Urban planning for Radio Communications

SP 2

Mesures, métrologie et mécanismes avancés de gestion du spectre

Task 2.1.4

Etude d'optimisation des algorithmes de gestion des ressources radio

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Contents

Résumé

Les technologies d'accès radio (RAT) se diversifient. Les téléphones portables (mobiles) ont de plus en plus la faculté d'utiliser plusieurs technologies. Les opérateurs de réseau ont donc la possibilité d'adapter et optimiser l'affectation d'un mobile à un type de réseau d'accès, en fonction de différents critères, tels que la demande en trafic, la charge du système, le coût d'une connexion, l'utilisation des fréquences etc…. Connaissant les performances d'un réseau d'accès, la charge qu'il supporte et les possibilités d'un mobile, la question se pose de savoir quel RAT doit être choisi pour fournir le service demandé par un mobile entrant.

Dans la première partie de cette étude, **SMDP Approach for JRRM Analysis in Heterogeneous Networks**, nous abordons cette question pour des cellules (femto à micro) où deux RAT sont "co-localisés", c-à-d. qu'il y a un point d'accès commun. De plus, les cellules se recouvrent. Nous analysons des algorithmes entièrement commandés par le réseau, qui tiennent compte non seulement de la charge courante de chaque RAT mais également de la distribution spatiale des mobiles dans la cellule.

La notion de gestion de ressource radio commune (JRRM) est clairement définie dans [6] pour une utilisation efficace d'une ressource commune appartenant à plusieurs RAT. Dans notre approche, nous analysons le choix du RAT et la commande d'admission. Nous adoptons une approche basée sur le procédé SMDP (Semi-Markov Decision Process) [18]. Nous définissons deux classes de politiques de JRRM. Nous en déterminons des politiques optimales, pour chacune d'elles, et en faisons l'analyse. Nous utilisons un algorithme itératif pour calculer la politique optimale d'affectation des mobiles à un RAT donné, en tenant compte de la distribution spatiale des utilisateurs dans la cellule et de la probabilité de blocage des mobiles dans le système. Puis nous comparons la politique optimale obtenue à une politique de "bon sens". Les applications numériques que nous proposons montrent que la politique optimale peut largement améliorer un algorithme a priori de "bon sens". On montre également que les performances globales en termes de débits et probabilité de blocage sont excellentes. Ceci peut être expliqué par le fait que les politiques optimales limitent la charge induite par les mobiles situés loin des points d'accès, voire en bordure de cellule.

Dans la deuxième partie de cette étude, **Radio Resource Management Using Forced Vertical Handover,** nous étudions l'optimisation des ressources radio par une technique de handover verticale. Pour le réseau, elle a permet un "équilibrage" de la charge entre les RAT, augmente l'utilisation de la largeur de bande et permet d'éviter la congestion. Pour les mobiles, le résultat est une amélioration de la QoS et des performances tels que le débit, le délai d'accès et la probabilité de blocage dans un réseau d'accès multi-RAT. Nous utilisons une technique d'optimisation des ressources basée sur des mesures radio, des mesures de congestion de réseau, et un "plan de contrôle" qui "force" le handover vertical. Dans l'approche proposée, c'est le réseau qui détermine les actions.

Part I

SMDP Approach for JRRM Analysis in Heterogeneous Networks

1 Introduction

As radio access technologies (RAT) diversify and mobile stations (MS) become more and more agile, network operators are faced to the problem of MS assignment to RAT. With the knowledge of RAT performance (data rates and coverage) and loads on the one hand, the knowledge of MS capabilities and demand (associated to QoS parameters) on the other hand, the question arises to know which RAT should be chosen to deliver the requested service and who should take the decision.
In this study, we address this issue by focusing on small cells (typically femto to micro) where two RAT are colocalized, i.e., there is a common access point and geographical cells are overlapping. We concentrate on algorithms fully controlled by the network that take into account not only the current load of each RAT but also the spatial distribution of MS in the cell. This approach has to be opposed to user-centric schemes (MS takes alone the decision based on measurements) or hybrid schemes (MS decision is assisted by the network) [4]. We also assume a dynamic scenario where MS are assigned to RAT on a packet call basis.
The notion of joint radio resource management (JRRM) is clearly defined in [6] as a way of achieving an efficient usage of a joint pool of resources belonging to several RAT. Authors of [6] distinguish three main functions for JRRM: RAT and cell selection (which includes joint load control and vertical handover), bit rate allocation and admission control (also known as joint session admission control). Reference [7] adds the joint resource scheduling to this list. In our analysis, we focus on RAT selection and admission control. On this specific subject, there are some papers dealing with the issue of making a decision based on many available parameters. For example, [8] applies Analytic Hierarchy Process and Gray Relational Processes to rank network alternatives. References [5] and [6] propose a framework for JRRM based on fuzzy neural methodology, reinforcement learning and multiple objective decision making. Different implementations are compared through simulations. Authors of [9] elaborate an optimal solution and an associated heuristic algorithm for the problem of RAT association in a static scenario using the framework of combinatorial optimization.
In our study, we adopt a different approach already proposed in [1] (see [2] for the related conference paper) and based on Semi Markov Decision Process (SMDP) [18]. Compared to [1], this study takes into account the spatial distribution of users in the cell, uses the policy iteration algorithm, accounts for blocking in the utility function and compares the optimal policy to a common sense policy. In [3], we have highlighted an optimal policy for a given class of JRRM algorithms. In this study, we define two different classes of JRRM policies, find optimal policies for each of them, study standard performance parameters and discuss in more details the obtained results.
Several papers have used the framework of SMDP in the context of cellular networks, e.g. for the admission of multimedia calls [11][10], to account for hand-over calls [12] or for multi-class calls in EGPRS networks [13]. However, this framework has not been used for heterogeneous networks before [1].
In the next section, we first present the network model and two classes of JRRM policies.Then, we describe the SMDP approach and the policy iteration algorithm in section III. Section IV gives an example of numerical application and shows how optimal policies clearly outperforms a common sense policy. At last, section V concludes the analysis.

2 Network Model

2.1 Radio Access Technologies

We consider a cell with two co-localized RATs with different characteristics, e.g. :
• RAT1 = WLAN and
• RAT2 = HSDPA.
The cell is divided into r rings. The ring the closest to the base station is ring number 1 and the farthest one is ring number r. A ring is characterized by the fact that RAT1 and RAT2 roughly offer a constant physical data rate for a mobile station located in this area.RAT1 and RAT2 are characterized by :
• the nominal data rates characterizing the available bandwidth in each ring = (~D11, ..., ~D 1r , ~D21, ..., ~D2r).
Nominal data rate ~Dj is the available throughput above the physical layer in ring *i* of RAT *j.*
• the maximum number of users = n^1_{max} and n^2_{max} that are fixed in order to ensure a minimal throughput to mobile users in the cell.
We assume that access points and base stations are colocalized and coverage areas are identical for the two RATs (see figure 1). This is realistic in case of hot spots micro, pico or femto cells. This is not realistic in other cases, the generic discussion below can however be adapted to non-overlapping cells.

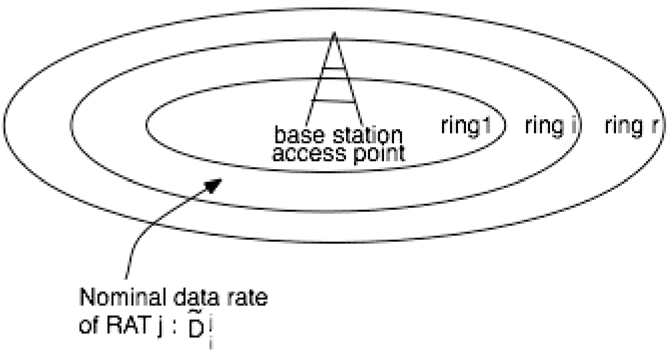

Fig. 1. Illustration of a RAT cell with several rings around the access point or base-station.

2.2 Traffic

We consider a packet type of traffic, such as web browsing or file downloading on the downlink: a user alternates between packet calls (several packets are transfered in an very short time) and reading times (there is no transfer). In this study, we focus on the packet call level and so neglect the details of the packet level.
We assume Poisson arrivals of user downlink packet calls with rate λ. The arrivals in each ring are supposed to be equiprobable. Traffic is supposed to be elastic: the packet call size is exponentially distributed with mean X_{ON} bits and so the service rate depends on the available throughput. MS are supposed to be able to access both RATs indifferently. Considering single-RAT MS (like in [1]) leads to higher computational load but can again be integrated in the presented framework.

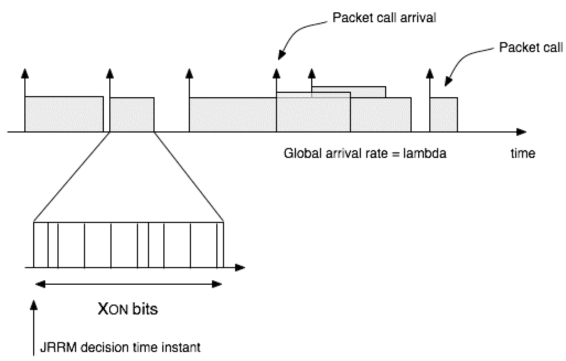

Fig. 2. Assumed traffic model.

2.3 Scheduling and Data Rates

The scheduling algorithms allocate in each RAT resources from the total available bandwidth to individual MS present in the RAT. In this study, we consider two simple algorithms for WLAN and HSDPA.
For WLAN, we approximate the CSMA/CA algorithm by a fair scheduling in throughput. Note that the common throughput depends on the distribution of MS in the cell. This effect is known as the near-far effect in the literature on WLAN networks, see e.g. [14]. For a r-tuple $(n_{11}, ..., n_{1r})$ representing the number of users in each ring, the service rates do not depend on the location and are given, for $(n_{11}, ..., n_{1r}) \neq (0, ..., 0)$, by:

$$\forall i \ \mu_i^1 = \left(X_{ON} \sum_{k=1}^{r} \frac{n_k^1}{\tilde{D}_k^1} \right)^{-1} .$$

As an illustrative example, figure 3 shows the scenario, where two MS are sharing the resource in a WLAN cell. If packets have all the same length L, the throughput experienced by each user is approximately $(1/\tilde{D}^1_1 + 1/\tilde{D}^1_2)^{-1}$. The allocation is fair in throughput. This model is assumed for the sake of simplicity although it does not take into account the time wasted by the backoff algorithm nor the uplink traffic also competing for channel access.

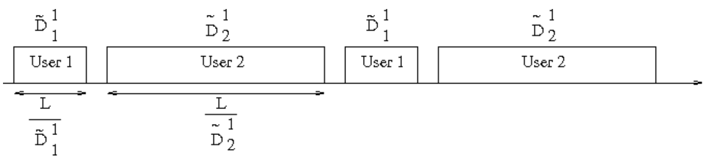

Fig. 3. Illustration of the alternate transmissions of two MS in a WLAN cell. As $\tilde{D}_{12} < \tilde{D}_{11}$, the time spent to send a packet of length L is greater for user 2 than for user 1.

For HSDPA, we assume a fair scheduling in time, i.e., the scheduling algorithm allocates one TTI (Transmission Time Interval) alternatively to each active MS. In a given TTI, the MS benefits from its nominal data rate. For a r-tuple $(n_{21}, ..., n_{2r})$ representing the number of users in each ring, the service rates are given, for $(n_{21}, ..., n_{2r}) \neq (0, ..., 0)$, by:

$$\forall i \ \mu_i^2 = \left(X_{ON} \frac{\sum_{k=1}^{r} n_k^2}{\tilde{D}_i^2} \right)^{-1} .$$

Figure 4 shows an example of alternate transmissions between two users in the HSDPA cell. If there is a single user scheduled by TTI, the throughput experienced by the first user is $\tilde{D}_{21}/2$ and by user 2 is $\tilde{D}_{22}/2$. The allocation is fair in time.

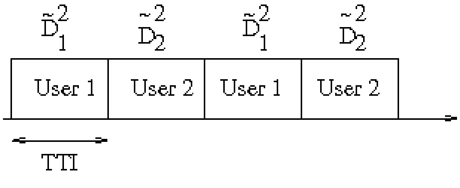

Fig. 4. Illustration of the alternate transmissions of two MS in a HSDPAcell. Users equally share the resources in time.

2.4 Joint Radio Resource Management

A joint radio resource management policy is an algorithm that decides for each new packet call arrival whether the packet call is rejected, accepted in RAT1 or accepted inRAT2. JRRM is thus here assumed to be more dynamic than session admission control. We consider two policy classes.

RS-JRRM : "ring dependent state JRRM". In this class, the system is defined by the number of users in each ring (state of the system). The JRRM policy decision (action of the policy) for a new packet call arrival does not depend on the location of the user in the cell. An example of decision for RS-JRRM is "accept any new arrival and assign it to RAT1".

RSA-JRRM : "ring dependent state and action JRRM". In this class, the system is defined by the number of users in each ring (state of the system). The JRRM policy decision (action of the policy) for a new packet call arrival depends on the location of the user in the cell. An example of decision for RSA-JRRM is "accept any new arrival in ring 1 and assign it to RAT1, but reject any new arrival in ring 2".

As RSA-JRRM type of policies is more precise, it is expected to provide better results. The goal of this study is to find an optimal JRRM policy for each of the presented classes; optimality is defined below.

3 Semi-Markov Decision Process

In order to achieve this goal, we rely on the SMDP framework. We first define the SMDP and the reward function, then use uniformization to obtain an MDP and use the policy iteration to find the optimal JRRM policy.

3.1 States of the SMDP

The states of the SMDP are the 2r-tuple $(n_1^1, ..., n_r^1, n_1^2, ..., n_r^2)$ with the constraints associated to each RAT:

- $\sum_{i=1}^{r} n_i^1 \leq n_{max}^1$ for RAT1 and
- $\sum_{j=1}^{r} n_j^2 \leq n_{max}^2$ for RAT2.

Let S be the state set.

3.2 Actions

1) RS-JRRM: There are three possible actions for a JRRM policy in this class: reject, accept in RAT1or accept in RAT2. These actions are given by a vector a = (a1, a2), where aj = 1 (resp. 0) if the policy accepts (resp. rejects) any new packet call in RAT j (see table I).

TABLE I
LIST OF POSSIBLE ACTIONS WITH RS-JRRM

Action	a Vector
Reject	$(0, 0)$
Accept in RAT1	$(1, 0)$
Accept in RAT2	$(0, 1)$

The set of possible actions is state dependent. Let A(s) the action set in state s. For a generic state s, A(s) = {(0, 0), (1, 0), (0, 1)}. This set can however be reduced in some specific cases:

• if RAT1 is blocked, i.e., $\sum_{i=1}^{r} n_i^1 = n_{max}^1$ and RAT2 is not blocked, i.e., $\sum_{j=1}^{r} n_j^2 \leq n_{max}^2$, A(s) ={(0, 0), (0, 1)},

• if RAT2 is blocked and RAT1 is not blocked, $A(s) = \{(0, 0), (1, 0)\}$,• if RAT1 and RAT2 are blocked, $A(s) = \{(0, 0)\}$,• if $s = (0, ..., 0)$, $A(0) = \{(0, 1), (1, 0)\}$.

2) RSA-JRRM: In this class, actions are described by a vector $(a_{11}, a_{12}, ..., a_{ji}, ..., a_{2r})$, where $a_{ji} = 1$ (resp.0) if a new packet call is accepted (resp. rejected) in RAT j and ring i, and with the condition $\sum_i a_i^j \leq 1$ (we cannot assign to several RAT at the same time).If there are two rings, there are nine possible actions for a JRRM policy in this class. These actions are given by a vector $a = (a_{11}, a_{12}, a_{21}, a_{22})$ (see table II).

TABLE II
LIST OF POSSIBLE ACTIONS FOR TWO RINGS WITH RSA-JRRM

Action	a Vector
Reject	$(0, 0, 0, 0)$
Accept in RAT1 ring1	$(1, 0, 0, 0)$
Accept in RAT1 ring2	$(0, 1, 0, 0)$
Accept in RAT2 ring1	$(0, 0, 1, 0)$
Accept in RAT2 ring2	$(0, 0, 0, 1)$
Accept in RAT1 ring1 and 2	$(1, 1, 0, 0)$
Accept in RAT2 ring1 and 2	$(0, 0, 1, 1)$
Accept in RAT1 ring1 and RAT2 ring2	$(1, 0, 0, 1)$
Accept in RAT1 ring2 and RAT2 ring1	$(0, 1, 1, 0)$

The action state includes all actions given in table II for a generic state, but it can be again reduced in some specific states (when RAT are blocked or empty).

3.3 Transition probabilities

Let $p_{s,s'}(a)$ be the probability that at next decision epoch, system will be in state s' if a is chosen instate s and let $\tau_s(a)$ be the expected time until next decision epoch if action a is chosen in state s. Let_$\delta_{ji} = 1$ if there is an active MS is ring i of RAT j, and $\delta_{ji} = 0$ otherwise.

1) RS-JRRM: In a given state, $s = (n_{11}, ..., n_{1r}, n_{21}, ..., n_{2r})$, and for a given decision a, several transitions are possible according to the values of the n_{ji} :
• if $n_{ji} \neq 0$, i.e., $\delta_{ji} = 1$, a departure is possible in this ring with rate $\mu_{ji}(s)$,
• if RAT j is not blocked, an arrival implies a state transition if $a_j = 1$ and so an arrival occurs with rate $a_j \lambda/r$. Note that here, arrivals in rings are assumed to be equiprobable; if not, differentprobabilities should be taken into account in the latter rate instead of dividing by r.

So the transition probabilities are:

$$\begin{aligned} p_{s,s'}(a) &= \frac{\delta_i^j \mu_i^j(s)}{\sum_{i,j}\left(a_j\lambda/r + \delta_i^j \mu_i^j(s)\right)}, \qquad (1) \\ \text{where } s' &= (n_1^1, ..., n_i^j - 1, ..., n_r^2), \end{aligned}$$

in case of departure in ring i of RAT j.

$$\begin{aligned} p_{s,s'}(a) &= \frac{a_j\lambda/r}{\sum_{i,j}\left(a_j\lambda/r + \delta_i^j \mu_i^j(s)\right)}, \qquad (2) \\ \text{where } s' &= (n_1^1, ..., n_i^j + 1, ..., n_r^2), \end{aligned}$$

in case of arrival in ring i of RAT j.

The expected time until next decision epoch is thus given by :

$$\tau_s(a) = 1/\sum_{i,j}\left(a_j\lambda/r + \delta_i^j\mu_i^j(s)\right). \qquad (3)$$

2) RSA-JRRM: Equations 1, 2, and 3 are still valid provided that a_j is replaced by a_{ji} .

3.4 Rewards

Let $c_s(a)$ be the expected reward incurred until next decision epoch if a is chosen in s. $c_s(a)$ is a reward, so a priori without dimension in our analysis. Let us define the user satisfaction for a user having data rate D: $\Phi(D) = 1 - \exp(-D/D_c)$, where $D_c$is a so called comfort throughput [15].
In our case, we consider a user in ring i of RAT j: his departure rate is $\mu_{ji}(s)$. So the satisfaction of an accepted user is: $\_(\mu_{ji}(s), n_{ji}) = 1 - \exp(-\mu_{ji}(s)/\mu_c)$, where $\mu_c = D_c/X_{ON}$. Note that individual user satisfaction is between 0 and 1.
We define the global reward as the sum of all user satisfactions. If a user is in transfer, his satisfaction is a function of his data rate. If a user is blocked, a penalty is paid (and so subtracted from the accumulated reward so far) to take into account the fact that rejected users are dissatisfied. As a consequence, the sum of all active user satisfactions in state s is:

$$U(s) = \sum_{i,j} n_i^j(1 - exp(-\mu_i^j(s)/(n_i^j\mu_c))).$$

Note that this satisfaction is without dimension.

To take into account the dissatisfaction incurred by blocking, we now introduce a penalty proportional to the arrival rate in blocking states.

1) RS-JRRM: For this class of policies, the penalty is set to $K_b\lambda$ in blocking states (note that $K_b\lambda$ is a satisfaction and so without dimension). If action a is chosen, the penalty in state s is thus $K_b(1 - a_1)(1-a_2)\lambda$. Note that if the JRRM algorithm accepts new packet calls in RAT j, $a_j = 1$ and the penalty is zero. Penalty is non-zero only if the JRRM rejects all incoming packet calls in a given state. As a conclusion, the global reward obtained in state s if action a is taken is:
$c_s(a) = U(s) - K_b(1 - a_1)(1 - a_2)\lambda$.
2) RSA-JRRM: For this class of policies, the penalty is set to $K_b\lambda/r$ for each ring blocked by theJRRM. If action a is chosen, the penalty in state s is thus:

$$\sum_{i=1}^{r} K_b\prod_{j=1}^{2}(1 - a_i^j)\lambda/r.$$

For both classes, RS and RSA-JRRM, we are considering an infinite planning horizon and the goal ofthe study is to find a JRRM algorithm that maximizes the long-run average reward per time unit.

3.5 Policy

A JRRM policy is a n-tuple of a vectors specifying for each state of the MDP the action to be selected in that state. We consider here stationary and deterministic policy, i.e., the policy does not change in time and in a given state, the policy specifies a single action (with probability 1).

Note that for the average cost Markov decision model with finite state space and finite action sets, there exists an optimal policy and the optimal policy is stationary and deterministic.
Such a policy is an application from S to A, which associates at each state s an action in A(s):

$$\forall s \in S, R_s \in A(s).$$

It is useful to notice for the derivation of performance parameters for a given policy that the SMDP with transition probabilities $p_{s,s'}(R_s)$ is a traditional continuous time Markov chain.

3.6 Uniformization

In order to find the optimal policy with the algorithm "policy iteration", a stage of uniformization is needed. This stage is a transformation of the continuous Markov chain into a discrete Markov chain. This is done by choosing a sufficiently small transition step $0 \leq \tau \leq \min_{s,a} \tau_s(a)$ and allowing self-transitions from a state to itself. Transition probabilities are modified in the following way:

- $\bar{p}_{s,s'}(a) = p_{s,s'}(a)\tau/\tau_s(a)$ for $s \neq s'$,
- $\bar{p}_{s,s}(a) = 1 - \sum_{s' \neq s} \bar{p}_{s,s'}(a)$ otherwise.

So the new transition probabilities can be written:

$$\bar{p}_{s,s'}(a) = \delta_i^j \mu_i^j(s)\tau,$$

in case of departure in ring i of RAT j, and:

$\bar{p}_{s,s'}(a) = a_j \lambda\tau/r$ for RS-JRRM,

$\bar{p}_{s,s'}(a) = a_i^j \lambda\tau/r$ for RSA-JRRM,

in case of arrival in ring i of RAT j.
For RS-JRRM, the reward is modified as follows:

$$\bar{c}_s(a) = U(s)/\tau_s(a) - K_b(1-a_1)(1-a_2)\lambda/\tau_s(a).$$

For RSA-JRRM, the reward can be written:

$$\bar{c}_s(a) = U(s)/\tau_s(a) - \sum_{i=1}^{r} K_b \prod_{j=1}^{2}(1-a_i^j)\lambda/(r\tau_s(a)).$$

3.7 Policy Iteration

We use the policy iteration algorithm to find out the optimal JRRM policy. The iterative algorithm isnow succinctly described.
Step 0 (initialization) : We choose an arbitrary stationary policy R.

Step 1 (value-determination) : For the current policy R, we solve the system of linear equations whose unknown are the variables {g(R), v_s(R)}: $v_1 = 0$ and

$$v_s(R) = \bar{c}_s(R_s) - g(R) + \sum_{s' \in S} \bar{p}_{s,s'}(R_s) v_{s'}(R).$$

Step 2 (policy improvement) : For each s 2 S, we find:

$$\bar{R}_s = arg \max_{a \in A(s)} \left\{ \bar{c}_s(a) - g(R) + \sum_{s' \in S} \bar{p}_{s,s'}(a) v_{s'}(R) \right\}$$

Step 3 (convergence test) : if $\bar{R} = R$, the algorithm is stopped, otherwise, we go to step 1.

4 Numerical Application

4.1 Traffic

We assume a web browsing traffic with the following parameters: varying λ (in order to consider several loads of the cell) and $X_{ON} = 3$ Mbits (this is the aggregate average size of all objects during packet call duration in [16] for the web browsing model).

4.2 Nominal Data Rates

For the sake of simplicity, we only consider two rings (r = 2). For WLAN, two nominal rates are chosen, which are also two mandatory rates of the IEEE 802.11g standard:
$\tilde{D}_{11} = 24$ Mbps, $\tilde{D}_{12} = 6$ Mbps. Comfort throughput is $D_c = 1$ Mbps and $n_{1max} = n_{2max} = 6$.
In HSDPA networks, the SINR in each ring i can be approximated by [1]:

$$SINR_i = \frac{1 - \psi}{\alpha\psi + f_i},$$

where   is the fraction of power dedicated to common channels, _ is the orthogonality factor and f_i is the interference factor (the ratio between the total power received by all other base stations and the total received power from the own station). Let us assume the following values for the parameters: Φ = 0.2, α = 0.7, $f_1 = 0.1$, $f_2 = 1.2$ for two rings. If we assume that the system is able to provide the Shannon capacity: $\tilde{D}_{2i} = W\log_2(1 + SINR_i)$, where W = 3.84MHz is the signal bandwidth. The numerical application provides: $\tilde{D}_{21} = 8.1$ Mbps and $\tilde{D}_{22} = 2.6$ Mbps. However, we choose more realistic values [17] (for Pedestrian A3 channel) that are given by: $\tilde{D}_{21} = 2$ Mbps and $\tilde{D}_{22} = 800$ Kbps.

4.3 Reference Policy

In order to see the improvements brought by the optimal JRRM policy, we define a simple and commonsense policy, which is also the initial policy in the policy iteration algorithm. As WLAN is the fastest RAT, we assign the packet calls to WLAN until n_{1max} is reached. We then assign MS to HSDPA until n_{2max} is reached. When both RAT have reached their maximum number of simultaneous active users, any new packet call is rejected.

4.4 Results

1) User satisfaction: Figure 5 shows the global user satisfaction per time unit as a function of the arrival rate for three different cases: the reference policy that chooses WLAN cell in priority, optimal RS-JRRM policies, and optimal RSA-JRRM policies. Note that the optimal policy is load (and so λ) dependent: solid curves are thus a set of optimal policies obtained for each value of λ.Recall that RSA-JRRM policies are allowed to accept or reject new packet calls depending on the ring of arrival. On the contrary, RS-JRRM policies take decisions based only on the state of the system (and so the spatial distribution of on going packet calls). As expected, the global user satisfaction per time unit, which is also the utility function to be maximized, is better with RSA than for RS, and both policies outperform the reference policy.

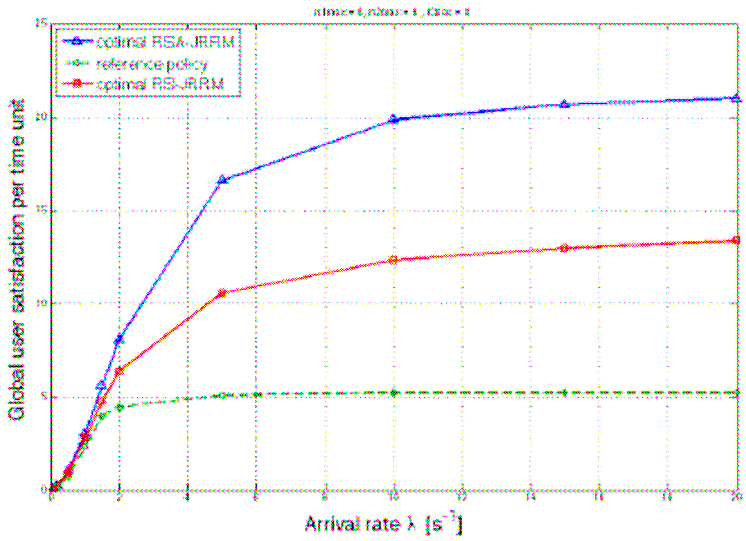

Fig. 5. Global user satisfaction per time unit ($K_b = 0$, $n^1_{max} = n^2_{max} = 6$) for the reference policy, RS-JRRM, and RSA-JRRM policies.

2) Performance parameters: As it is not obvious to figure out exactly what user satisfaction means, we now show some more common performance parameters. Figure 6 and 7 show the blocking probability, the average user throughput, the average number of simultaneous packet calls and the average sojourn time. RS and RSA optimal policies allow both a higher user throughput and thus a lower sojourn time. This result is however not obtained at the expense of the blocking probability. This apparently contradictory effect can be explained by the fact that less packet calls are accepted by optimal policies. Arrivals in the inner rings, where data rate is higher, are also more likely to be accepted. This results in higher throughputs and thus in higher service rates. At constant arrival rate, this means a lower load for the system and a reduced blocking probability. As optimal RSA is more precise in the selection of accepted packet calls, it provides also better performance than optimal RS-JRRM.

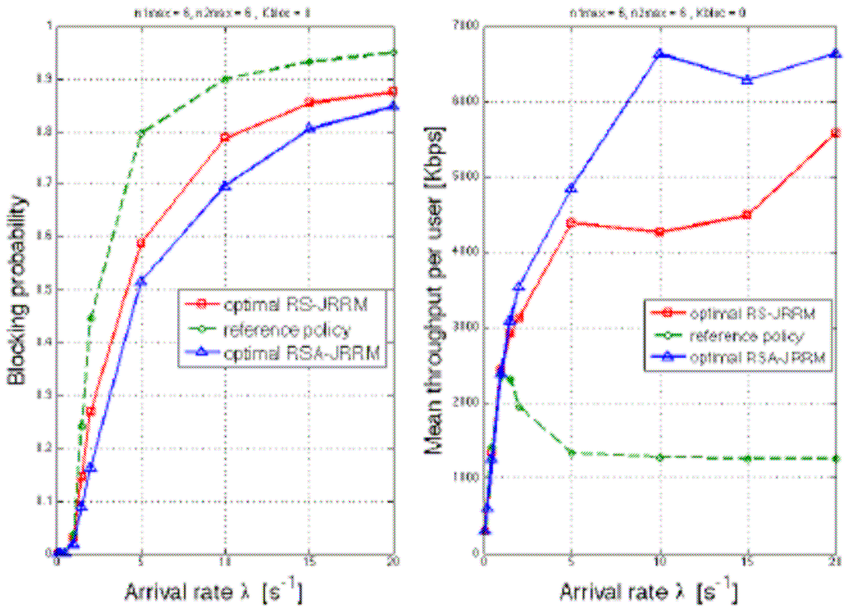

Fig. 6. Blocking probability and average user throughput ($K_b = 0$, $n^1_{max} = n^2_{max} = 6$) for the reference policy, RS-JRRM, and RSA-JRRM policies.

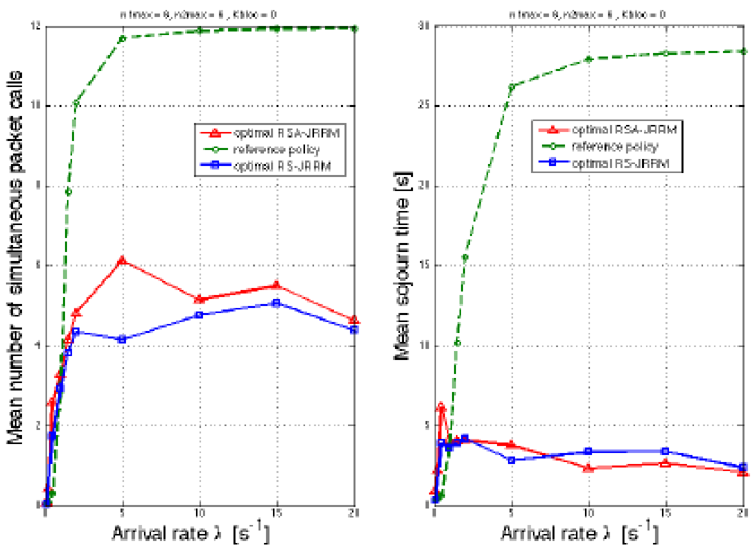

Fig. 7. Average number of simultaneous packet calls and average sojourn time ($K_b = 0$, $n^1_{max} = n^2_{max} = 6$) for the reference policy, RS-JRRM, and RSA-JRRM policies.

Figure 8 further illustrates this effect. System states (n_{11}, n_{12}, n_{21}, n_{22}) (784 in this example) are ordered by increasing average user satisfaction (before uniformization). Bar graphs show the state stationary probabilities under reference, optimal RS and RSA policies under high load, i.e., for a given high λ.

Under the reference policy, a lot of time is spent in inefficient states. On the contrary, states providing high user satisfaction are favored under optimal RS and RSA. This is confirmed by table III, where the three most probable states and their respective stationary probabilities are given for a highly loaded scenario. Under the reference policy, low throughput states (e.g. (0, 6, 0, 6)) are the most probable states because the departure rate is also very low.

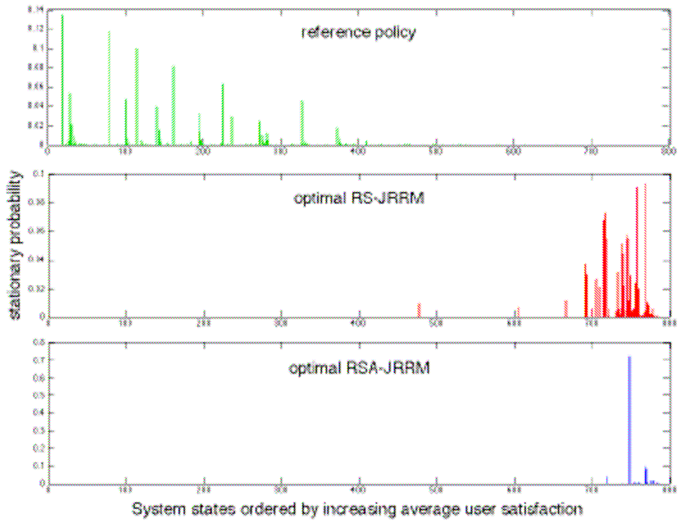

Fig. 8. Stationary probabilities with states ordered by increasing average user satisfaction ($K_b = 0$, $n^1_{max} = n^2_{max} = 6$, $\lambda = 20\ s^{-1}$) under the reference policy, RS-JRRM, and RSA-JRRM policies.

Figure 9 shows how the probability of state (0, 6, 0, 6) increases with load under the reference policy. A similar effect has been highlighted in [19]: As for CDMA/HDR networks, most load is concentrated in outer rings and outer rings users have a significant impact on inner rings user performance.

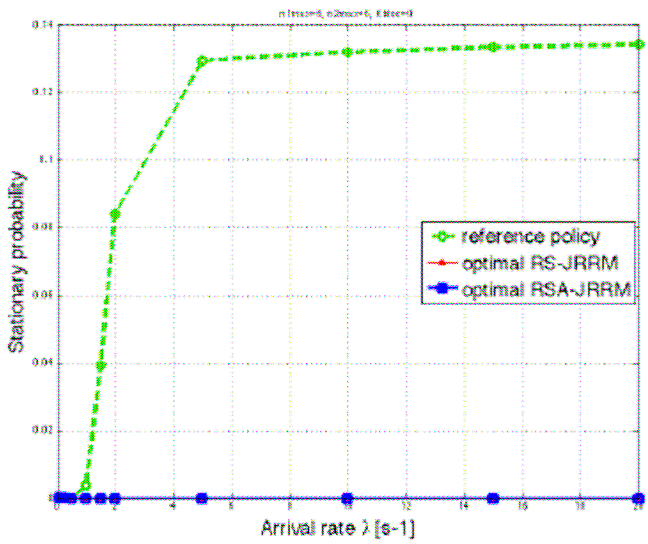

Fig. 9. Stationary probabilities for the state $(0, 6, 0, 6)$ ($K_b = 0$, $n^1_{max} = n^2_{max} = 6$, $\lambda = 20\ s^{-1}$) for the reference policy, RS-JRRM, and RSA-JRRM (the two latter curves are confounded and very close to zero).

On the other side, optimal policies selectively reject packet calls in order to avoid such trap states (probability of state (0, 6, 0, 6) is almost zero for all loads in figure 9).

TABLE III
THREE MOST PROBABLE STATES UNDER THE REFERENCE POLICY, OPTIMAL RS-JRRM AND OPTIMAL RSA-JRRM ($\lambda = 20\,\mathrm{s}^{-1}$)

Reference		RS-JRRM		RSA-JRRM	
proba.	state	proba.	state	proba.	state
0.13	$(0, 6, 0, 6)$	0.09	$(2, 1, 0, 1)$	0.72	$(3, 1, 1, 0)$
0.12	$(1, 5, 0, 6)$	0.09	$(0, 1, 0, 1)$	0.09	$(2, 1, 1, 0)$
0.10	$(2, 4, 0, 6)$	0.07	$(0, 1, 2, 0)$	0.04	$(3, 0, 1, 0)$

3) Control of the blocking probability: Figure 10 shows how it is possible to reduce the blocking probability by tuning the penalty parameter K_b. Increasing K_b from 0 to 20 significantly reduces the blocking probability. This reduction in blocking is obtained at the cost of a reduced global satisfaction (not shown here). This is explained by the fact that the penalty caused by blocking is subtracted from there ward and is proportional to the arrival rate.

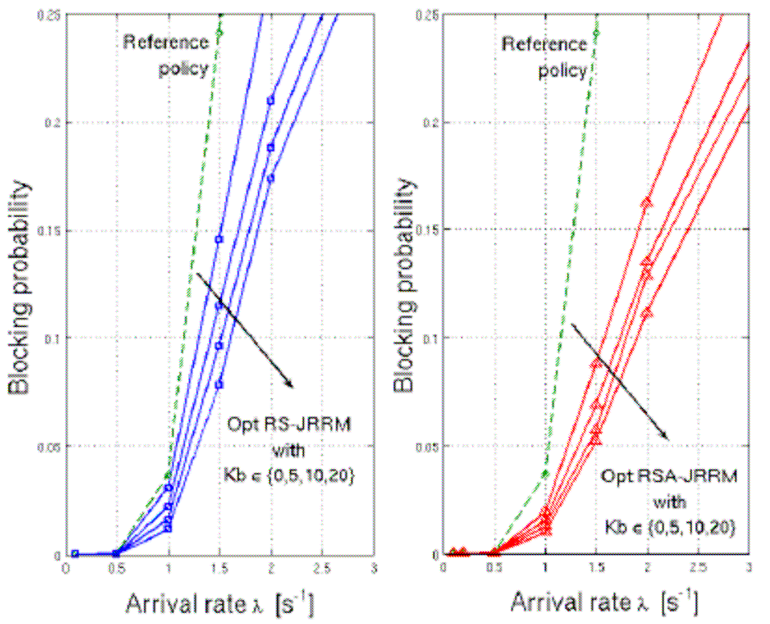

Fig. 10. Blocking probability for various figures of K_b ($n^1_{max} = n^2_{max} = 6$) for the reference policy (dotted line), optimal RS-JRRM (left), and optimal RSA-JRRM (right) policies.

5 ACKNOWLEDGMENT

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Part II: Radio Resource Management Using Forced Vertical Handover

In this part, we study radio resources optimisation by forced vertical handover technique. For the network, it results in load balancing between different RATs to enhance the whole bandwidth utilisation and avoid congestion. For the mobile nodes, the result will be an enhancement in term of QoS and performances like throughput, access delay and blocking probability in the whole multi-RAT network.

7 Proposed forced handover scheme

The proposed model is based on periodical measurements done by each cell on its coverage. In case of congestion, concerned cell asks mobile nodes involved to launch a discovery of other networks on their coverage. Each node starts scanning the neighbour RATs via dedicated radio interfaces, and determines the cell that covers it. Then, it sends all these neighbours network information to its home cell which should establish connexion with those neighbours' cells via a peer to peer network (P2P), using the control plane, and then downloads all their information. The home cell asks the mobile's neighbourhood cells if they could accept the different service level specifications (SLS) of mobile nodes. Finally, the home cell resumes responses, then sends it to mobile nodes, and each of them selects a new home cell using it own metrics (energy, cost, SNR ratio etc.); an illustration is shown in fig. 1. The use of control plane serves to get a federate control network, this last releases some load from communication and access networks. Security, control information and mobility management are plugged into this peer-to-peer network.

As described, proposed scheme requires periodic radio and congestion measurements and information exchange between neighbour networks in the control plane. Those control messages are related to networks cells (cells configuration, neighbourhood) as well to mobile nodes (subscription, security, SLS …).

Moreover, to ensure vertical handover execution when needed, a mobility management protocol should be defined.

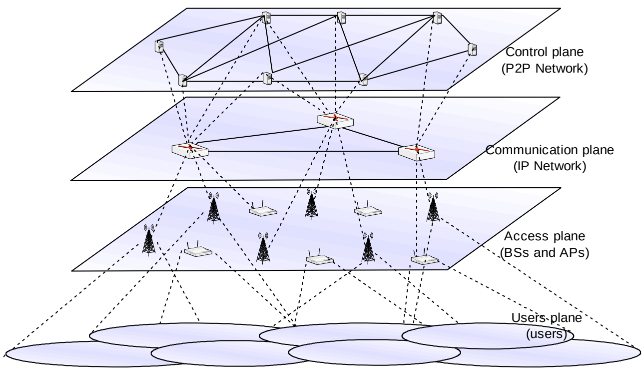

Fig. 1. Network Architecture

Below a description of the proposed scheme and inter – plane communications. We see measurement done by the cell, BS or AP and the decision taken in consequence. Note that those measurements are in both radio layer and network layer for queue size which gives information about congestion in the cell coverage.

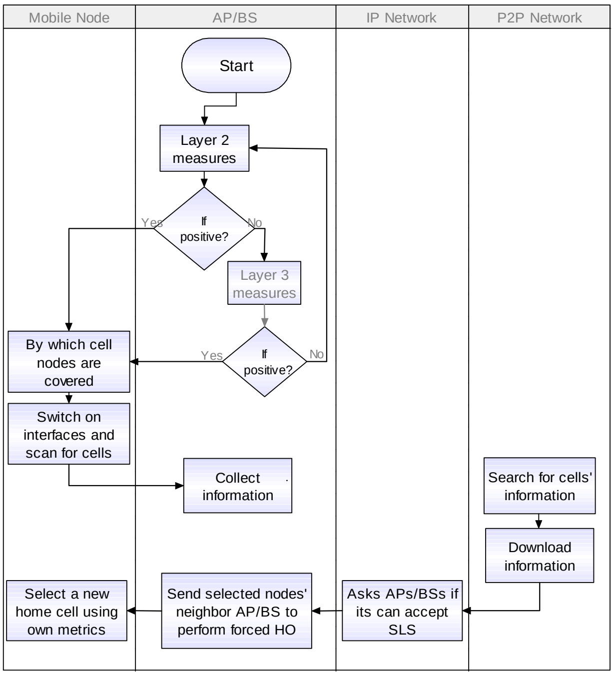

Fig. 2. Forced vertical handover algorithm

7.1 Control information

Discovering the Cells neighborhood is very important to have a knowledge topology of access network. Each cell knows, in on-demand, all their neighbors using different control messages. The peer-to-peer network serves to exchange these control messages; they are used to discover neighbor cells using mobile nodes. Hence, this information keeps knowledge about the topology of all neighbor cells.

7.2 Subscription, authentication and security information

In this sub-section, we outline a security management. The peer-to-peer network exchange messages corresponding to authentication and security in wireless networks. Cells exchange security messages with nodes to authentication and encrypting packets, these cells exchange these messages in peer-to-peer network. Indeed, when nodes change their point of attachment and move to secured cell, all security information is moved to nodes for a fast registration. Therefore, we could get a profit in delay registration.

7.3 Mobility management

To manage mobility and handover, we propose to apply an anticipated vertical handover (AVHO) proposed in [13], based on Fast mobile IPv6 (FMIPv6) mobility protocol. This will allow a seamless handover based on pre-CoA acquisition due to the FMIPv6 signaling messages done prior to Handover initiation. FMIPv6 aims to improve Mobile IP [[7]] inter-domain handover latency thanks to an inter-gateways tunneling, in the other side, we can use micro mobility protocols (like HMIP, cellular IP …) to handle intra-domain handoff. In our scheme, signaling is anticipated prior to handover, based on a forced handover scenario, where the mobile node is notified to start the handover process before moving to the new access network in order to minimize the handover latency and packet loss.

Mobility management is plugged into peer-to-peer network, for instance, home agents are found into peer nodes, control messages, like binding update/acknowledgement, router solicitation, etc., are sent using the peer-to-peer links. Consequently, this approach reduces the load of control messages used to handle mobility into IP network.

The handover is prepared on advance or a “make before break” approach, the mobile initiates the registration request while still receiving packets on the old link and after receiving the care of address (COA) it starts receiving packets on the new link using a dedicated interface. Our choice was based on this proposal because of there likeness with our method. Likewise, we assume that each mobile node is equipped with many interfaces, it can proceed the handover initiation stages, it enable the MN to be still connected to the previous access network while preparing the handover to the new one.

8 Example of a WiMAX/WiFi cooperative scheme

In this part we apply our proposed model to a heterogeneous radio access network composed of WiMAX and WiFi cells. Measurements should be done according to the radio layer of each RAT.

Each access point (AP), base station (BS) or access routers (AR) make periodic measurements, the radio access in layer 2 and queue size in layer 3, each of them in T time interval during which it calculates collision times, successful times, idle time and transmission time respectively t_{coll}, t_{succ}, t_{idle} and t_{tr}.

We will present in the following parts how to achieve those measurements in both the WiMAX and in the WiFi RATs. Then, we will analysis obtained performances in term of bandwidth, delay and blocking probablility with the proposed scheme.

8.1 Measurements in the radio and network layers

In radio access network, three periods are defined, successful time (t_{succ}) indicates a time in which a packet is received successfully, collision time (t_{coll}) indicates a time which happen collision and idle time (t_{idle}) indicates a time during which the media is free.

Packets losses and collisions can be deduced thanks to received signals in the physical and/or in the MAC layer. Below an example for measurements in IEEE 802.11 cells.

$$t_{coll}\begin{cases}\textit{Scrambled signals in downlink (layer 1)}\\ \textit{Packet sent without Ack in uplink (layer 2)}\end{cases}$$

$$t_{succ}\begin{cases}\textit{Correct signal in downlink (layer 1)}\\ \textit{Packet sent with Ack in uplink (layer 2)}\end{cases}$$

After measuring all this parameters, the following factors are calculated, using network interfaces:

$$\alpha = \frac{\sum_{i=1}^{n_c} t_{coll_i}}{T} \quad (1) \quad \beta = \frac{\sum_{j=1}^{n_s} t_{succ_j}}{T} \quad (2) \quad \chi = \frac{\sum_{i=1}^{n_{tr}} t_{tr_i}}{T} \quad (3)$$

Where:

n_c: number of collisions;
n_s: number of successful transmissions.
n_{tr}: number of successful transmission in slotted part.

With (1) and (2), we calculate a ratio: $\frac{\alpha}{\beta}$

If $\frac{\alpha}{\beta} \geq \sigma_{wf}$ with $\sigma_{wf} > 1$, AP takes a decision that there is layer 2 congestion, else AR makes layer 3 measurements.

In 802.16 WiMAX networks [11], two parts are distinguished, contention part and slotted part. In a contention part, like in WLAN, BS calculates factors α(1) and β(2), a third factor is measured within the slotted part,

When WiMAX is used, a new factor χ(3) is calculated, and from (1), (2) and (3) a new ratio is calculated $\frac{\alpha}{\beta+\varphi}$:

Where φ is the ratio of rejected calls number over all calls in IEEE 802.16 networks.

If $\frac{\alpha}{\beta+\varphi} \geq \sigma_{mx}$ where $\sigma_{mx} > 0$, BS takes a decision that there is layer 2 congestion.

If the cell is not congested, layer 3 measurement is done by access router:

$$M_k = \alpha \times M_{k-1} + (1-\alpha) \times V_{inst} \quad (4)$$

Where:
M_k: a smoothed value of a queue
α: a factor $\in$ [0,1], generally have a value: 0.8
V_{inst}: Instant value of the queue size.

Using these two measurements, if no congestion is founded, then nothing is done. Else ask for base stations and/or access points that cover these mobile nodes. Then, search these cells information in P2P network, asks them if SLS could be accepted, selects a dedicated APs/BSs which could accept these nodes. Finally, these last receives all the information then selects a dedicated AP/BS using its own metrics, fig. 1.

To manage the handover, after the initiation stage, the mobile node sends fast binding update to the old access router (AR) by using its COA just before it carries out handover. The mobile node then receives fast binding acknowledgment of the old AR by indicating that the updating has been achieved. Indeed, the old AR sends the F-Back message to the mobile node by building a temporary tunnel. The old AR can also send the F-Back message to the mobile node on its old connection (to ensure the message reception by the mobile node).

8.2 Performance analysis

Performance evaluation was done using the OPNET Modeler [12], a discrete event simulator. In our simulation we have considered simple network topology, one access point router (APR) using IEEE 802.11e for the radio interface providing QoS, one base station (BS) using IEEE 802.16 for radio access linked to an access router (AR), BS and APR are connected to peer-to-peer (P2P) servers to use the control plane, (see fig. 3). To manage mobility, anticipated vertical handover (AVHO) [13] was implemented in our simulation scenario, which is based on fast mobile IPv6 protocol (FMIPv6); this anticipated handover used two interfaces, one is connected to home cell when the second one initiates the handover in the second one.

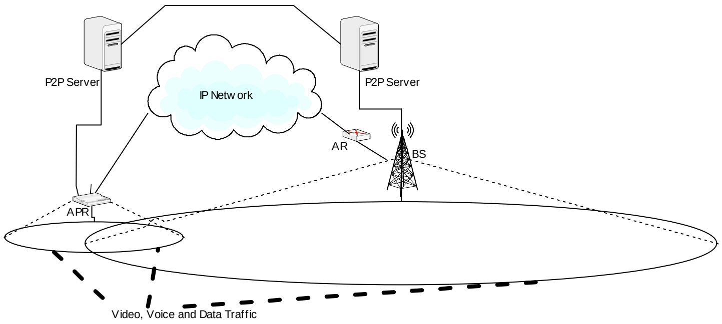

Fig. 3. The Simulation example

The side of the square is set to 10000m, while the coverage areas of the 802.11 and 802.16 cells are set to 350m and 8000m, respectively. 15 mobile nodes equipped with two interfaces to perform a vertical handover and 5 mobile nodes for each cell. To evaluate the performances, we have considered three kinds of traffic, ftp, voice and video traffic.

Tables given below show the considered Traffic used in the simulation.

Each mobile node handles these three types of traffic. We start simulation with minimum traffic per mobile node, and we increase the offered load of each node periodically. The simulation duration is about 10 min, the destination is randomly chosen.

Table I shows the detailed description of traffic, sessions and profiles used. Table I.a gives an indication of a packet generator for voice traffic, table I.b shows for a video traffic and table I.c for ftp traffic.

TABLE I
a. VOICE TRAFFIC GENERATOR

	IP Telephony & Silence Suppressed	GSM Quality & Silence Suppressed
Silence length (sec)	Incoming silence length = exponential (0.65)	
	Outcoming silence length = exponential (0.65)	
Talk spurt length (sec)	Incoming talk spurt length = exponential (0.352)	
	Outcoming talk spurt length = exponential (0.352)	
Encoder scheme	G.729 A (Silence)	GSM (FR) (Silence)
Voice frame/packet	1	
Type of Service	Interactive voice (6)	
Compression delay	0.02 sec	
Decompression delay	0.02 sec	

b. VIDEO TRAFFIC GENERATOR

	High Resolution Video	VCR Quality Video
Frame Interval Time Information	15 Frames / sec	30 Frame / sec
File size information (bytes)	128 240 Pixels	352 240 Pixels
Type of Service	Interactive Multimedia (5)	

c. FTP TRAFFIC GENERATOR

	High Load	Low Load
Command Mix (Get/Total)	50%	
Inter request time (sec)	Exponential (35)	Exponential (70)
File Size (bytes)	Constant (50000)	Constant (7000)
Type of Service	Best Effort (0)	

TABLE II
SESSION PARAMETERS USED IN SIMULATION

	FTP	Voice Traffic	Video Traffic
Session Duration (sec)	Poisson (400)	Poisson (180)	Poisson (180)
Inter repetition time (sec)	Exponen-	Exponential	Exponential

	tial (50)	(90)	(120)
Number of repetitions	Unlimited		

Fig. 4. shows the end-to-end delay in WLAN cell, we can see that when we increase the traffic in WLAN cell, there is a significant increase of delay amplitude. We see, when new traffic were started, that end-to-end delay in a cell is much more important with a classical topology control compared to our scheme. With our approach, APR makes the different measurements (radio access and queue size), these last was positive, it takes the decision to send a forced handover order to mobile nodes. Applies algorithms to discover and answer neighbors' cell mobile nodes, these latter disconnect from APR after starting there connection with there new cell (BS).

As in the fig. 5, the global throughput in APR cell's decreases significantly. When it makes the forced vertical handover decisions and disconnects some mobile nodes, we can clearly see that average throughput in WLAN cell is more more important with our method, due to the disconnection of some mobile nodes. In other words, packets that should be sent, with a classical topology control, are sent in WiMAX network, using our approach.

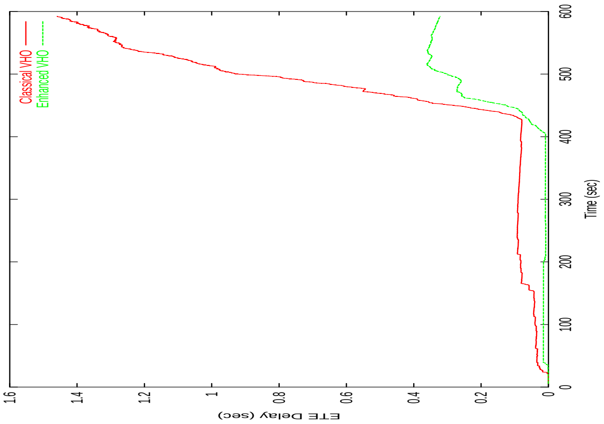

Fig. 4. End-to-end Delay in WLAN cell.

In fig. 6, throughput in WiMAX cell is shown. All nodes disconnected from WLAN cell, start their traffic in WiMAX cell, this why we can see an increasing in the downlink throughput. This last increasing is because some mobile nodes join a WiMAX cell already having some traffic load.

To show the impact of our topology control, we simulate nodes equipped with a voice application (IP Telephony & Silence Suppressed). We evaluate results according to delay (fig. 7).

We can see in fig. 7, delay of the voice node is evaluated (delay here is between mobile node and correspondent nodes CNs), we see a decrease of delay in our topology control, this due to liberation of the shared radio with the disconnected nodes. In classical topology control, the packets of other nodes cause delay in voice node, because of the shared media, when these nodes are forced to disconnect from WLAN cell and guarantee their connection to another cells, it causes a diminution of delay, which enhance significantly the QoS.

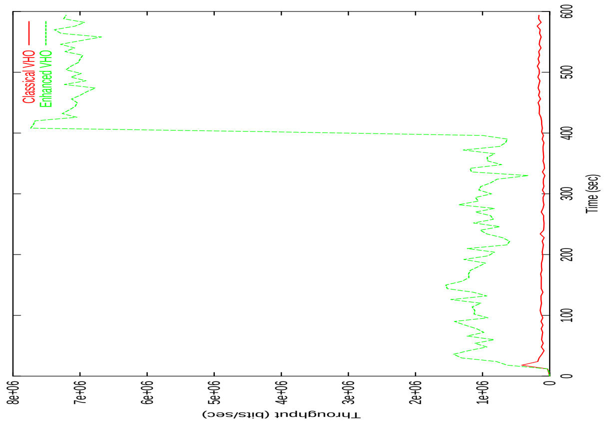

Fig. 5. Throughput in WLAN cell

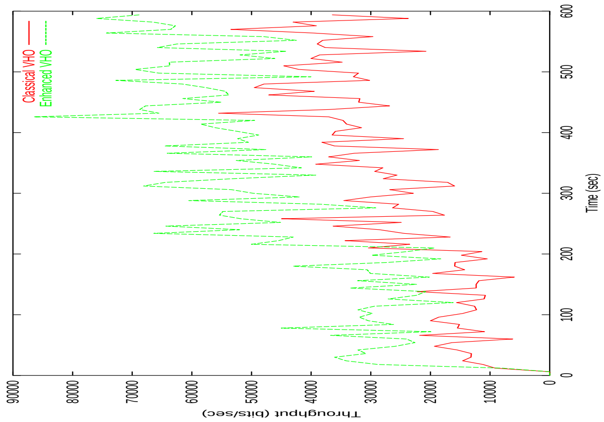

Fig. 6. Throughput in WiMAX cell

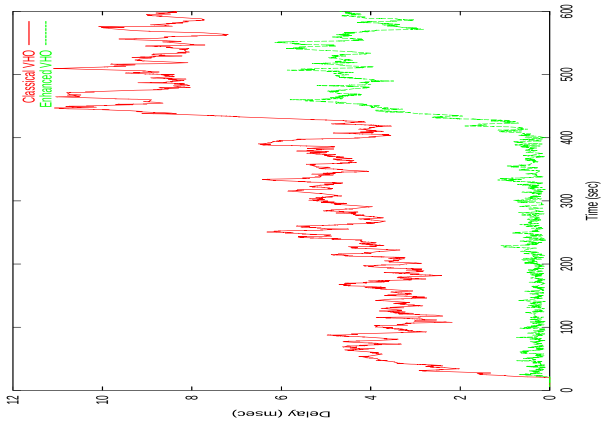

Fig. 7. Delay in voice node

Fig 8 shows the plot of blocking probability in WLAN cell; we can see in classical method that 28% of packets are blocked in APR, which is a high value. Otherwise, with our approach less than 5% of packets are blocked, this is due to the low load in WLAN cell. In contrast, traffic signalization has increase, but this increasing does not affect the users traffic. This is due to the use of independent control plane dedicated for this signaling traffic, fig. 9.

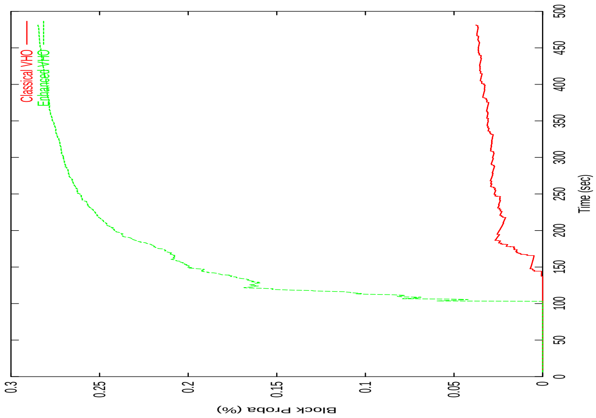
Fig. 8. Blocking probability in WLAN cell

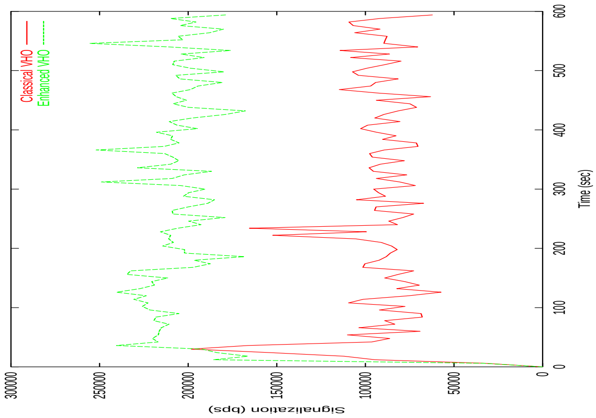
Fig. 9. Signalization traffic

As we can observe, the main advantage of this model is a gain in throughput, delay and quality of service. This is due to the independent control plan with P2P networks and with the help of mobile nodes.

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Part III: Conclusion

In the first part of our analysis, **SMDP Approach for JRRM Analysis in Heterogeneous Networks,** we have used the Semi Markov Decision Process framework to derive optimal JRRM policies for an heterogeneous cell shared by two RAT. We have taken into account the spatial distribution of the mobile stations in the cell. The throughput experienced by a user is indeed dependent on its distance to the access point or base station and is also dependent on the number of stations in each ring of the RAT. In this study, the proposed criteria of optimality include both user satisfactions, which is a function of the throughput and a penalty to account for the dissatisfaction caused by blocking. We have identified two classes of JRRM packet call admission control algorithms and highlighted optimal policies for each of these classes. Numerical applications show that the optimal policy is not an obvious one and can clearly outperform an a priori common sense algorithm. It is also shown that very good overall performances are obtained in terms of throughput and blocking probability; this can be explained by the fact that optimal policies limit the load induced by outer rings of the cell.

In the second part of our analysis, **Radio Resource Management Using Forced Vertical Handover,** we have studied radio resources optimisation by forced vertical handover technique. For the network, it results in load balancing between different RATs to enhance the whole bandwidth utilisation and avoid congestion. For the mobile nodes, the result will be an enhancement in term of QoS and performances like throughput, access delay and blocking probability in the whole multi-RAT network. In this purpose, we use a resource optimising technique. It is based on radio measurements, network congestion measurements, and a control plane for forced vertical handover execution. It consists in anticipating a RAT overload by forcing mobile nodes to connect to another RAT after appropriate measurements and controls. Each mobile is supposed to be equipped with the corresponding radio interfaces to be connected to the considered RATs. The proposed model is network controlled with mobile nodes cooperation. In fact, if periodical measurements done by cells require a forced handover, mobile node should give information about potential target RATs to allow service continuation. To ensure this, in addition to the radio access plane, are proposed a control plane for control information exchange and a communication plane for data exchange during handover.