Policy-based Initial RAT Selection algorithms in Heterogeneous Networks

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Abstract
The heterogeneous network concept offers a flexible architecture that allows an efficient utilization of radio resources by means of Common RRM strategies that ensure a coordinated management of the resource pools in each Radio Access Network. In this context, this paper discusses different strategies for initial RAT selection as one of the key CRRM strategies. A general framework for the definition of policy-based RAT selection strategies is proposed and some specific examples are evaluated by means of simulations.

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Common Radio Resource Management, heterogeneous networks, RAT selection, Beyond 3G systems.

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I. INTRODUCTION

The strong demand in wireless systems will definitively require more and more capacity to the advanced mobile cellular systems. The increasing popularity of WLAN, the inheritance from GSM/GPRS and the introduction of UMTS will promote mixed solutions depending on the capacity and/or coverage area required for a certain service. Clearly, a common, or at least consistent, QoS control over such integrated UMTS/GSM/WLAN system should be addressed [1][2][3]. The envisaged architecture is based on several radio access networks interfacing a common core network. This heterogeneous network concept proposes a flexible and open architecture for a large variety of different wireless access technologies, for applications and services with different QoS demands, and for different protocols. In this concept, services should be delivered via the network that is most efficient for that service under the current system state conditions. A fundamental goal is to make the heterogeneous network transparent to the user.

The heterogeneous network concept facilitates the utilization of a common manager of the radio resources in each radio access network (RAN). Following the 3GPP approach, CRRM (Common Radio Resource Management) strategies are considered to co-ordinately manage the radio resources belonging to multiple radio access technologies (RATs) in an efficient way. CRRM is then a general concept, applicable to any combination of RATs, although the specific implementation and the degree of coordination highly depend on the coupling between the specific RANs.

The functional model considered in 3GPP recommendations for CRRM operation assumes the total amount of resources available for an operator divided into radio resource pools [2]. The management of the radio resources is then handled by two different entities. On the one hand, the RRM entity is responsible of the resources in one radio resource pool of a certain radio access network and, on the other hand, the CRRM entity executes the coordinated management of the resource pools belonging to different RRM entities. The interactions between CRRM and RRM entities involve the information reporting function, including measurements from RRM to CRRM, and the decision support function provided by CRRM [1][2]. Several centralised and decentralised architectures are under consideration for CRRM operation depending on the implementation of RRM and CRRM entities [1][2][4]. Furthermore, the split of functionalities between RRM and CRRM entities leads to a trade-off, since a more efficient management of the radio resources could be achieved if most of the RRM functionalities (e.g. admission control, congestion control, handover, scheduling, etc.) were moved to the CRRM entity, thus executing them having a joint vision of the different RATs. Nevertheless, this would require very frequent interactions between both entities thus leading to a higher amount of signalling.

Within the set of radio resource management functions, the initial RAT selection and the vertical or intersystem handover are devoted to decide the appropriate RAT for a given service at session initiation and during the session lifetime, respectively. Therefore, they necessarily involve different radio access technologies and it is appropriate to devise them from a CRRM perspective. In that sense, the algorithm operation might then respond to specific policies taking into account both technical and/or economical aspects (e.g. operator or user preferences).

Not much effort has been devoted up to date in the open literature to deal with the CRRM problem. In [5] the benefits of CRRM in terms of inter-system handover and inter-system network controlled cell reselection are analysed in a heterogeneous UTRAN/GERAN scenario. With respect to the combination of cellular and WLAN technologies, in [6] a methodology based on fuzzy logic and reinforcement learning mechanisms is presented that combines technical and economical issues to provide the specific RAT and bandwidth allocations. Similarly, in [7] a joint scheduling algorithm between UMTS and HIPERLAN is proposed.

Within the CRRM context, this paper discusses a framework for developing policy-based initial RAT selection algorithms and provides an insight into some sample policies. Section II presents an algebraic framework for policy definition, devised from an initial set of basic policies that can be combined, leading to more sophisticated policies that better capture the specificities of the RAT selection process. Section III presents the simulation considerations taken into account for the evaluation of different policies. Results are shown in Section IV and conclusions are summarised in Section V.

II. INITIAL RAT SELECTION POLICIES

Let assume a heterogeneous network scenario in which a set of radio access networks are available, and let define R as the domain of corresponding RATs. For instance, and without lack of generality, R can be given by {UTRAN, GERAN, WLAN}. A basic initial RAT selection policy can be then defined as a function *f* that, given a set of different inputs (ξ_1, ξ_2,..., ξ_M), e.g. service class, load in each RAN, UE features, mobile speed, etc. provides a suitable RAT to be allocated. Mathematically, a policy *p* can then be expressed as:

$$p=f(\xi_1, \xi_2,..., \xi_M) \in R \quad (1)$$

Some sample examples of basic policies for a scenario with GERAN and UTRAN networks and a mix of voice and interactive users (e.g. www browsing) are defined in the following:

- *VG (voice GERAN) policy:* This policy has only the service type as input, and allocates voice users into GERAN and other services into UTRAN. This is:

$$p_{VG} = f(\text{service}) = \begin{cases} \text{GERAN, if service = voice} \\ \text{UTRAN, if service = www} \end{cases} \quad (2)$$

- *VU (voice UTRAN) policy:* This policy acts in the opposite direction as VG and allocates voice users to UTRAN and interactive users to GERAN.

$$p_{VU} = f(\text{service}) = \begin{cases} \text{UTRAN, if service = voice} \\ \text{GERAN, if service = www} \end{cases} \quad (3)$$

- *IN (indoor) policy*: In this case the selection would be done taking into account whether a user is indoor or outdoor, under the consideration that WCDMA capacity is highly degraded by indoor traffic users, as stated in [8], where capacity reductions of up to 80% are observed when half of the users in a scenario are indoor. Therefore, according to this policy, indoor users would be allocated in GERAN. Then:

$$p_{IN} = f(\text{indoor\_user}) = \begin{cases} \text{GERAN, if indoor\_user = true} \\ \text{UTRAN, if indoor\_user = false} \end{cases} \quad (4)$$

Notice that the application of such basic policies would mean that, if there is no capacity available in the selected RAT, the service request is blocked because, otherwise, the policy would be violated. Consequently, these basic policies could lead to blockings even if there is capacity available in other RATs. This undesirable effect can be avoided by defining complex policies in which the output is a prioritised list of RATs, so that if no capacity is available in the first one, the second one would be selected, and so on. In this case, the service would be blocked if there is no capacity in any of the listed RATs. Mathematically, let define an *n-complex policy* as a function:

$$p=f(\xi_1, \xi_2,..., \xi_M) \in R^n \quad (5)$$

leading to a list of *n* RATs. Notice that the combination of basic policies leads to *n*-complex policies. In that sense, it is defined the combination of two basic policies p_i*p_j as a list of two RATs, the first one according to p_i (corresponding to the first choice) and the second according to p_j (corresponding to the second choice if there is not capacity in the first RAT).

Some examples of 2-complex policies constituted by the previous basic policies are presented in the following:

VG*IN=*f*(service, indoor_user) (6)

service	**indoor_user**	**VG*IN$\in$R^2**
voice	true	GERAN, GERAN
voice	false	GERAN, UTRAN
www	true	UTRAN, GERAN
www	false	UTRAN, UTRAN

As an example of this policy, if the service is voice and the user is outdoor, the first choice will be to allocate it in GERAN (i.e. according to the VG policy). If no capacity is available in GERAN, the second choice will be to allocate it in UTRAN (i.e. according to the IN policy). Notice also that, if the service is www and the user is outdoor, a blocking will occur if there is not capacity in UTRAN because, otherwise, both VG and IN policies would be violated. The same occurs if the service is voice and the user is indoor and there is not capacity in GERAN.

IN*VG=*f*(service,indoor_user) (7)

service	**indoor_user**	**IN*VG$\in$R^2**
voice	true	GERAN, GERAN
voice	false	UTRAN, GERAN
www	true	GERAN, UTRAN
www	false	UTRAN, UTRAN

In this case, the first choice takes into account whether the user is indoor or outdoor and, if no capacity is available in the selected RAT, the second choice considers the service type.

VG*VU=*f*(service) (8)

service	**VG*VU$\in$R^2**
voice	GERAN, UTRAN
www	UTRAN, GERAN

According to this policy, voice users will first fill the capacity available in GERAN and then they will be directed to UTRAN. In turn, www users will first fill the capacity in UTRAN and then they will be directed to GERAN. In this case, no request is blocked provided that there is capacity available in either UTRAN or GERAN.

III. SIMULATION ENVIRONMENT

The previous initial RAT selection policies are evaluated within a detailed scenario with UTRAN and GERAN access technologies. The dynamic simulations consider a 2.25*2.25 km^2 scenario with 7 omnidirectional cells for GERAN and 7 for UTRAN. The cells of both RATs are collocated with 1km distance between sites. In case of GERAN, it is assumed that the 7 cells represent a cluster so that all the cells operate with different carrier frequencies. The parameters of the UE and the UTRAN and GERAN cells are summarised in Table I and Table II, respectively. Three carriers per cell are assumed in GERAN and a single UTRAN FDD carrier is considered in UTRAN. In this way, the total bandwidth available in the cluster of seven GERAN cells is approximately the same as the bandwidth used by UTRAN. The GERAN carriers are in the 1800 MHz band. The urban macrocell propagation model in [9] with a shadowing of 10 dB is considered. Mobile speed is 3 km/h. For indoor users, an additional penetration loss of 20 dB is considered.

TABLE I
UTRAN BS AND UE PARAMETERS

BS parameters	
Maximum transmitted power	43 dBm
Thermal noise	-104 dBm
Common Control Channels Power	33 dBm
Maximum DL power per user	41 dBm
UE parameters	
Maximum transmitted power	21 dBm
Minimum transmitted power	-44 dBm
Thermal noise	-100 dBm
DL Orthogonality factor	0.4

TABLE II
GERAN BS AND UE PARAMETERS

BS parameters	
DL transmitted power	43 dBm
Thermal noise	-117 dBm
Number of carriers	3
EGPRS slots	All slots reversible except BCCH
UE parameters	
Maximum transmitted power	33 dBm
Minimum transmitted power	0 dBm
Thermal noise	-113 dBm
Multislot class	2 UL, 3 DL, 4 UL+DL

A mix of voice and interactive users is considered. Voice calls are generated according to a Poisson process with an average call rate of 10 calls/h/user and exponentially distributed call duration with an average of 180 s. In UTRAN, the RAB for voice users is the 12.2 kb/s speech defined in [10], considering a dedicated channel (DCH) with spreading factor 64 in the uplink and 128 in the downlink. In turn, in GERAN, voice users are allocated to a TCH-FS (traffic channel full-rate speech), i.e. one time slot in each frame. Interactive users follow the www browsing model given in [11], with 5 pages per session, an average reading time between pages of 30s, an average of 25 objects (packets) per page, and interarrival packet time 0.125s for the uplink and 0.0228s for the downlink. The average packet size is 366 bytes. This leads to an average bit rate during activity periods of 24 kb/s in the uplink and 128 kb/s in the downlink. A session rate of 24 sessions/h/user is assumed. WWW browsing service is provided in UTRAN by means of DCH making use of transport channel type switching (i.e. the DCH is allocated only during activity periods, e.g. page downloads, while during inactivity periods no dedicated resources are allocated). The considered RAB assumes a maximum bit rate of 64 kb/s in the uplink (corresponding to a minimum spreading factor of 16) and 128 kb/s in the downlink (with a spreading factor of 16). The RAB characteristics are given in [10]. In turn, in GERAN, the www service is provided through a PDCH (Packet Data Channel). A link adaptation mechanism is used that selects the highest modulation and coding scheme (MCS) that ensures the specific signal-to-noise-and-interference requirements. The highest modulation scheme is MCS-7, corresponding to a bit rate of 44.8 kb/s per time slot. Then, assuming that the multislot class allows up to 2 uplink slots and 3 downlink slots (see Table II), the maximum bit rate is 89.6 kb/s in the uplink and 134.4 kb/s in the downlink. Consequently, in terms of maximum bit rate, similar capabilities are considered for both UTRAN and GERAN. A summary of the main RRM parameters residing at the local RRM entities in both UTRAN and GERAN is given in Table III and Table IV.

TABLE III
UTRAN RRM PARAMETERS

RRM parameters	
UL admission threshold (η_{max})	1.0
DL admission threshold (P_{max})	42 dBm
Measurement time	1s
Active Set size	1
Replacement hystheresis	3 dB
Time to trigger handover	0.64 s
QoS parameters	
BLER target voice	1%
BLER target interactive	10%
Dropping condition	1 dB below target during 20 s

TABLE IV
GERAN RRM PARAMETERS

RRM parameters	
Link adaptation period	1s.
Scheduling algorithm	Round Robin
BS_CV_MAX	15
GPRS_MS_TXPWR_MAX_CCH	43 dBm
GPRS_RESELECT_OFFSET	-2 dB
GPRS_RXLEV_ACCESS_MIN	-105 dBm
Maximum number of TBFs per slot	UL: 8, DL:32
L_RXLEV_UL_H	-100 dBm
L_RXLEV_DL_H	-100 dBm
MS_RANGE_MAX	35 km
P5	3
P8	3
QoS parameters	
BLER target voice	1%
BLER target interactive	10%
Dropping condition	5 dB below target during 20 s or 10 consecutive unsuccessful HO

IV. RESULTS

This section evaluates the considered initial RAT selection policies in the previously described scenario. Since the focus of the paper is on the initial RAT selection, no vertical handover is considered. This procedure should be analysed separately according to specific policies and/or triggering conditions and, therefore, it is out of the scope of this paper.

A.- Performance of basic policies

The first results intend to provide an initial insight in the system performance when only basic RAT selection policies are considered. In particular, Table V compares the performance in terms of aggregated throughput (i.e. including both voice and www users) in the overall scenario when basic policies VU and VG are considered. In these results, all users are outdoor and a separation between cell sites of 2 km has been considered. 400 voice users and different numbers of www users are considered in the scenario Notice that, in all the cases, VG policy outperforms VU, revealing the suitability of allocating voice users in GERAN. The main reasons are two-fold. First, with respect to www users, a higher throughput can be obtained in UTRAN as long as DCH channels are used while in GERAN www users are subject to a scheduling algorithm. In turn, from the voice users' point of view, if the distance between cell sites was set to 1 km, no significant differences would be observed between VU and VG (the results are not shown for the sake of brevity), but when increasing the distance between sites, a higher degradation is observed in VU because UTRAN users at the cell edge experience some erroneous transmissions due to power limitations and the interference-limited nature of the WCDMA technique.

TABLE V
TOTAL THROUGHPUT (MB/S) FOR TWO BASIC POLICIES

Users		VU		VG	
Voice	www	UL	DL	UL	DL
400	200	2.08	2.17	2.14	2.22
	600	2.88	3.09	2.95	3.15
	1000	3.64	3.96	3.76	4.08

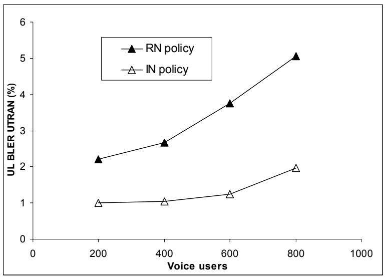

Fig. 1. UL BLER in UTRAN for two basic policies.

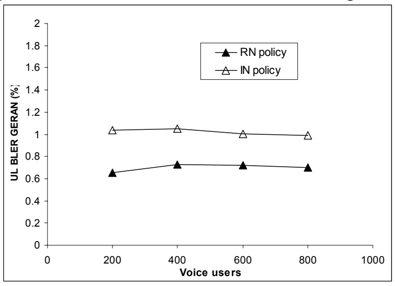

Fig. 2. UL BLER in GERAN for two basic policies.

Fig. 1 and Fig. 2 consider a scenario where 30% of the users are indoor and the distance between sites is 1 km. In order to see clearly the effects of the IN policy (i.e. allocate indoor users to GERAN) only voice traffic is considered, and the IN policy is compared with a reference random policy (RN) in which users are allocated randomly with equal probability in GERAN and in UTRAN. The results are presented in terms of the block error rate (BLER) in the uplink direction for both UTRAN and GERAN systems. It can be observed that, when the IN policy is applied, the BLER is reduced in UTRAN. On the other hand, in GERAN an increase in the BLER is observed because there are more indoor users than with the RN policy. Nevertheless, the BLER improvement experienced in UTRAN is significantly higher than the degradation in GERAN, which suggests the suitability of using IN policy in the presence of indoor users.

B.- Performance of 2-complex policies

In realistic scenarios, where different types of services are used by customers located either indoor or outdoor, the use of basic policies like VG or IN may not sufficiently capture the required features to do a proper initial RAT selection and therefore, *n*-complex policies should be applied. For such a scenario, Table VI and Table VII present the aggregated throughput for different numbers of voice and www users and when there are 10% and 50% of indoor users, respectively. Results are presented for both the uplink and downlink directions. The 2-complex policies VG*IN, IN*VG and VG*VU described in Section II are compared.

TABLE VI
TOTAL THROUGHPUT (MB/S) WITH 10% INDOOR USERS

10% indoor		VG*IN		IN*VG		VG*VU	
Voice users	www users	UL	DL	UL	DL	UL	DL
200	200	1.38	1.44	1.37	1.43	1.37	1.43
	600	2.21	2.40	2.15	2.32	2.18	2.36
	1000	2.99	3.30	2.94	3.23	2.98	3.30
400	200	2.14	2.22	2.30	2.34	2.16	2.23
	600	2.96	3.15	2.94	3.10	2.95	3.14
	1000	3.79	4.10	3.58	3.81	3.78	4.10
600	200	2.59	2.65	3.13	3.11	2.76	2.86
	600	3.41	3.59	3.63	3.69	3.51	3.73
	800	3.80	4.04	3.83	3.93	3.91	4.19

TABLE VII
TOTAL THROUGHPUT (MB/S) WITH 50% INDOOR USERS

50% indoor		VG*IN		IN*VG		VG*VU	
Voice users	www users	UL	DL	UL	DL	UL	DL
200	200	1.37	1.45	1.33	1.39	1.37	1.45
	600	2.14	2.34	2.02	2.21	2.16	2.36
	1000	2.94	3.27	2.71	3.00	2.93	3.26
400	200	2.12	2.19	2.24	2.31	2.14	2.21
	600	2.88	3.09	2.95	3.13	2.93	3.14
	1000	3.68	4.02	3.62	3.92	3.71	4.06
600	200	2.38	2.47	3.21	3.28	2.76	2.86
	600	3.18	3.38	3.78	3.94	3.51	3.74
	800	3.60	3.86	4.06	4.29	3.90	4.19

Up to medium voice loads (i.e. 200 users) no relevant differences between the policies are observed, although in general the performance of IN*VG is somewhat poorer, mainly when the number of www users increases. The reason is that, with IN*VG, there is a higher number of www users that are served through GERAN (i.e. those that are indoor), which provides higher delays and lower www throughput than UTRAN (see Fig. 3 and Fig. 4). Further, when the ratio of indoor users increases, the number of interactive users allocated in GERAN also increases and, consequently, IN*VG performance is more degraded.

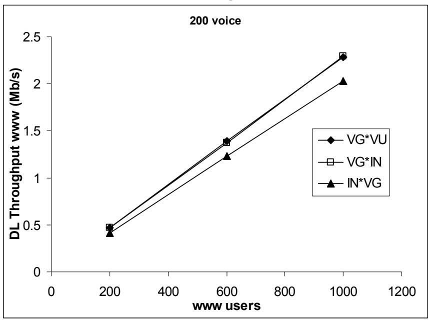

Fig. 3. Total DL www throughput with 50% indoor traffic.

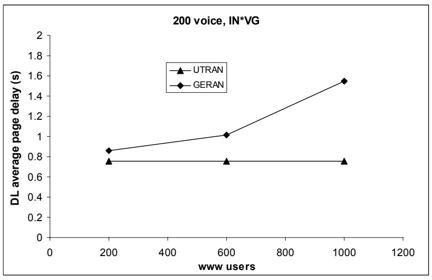

Fig. 4. DL average page delay with IN*VG policy and 50% indoor traffic.

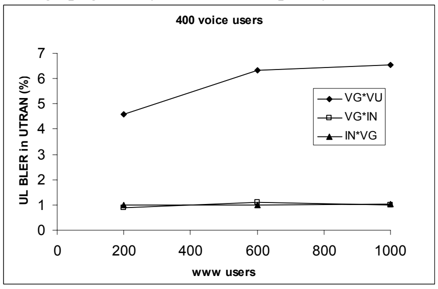

Fig. 5. UL BLER in UTRAN for voice users with 50% indoor traffic.

Nevertheless, when the voice load increases (i.e. 400 and 600 voice users), policy IN*VG achieves a higher throughput than the other two policies. The improvement is more significant for low number of www users because of the throughput reduction when www users are served through GERAN. It is important to note that with IN*VG the load is more distributed between both access networks. For example, for 400 voice users and 50% indoor, with IN*VG 50% of the voice traffic goes through GERAN while with VG*IN the ratio is approximately 99%, thus existing a higher occupation in GERAN with VG*IN that can originate some voice droppings. Furthermore, Fig. 5 shows the improvement in terms of BLER when the policies that take into account the indoor condition (i.e. IN*VG and VG*IN) are compared with the policy VG*VU.

Finally, with respect to the comparison between VG*VU and VG*IN, notice that, in general, both have similar performance although for high loads VG*VU uses to have a higher throughput because of the low number of blockings (i.e. notice that in VG*VU a blocking only occurs when there is no capacity in neither UTRAN nor GERAN, while with VG*IN this is no longer true).

V. Conclusions

This paper has focused on the development of initial RAT selection algorithms for CRRM operation in heterogeneous networks. A general policy-based framework for the specification of such algorithms has been defined and different policies considering the service type as well as the fact that the users may be indoor or outdoor have been evaluated through simulations. It has been obtained that, in outdoor scenarios, VG basic policy turns into a higher throughput than VU. In turn, in scenarios with a mix of indoor and outdoor users with different services, the performance of IN*VG policy improves when the voice load increases, the www load decreases and there is a high fraction of indoor users. On the contrary, for low voice loads and high www loads VG*IN achieves a better throughput. This suggests that the suitable configuration of the RRM and CRRM entities according to specific policies depends on the existing traffic conditions and therefore it may be modified at e.g. different periods of the day.

Acknowledgements

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