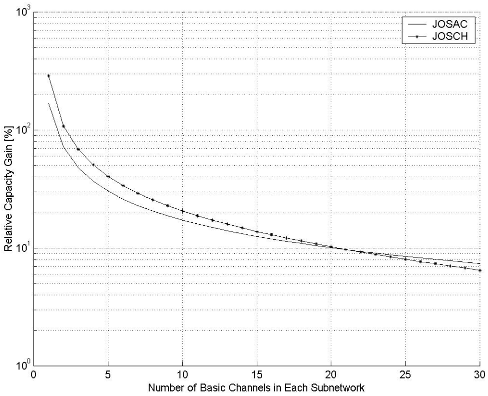

Figure 4: Gain Comparison (Target Gos: 0.1)

3.4 Performance depending on network deployment for interworking RATs

As investigated in another paper in this meeting [4], network constellation has big impact to the performance of JRRM. For instance, for packet switched services with agnostic traffic splitting, much displaced base stations result in worse performance than co-located case when JOSCH is deployed. However, for policy based traffic splitting scenario, the JOSCH is more effective when low coverage but high capacity (e.g., WLAN) subnetworks are remotely overlapped with the high coverage but low capacity (e.g., cellular network) [5]. It implies the pre-knowledge of network architecture, profile in capacity and coverage and the service scalability is needed for an optimised JRRM mechanism.

3.5 Performance depending on system load

Besides the coverage and capacity, the current system load as the dynamic radio network profile is also relevant to the performance gain given by the JRRM. From the hard-blocking system scenario, i.e., the system capacity is mainly limited by the available servers, e.g., time slot or code channels, the higher the system load is, the higher capacity gain is given by the JRRM. It implies that JRRM is more needed for highly loaded system.

In the soft-blocking scenario, i.e., the system load exponentially increases as the number of user increases. It also implies the high relevance of implementing JRRM, as load balancing is one of the most benefit we can obtain from JRRM.

3.6 Performance depending on centralised and distributed mode

JRRM can be deployed without the existence of RRCR. In fact, there are two main drawbacks can be noted for a centralised JRRM:

- New interfaces and new network are required.
- Additional handover delay might occur due to possible signalling latency (measurements) and out of date information. It could impact on the performance of delay sensitive procedures (such as call setup, handover and channel switching).

The studied distributed JRRM in this paper consists of radio load information exchanges locally inside each layer. The minimum load information exchange presents the advantage of a full backward compatibility since the existing interfaces are not affected as well as the existing standards and mechanisms. The simplicity of operation and deployment results in CAPEX reduction. As an example, decisions taken by the load balancing scheme could be based on pre-defined layer preferences or on the results of previous inter-layer handover experiences. These distributed approaches are achieved without introducing additional inter-layer handover or call setup delay and can operate between vendors. We study the performances based on three strategies during handover and call setup phases (idle mode):

Strategy “Cent1”: This strategy refers directly to centralised JRRM concept. As a consequence, the algorithm consists by selecting the most optimum cell among the target layers in term of cell load availability measurements.

Strategy “Dist1”: This algorithm does not require extra signalling or interfaces like “Cent1”. It selects a cell among the target layers while taking into account results of previous inter-system handovers and service handover preferences set by the core network. This solution is accompanied by recording the ‘barred cells’, i.e., once an inter-layer handover has been refused on a cell of the target layer, the source layer will not initiate other handovers to that target cell for a set period (according to a given timer). This strategy is included in Figure 6 as learning and excluding option for the distributed JRRM approach.

Strategy "Dist2": This strategy selects randomly a cell among the target layers, consequently regardless of cell load availability. This very simple strategy will serve as a reference case, when no optimization is considered in traffic management.

All the above strategies aim at distributing load among layers before congestion occurs. In this perspective, they try to avoid handover to full loaded cells. Handover triggering capacity thresholds are thus defined.

In our investigations, both centralise and distributed cases are based on the assumption of JOSAC, i.e., no traffic splitting [3]. A preliminary result (see Figure 5) compares the performance of the different schemes 'Cent1', 'Dist1' and 'Dist2'. The optimal timer for 'Dist1' algorithm is fixed to 3 seconds. The signalling delay regarding capacity report occurring in 'Cent1' scheme is in a first case fixed to 0 seconds (called 'Cent1 – 0s' i.e. ideal case) then set to an arbitrary value of 5 seconds (called 'Cent1 – 5s'). For the early study, it is assumed that the layers are perfectly superposed and presenting the same cell topology. In addition, same mobility model and single service class (i.e. CS traffic) are applied for all users. Comparatively to 'Dist2', 'Dist2' and 'Cent1 – 0s' approaches offer respectively system capacity gains of 10.67% and 8.1% corresponding to a dissatisfaction ratio of 5%. It can be noticed that Cent1 – 0s' leads to optimum results since it has full pre-knowledge on time. 'Dist1' strategy presents the same performance comparatively to 'Cent1 – 5s' solution. This investigation implies the performance degradation due to the absence of the RRCR which is responsible to coordinate and assign RUs from subnetworks to the terminals jointly.

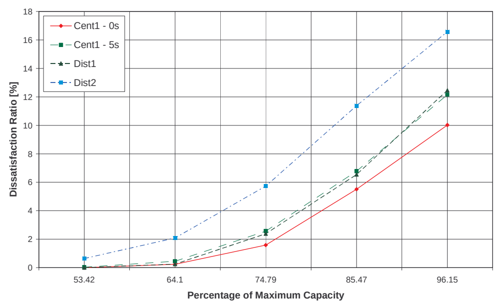

Figure 5: Performance Comparison between Centralised and Distributed JRRM Mode

4. A FRAMEWORK OF PRE-KNOWLEDGE BASED SELF-LEARNING JRRM

4.1 General ideal of Fuzzy Logic based self-learning JRRM

Optimizing the use of a pool of radio resources corresponding to a set of RATs is a non trivial problem. A mathematical formulation of the optimization problem would involve a large number of variables, with many cross-dependencies among them and with a high degree of dynamism in their time evolution due to changes in propagation conditions, mobile terminals speed, traffic generation processes, etc. The exploitation of the fuzzy logic concept, which provides a flexible methodology capable of operating with imprecise data in an uncertain scenario, could be a promising approach in order to take full advantage of the reconfigurable equipment capabilities and the diversity offered by available RATs in a multi-radio environment. Furthermore, in such uncertain scenarios, learning from interaction is a foundational idea underlying learning theories and intelligence. An interaction produces a wealth of information about cause and effect, about the consequences of actions, and about what to do in order to achieve explicit goals. Consequently, introducing reinforcement learning mechanisms in the fuzzy-neural methodology without relying on a complete model of the environment completes the approach. This methodology can be integrated in the JRRM Scheme block depicted in Figure 6.

4.2 Pre-knowledge based space-partitioning Approach

If we encounter a multiple inputs with totally n factors and each one of them has r possible realisations, the whole search space for the fuzzy-neural methodology will be r^n elements. The huge search space will results in either a slow reaction either a non-accurate result. Both of the consequence is not acceptable for a high quality radio network.

Therefore, we propose to use the pre-knowledge based on our aforementioned principles according to the interrelationship between the factors and the potential JRRM performance for the fuzzy logic machine. Therefore, for each available principle, 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 implies a much faster search methodology.

A general pre-knowledge based space-partitioning approach is shown in Figure 8, where after identifying the resulting subspace knowing from the given principles, ranges in terms of very high, high, medium, low and very low can be redefined with finer granularity.

The space–partitioning in Fuzzy logic terminology is carried out through a membership functions and inference rules capturing the essential features of the system under study. The reinforcement learning capability added through a Neural approach on top of the Fuzzy based mechanisms allows to introduce a basic element within the Network Cognitive paradigm (See [6] for a JOSAC approach). That is, the capability of the network to learn from the environment, particularly from user's activity, and update space-partitioning accordingly. That is, if the goal is to provide the user a certain blocking probability, Bit Rate better that a minimum value, etc, the learning mechanism allows the system to update the space partitioning so as the user QoS could be attained. Actually JRRM can be seen as a two level procedure trough the interactions of two modules:

- Module 1: Implement the set of rules (Inference Rules in Fuzzy Logic terminology). The complexity is low and allows the management of time scales at frame level. These rules can be transported trough network signalling.
- Module 2: It is a local System State memory (Local Database) where the membership functions reside. It is updated in a slow manner via a learning approach. That is a more involved process but it does not raise time constraints.

5. Conclusion

The performance of JRRM highly depends on the profiles of the involving entities and user services. We identified them and investigated on some typical ones. Besides that, an important implication from this study lies in the high complexity of JRRM implementation. However, the principles show the importance of a system with high flexible terminal which is capable in processing available RATs simultaneously. In order to obtain an efficient solution for a composite environment, empirical data and principles are required to be constructed as the pre-knowledge for a self-tuning network. This network is able to be self-learning and self-adjusting its implementation parameters using advanced heuristic searching mechanisms.

In order to reach the stage of a final network product, entities storing the pre-requisite knowledge in the radio network are needed.

6. Acknowledgement

This work is being performed within the framework of EU funded project E2R. The authors would like to acknowledge the contributions of their colleagues from the E2R consortium.

References

[1] J. Luo, E. Mohyeldin, N. Motte and M. Dillinger, Performance Investigations of ARMH in a Reconfigurable Environment, SCOUT Workshop, 16th, Paris, France Sep., 2003

[2] J. Luo, E. Mohyeldin, M. Dillinger, P. Demestichas, Kostas Tsagkaris, G. Dimitrakopoulos, and E. Schulz, Performance Analysis of Joint Radio Resource Management for Reconfigurable Terminals with Multi-class Circuit-switched Services, WWRF 12th Meeting, WG6, Toronto, Canada, Nov., 2004.

[3] Deliverable 5.2, End to end reconfigurability (E2R), IST-2003-507995, 12.2004

[4] P. Demestichas, A. Katidiotis, G. Dimitrakopoulos, J. Luo, R. A. Abou-Jaoude, M. Dillinger, Engineering Mechanisms for Planning a Reconfigurable Radio Network, WWRF 13th Meeting, 03. 2005

[5] Jijun Luo, Eiman Mohyeldin, Nicolas Motte and Markus Dillinger, Performance Investigations of ARMH in a Reconfigurable Environment, SCOUT Workshop, 16th, Sep., 2003, Paris, France.

[6] L. Giupponi, R. Agusti, J. Pérez-Romero, O. Sallent, “A Novel Joint Radio Resource Management Approach with Reinforcement Learning Mechanisms”, First IEEE International Workshop on Radio Resource Management for Wireless Cellular Networks (RRM-WCN), April 7-9, 2005 -Phoenix, Arizona, USA.

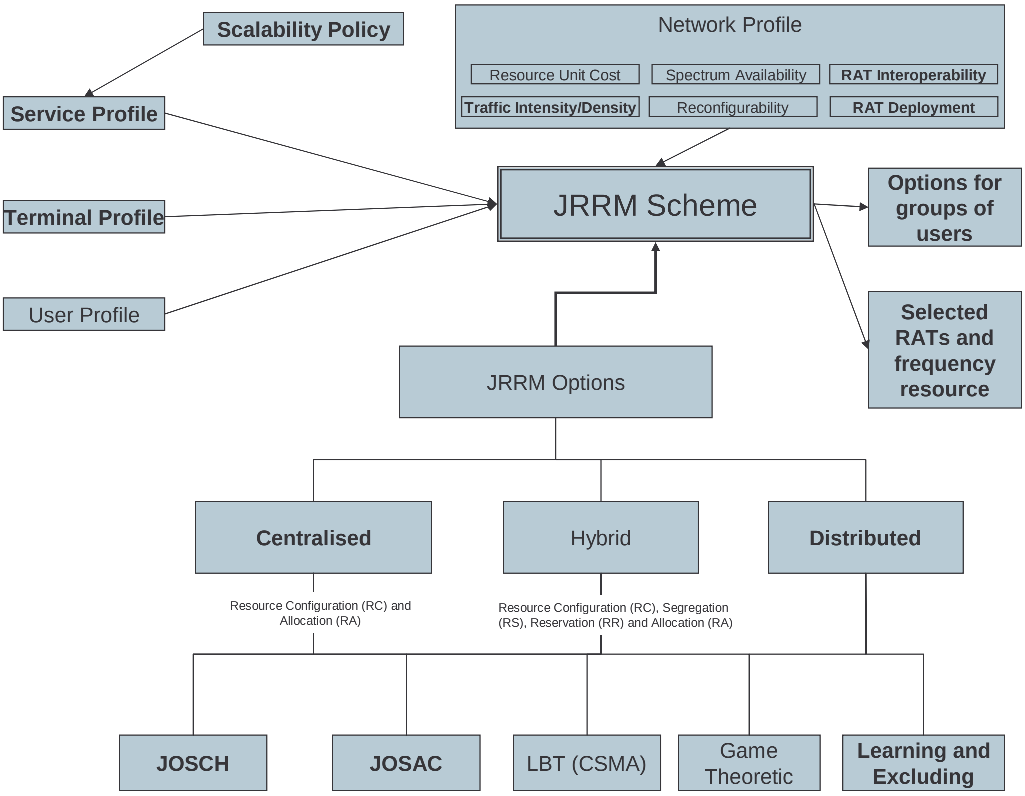

Figure 6: Dimensioning of Affecting Factors of JRRM

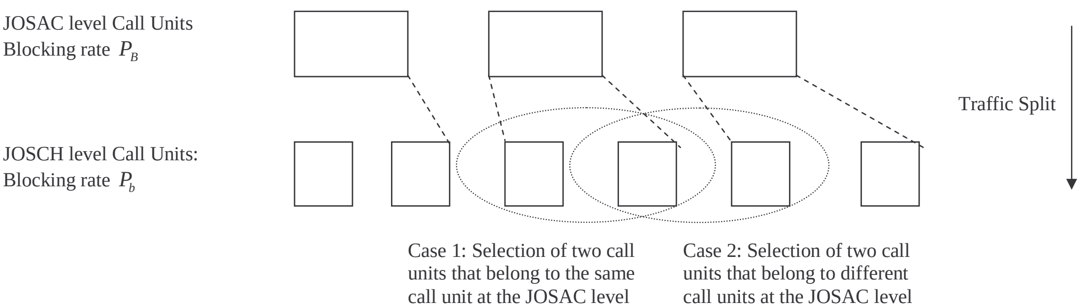

Figure 7: Inter-relationship between Original Call and Split Call

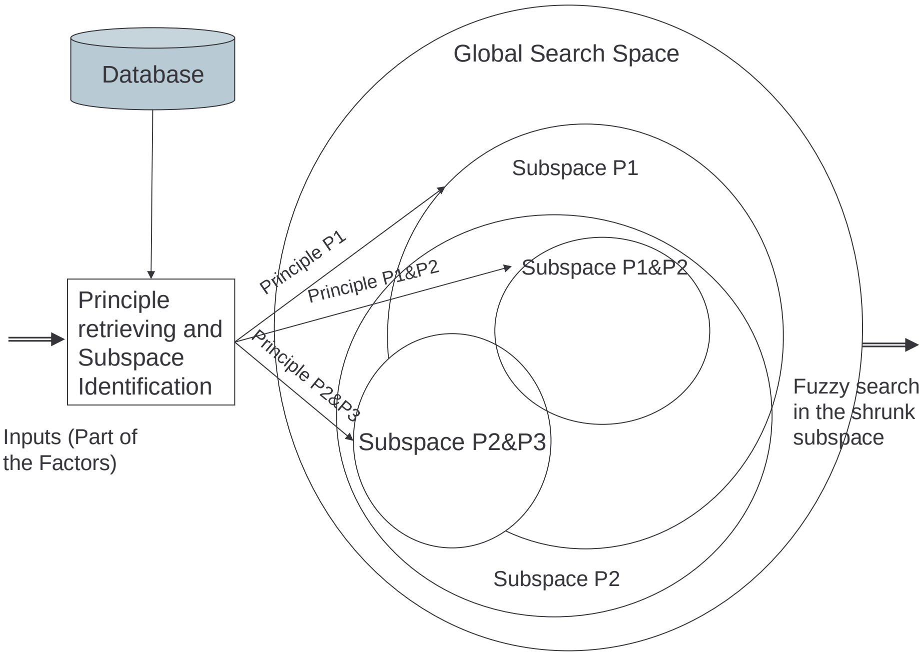

Figure 8: Space-Partitioning for Fuzzy Search