Dynamic Access Point Selection and Resource Allocation in Multi-Technology Wireless Network

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***Abstract*—Heterogeneous Network (HetNet) is among the most important challenges for the upcoming cellular wireless networks. In this paper, we propose a method to optimize the Radio Access Technologies (RATs) selection and resource allocation in multi-technology wireless networks during a time period. We optimized on a realistic topology of Base Stations (BS) with overlaps of the cellular coverage and dynamic users traffic (arrival and departure). The optimization takes into account the requested services, different users' contract, and user satisfaction. Furthermore, in the proposed approach, we add constraints to ban the session drops and handovers for static users. For each instance, we formulate the problem as a linear optimization problem and we optimize it successively. The aim of the optimization is to jointly maximize the overall user satisfaction and the number of users connected. Compared with a legacy approach, numerical results show that our solution outperforms in terms of user satisfaction.**

***Index Terms*—Multi-technology Wireless Networks, Access Point Selection, Resource Allocation, Handover.**

I. INTRODUCTION

The past few decades revealed a rapid increase in terms of data transfer and number of wireless devices connected to the network. As exhibited in [1], statistics show an important annual growth to 2020. This increase motivated network operators to work on Heterogeneous Network (HetNet) that has created some new challenges (resources management, offload, network access mechanism...). A survey on HetNet access point selection can be found in [2]. In the state-of-art, the problem of network selection in HetNet can be solved by using either a distributed, centralized or hybrid selection approaches.

With a distributed approach, the control is given to different network entities. For example, in the user-centric approach, the decision is given to the User Equipment (UE). In [3] authors model the Radio Access Technologies (RATs) selection problem as a non-cooperative game where users try to maximize their own throughputs without consideration for other users. The competition of the users is modelled as an incomplete information game where players are not aware of other players' actions. They propose a RAT selection strategy that converges to a Nash equilibrium of the game.

In [4] authors study the dynamics of network selection in heterogeneous wireless networks (WiMAX, LTE, 3G, WiFi) based on a user-centric approach. They formulate the problem as a non-cooperative game: users such networks selfishly select the best RAT that maximizes their own throughputs. They study its existence of equilibria, convergence time, efficiency, and practicality.

In centralized approach, a controller has a global view and tries to optimize overall network performance. This approach is more flexible in terms of resource association or load balancing. In [5], using a centralized approach, authors model user association problem in heterogeneous wireless network as a linear optimization problem. They use a utility function with various parameters, reflecting the requirements of both the users and the network. In [6], authors propose a dynamic algorithm which deals with the user mobility by sharing the resource blocks under the constraints of rate requirements in an heterogeneous wireless network (one macro cell (OFDMA) and several femto cells).

Hybrid approaches take into account both the user needs and network performances. The authors in [7] model the RAT selection problem as a maximization of the overall users satisfaction and solved it by linear programming under network capacity constraints. In [8] authors propose a two step process to solve the RAT selection problem. In the first step, users screen the available list of scanned networks based on received signal strength and make a sorted list of RATs. In the second step, based on the sorted list and a multi-criteria utility function, the network associates users to one (or more) RAT. In our previous work [9], we proposed a method to optimize the RAT selection and resource allocation problem with snapshots of a heterogeneous network (3G/4G/Wi-Fi). The aim was to maximise the users' satisfaction and the number of users connected without taking into account the users' traffic dynamic.

In this work, we propose a model for optimizing the access point selection and resource allocation in multi-technology wireless networks (3G/4G) with dynamic users' traffic model and activity. The optimization is done periodically, at the end of each period, by maximizing both the overall user satisfaction and the number of connected users. Users' satisfaction is modelled by different utility functions. Simulations were performed on a realistic network topology with cells overlapping and static users. The optimization solution is sensitive to perturbations like new active users. Indeed, the arrival or departure of users to the network can create new associations for all users. Physically, this could generate handovers. We study the impact of the optimization in terms of handover and propose a solution without handovers for static users. Furthermore, the proposed solution guarantees the continuity of services as it does not allow the communication to drop.

The paper is organized as follows. Firstly, we describe the network model in Section II. In Section III, we present our user satisfaction and traffic source model. Then, the mathematical formulation of the problem and results are presented in sections IV and V. Finally, conclusions and perspectives are given in Section VI.

II. WIRELESS NETWORK MODEL: RESOURCES AND THROUGHPUT

In this section, we introduce the wireless network model and user satisfaction. We used a semilar model as in our previous work [9].

A. *Network Architecture and Resources*

We consider a wireless network architecture that consists of N_{bs} base stations with N_j co-localized RATs. The indexes $i \in \mathrm{I} = [1, \ldots, \mathrm{N_{bs}}]$ and $j \in \mathrm{J} = [1, \ldots, \mathrm{N}_j]$ are used throughout the paper to refer to a given BS and a given RAT, respectively.

We also consider $\mathrm{N_u}$ users' equipment. The index $k \in \mathrm{K} = [1, \ldots, \mathrm{N_u}]$ is used to designate the User Equipment k ($\mathrm{UE_k}$). The sporadic users' activity model is presented in the section III-C1. Users activity varies in time. Time is discretized with a step denoted by Δt. We thus consider a discrete time represented by index $t \in [1, \ldots, \mathrm{N_T}]$.

Cellular network resources are divided into Resource Units (RUs). Each RAT_j has a fixed number of RU denoted by R_j. For 3G networks, we assume that all codes have the same power and only codes are then treated as RUs. In 4G, a resource block is the smallest RU that can be scheduled. This allows us to have a discrete formulation of the theoretical throughput perceived by UE_k.

B. *Throughput Model*

Let γ_k^t be the perceived throughput by UE_k using one cellular technology at t. Let $\varphi^t_{i,j,k}$ be the perceived throughput of UE_k from BS_i over RAT_j per RU and $\lambda^t_{i,j,k}$ be the number of RUs assigned to UE_k associated with BS_i over RAT_j at t. The expression of γ_k^t is given by:

$$\gamma_k^t = \sum_{i \in I, j \in J} \lambda^t_{i,j,k} \varphi^t_{i,j,k} \qquad \forall k \in K. \tag{1}$$

The theoretical value of unit throughput $\varphi^t_{i,j,k}$ is based on the Shannon formula. Let $\nu_{i,j,k}$ be the Signal-to-Interference-plus-Noise Ratio (SINR) of UE_k from BS_i over RAT_j, and w_j the bandwidth per RU. The throughput that can be delivered to UE_k from BS_i over RAT_j per RU is given by:

$$\varphi^t_{i,j,k} = w_j \log_2(1 + \nu^t_{i,j,k}). \tag{2}$$

As established in [10] the SINR is given by

$$\nu^t_{i,j,k} = \frac{G_j}{G_j(a + ISR^t_{i,j,k}) + L^t_{i,k}\frac{P_j}{P_o}} \ ,$$

where G_j is the transmit antenna gain for technology j and a the orthogonality factor ($a = 0$ in 4G), $L^t_{i,k}$ is the path loss between UE_k and BS_i, P_j is the noise power for a given technology and P_o is the power per RU. $ISR^t_{i,j,k}$ is the Interference to Signal Ratio of UE_k from BS_i over RAT_j:

$$ISR^t_{i,j,k} = \sum_{i' \in I_{bs}\ ,\ i' \neq i} \pi_{i',j} \frac{L^t_{i,k}}{L^t_{i',k}} \ , \tag{3}$$

where $\pi_{i',j}$ is the percentage of resource used by the interfering $\mathrm{BS}_{i'}$ over RAT_j.

III. THE USER UTILITY AND TRAFFIC MODEL

As described in [11], several criteria or parameters, as throughput or delay, may be chosen as indicators of satisfaction. In this paper, we model the user satisfaction as a function of the throughput. We also differentiate users in two ways: their class of data traffic (elastic or non-elastic) and their contract (low cost or premium). We use sigmoid and concave utility functions.

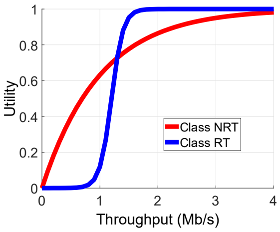

Fig. 1. Utility function per service.

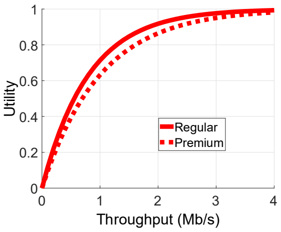

Fig. 2. Utility function per contract.

A. *Type of Contract*

We consider that the network operator provides two differentiated types of contracts, which are represented by index c. Regular contract ($c = R$) and Premium contract ($c = P$) differ in the user's satisfaction. As we can see on Fig. 2, for a given class of service, to achieve the same level of satisfaction, a premium user ($c = P$) will require a higher throughput than a regular user ($c = R$). A user has a fixed contract for all of the simulation.

B. *Class of data traffic*

We consider two types of traffic classes: non real-time (for elastic data use) and real-time (for non-elastic data use). Fig. 1 represents the utility per service. Index s is used throughout the paper to designate a given class of a service. Let U_k^s be the user's k utility function with class s service.

Non real-time services (s = NRT) are generated by traditional data applications such as mail download, web surfing, etc. Thus, we modelled the elasticity of the service by concave utility function:

$$U_k^{\mathrm{NRT}}(\gamma_k^t) = 1 - e^{-\frac{\gamma_k^t}{\gamma_c^T}}, \tag{4}$$

where γ_c^T is the target throughput demand of the user with contract c. We note that the satisfaction increases slowly after the throughput γ_c^T. Real-time services (s = RT) are generated by voice applications or video streaming. These services are non-elastic; we modelled the elasticity of the service by a sigmoid function:

$$U_k^{\mathrm{RT}}(\gamma_k^t) = \frac{1+e^{b\gamma_c^a}}{e^{b\gamma_c^a}}\left(\frac{1}{1+e^{b(\gamma_c^a-\gamma_k^t)}} - \frac{1}{1+e^{b\gamma_c^a}}\right), \tag{5}$$

where γ_c^a represents the average throughput demand of the user with contract c, b is a positive constant that determines the shape of the sigmoid.

For our simulation, the users proportion for a given service/contract is represented by α_c^s with:

$$\alpha_{\mathrm{R}}^{\mathrm{RT}} + \alpha_{\mathrm{P}}^{\mathrm{RT}} + \alpha_{\mathrm{R}}^{\mathrm{NRT}} + \alpha_{\mathrm{P}}^{\mathrm{NRT}} = 1. \tag{6}$$

C. *Traffic Source Model*

1) Non Real-Time Users: The NRT traffic source sporadically generates files with a random length. The inter-arrival time between two files is exponentially distributed with parameter λ_1. The size of the files is exponentially distributed with an average length of F bits. Fig. 3 depicts the NRT traffic.

The transmission time of the file depends on the throughput that is given by the network. This session goes on even if a user is not served during Δt. If the network is overloaded, some parts of the file can still be in the transmission buffer when a new file is generated. In that case, the first download is stopped and the transmission of the new file starts. The part of the file that has not been transmitted is cleared. In that case, the session is considered as dropped. Cases were the network capacity is sufficient and with a good resource management, this is a very rare event.

As long as there is some files to download in the transmission buffer the user is active. The user activity is represented by a state binary variable Φ_k^t which is equal to 1 when the user is active and 0 otherwise. Note that Φ_k^t is a state variable for the model but it is an input parameter for the optimization model.

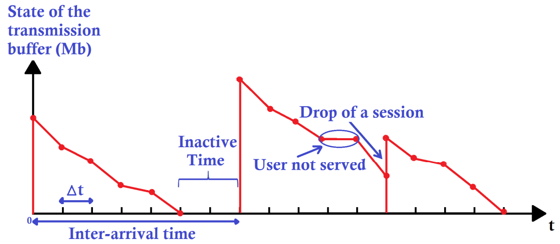

Fig. 3. Traffic source example for a Non Real-Time user.

2) Real-Time Users: The RT traffic is modeled as an ON/OFF process. A user is successively active (ON) then inactive (OFF). The ON duration is exponentially distributed with parameter λ_2. The OFF duration follows an exponentially distribution with parameter μ_2. The user activity is also represented by the state binary variable Φ_k^t. For RT users, Φ_k^t is equal to 1 with probability $\frac{\lambda_2}{\lambda_2+\mu_2}$.

If a real-time user is active but not served, the session is suspended but not dropped, at $t+1$ the request is remade. We assume that a user has only one traffic source (RT or NRT) for all of the simulation.

D. *Network Load and Capacity*

We define the load of the network as the average total bit rate generated by all active users with the hypothesis that network has the capacity to serve all of them. For NRT traffic, the load L^{NRT} is the average quantity of information divided by the average time of inter-arrival:

$$L^{\mathrm{NRT}} = F\ \lambda_1\ \mathrm{N_u}\ (\alpha_{\mathrm{R}}^{\mathrm{NRT}} + \alpha_{\mathrm{P}}^{\mathrm{NRT}}). \tag{7}$$

For RT traffic, we consider that users have γ_c^a as throughput. The load L^{RT} is:

$$L^{\mathrm{RT}} = \frac{\lambda_2}{\lambda_2+\mu_2}\mathrm{N_u}(\gamma_{\mathrm{P}}^a\ \alpha_{\mathrm{P}}^{\mathrm{RT}} + \gamma_{\mathrm{R}}^a\ \alpha_{\mathrm{R}}^{\mathrm{RT}}). \tag{8}$$

The total network load L is $L = L^{\mathrm{RT}} + L^{\mathrm{NRT}}$.

To estimate the network capacity C^{Net} we consider that a user is connected to his best available server, which is defined as the BS that gives the highest throughput per resource ($\varphi_{i,j,k}^t$). Let $\bar{\varphi}_j$ be the average throughput given by the best server for all users:

$$\bar{\varphi}_j = \frac{1}{N_u}\sum_k \max_i\ \varphi_{i,j,k}^t. \tag{9}$$

An estimation of the network capacity is:

$$\mathrm{C}^{Net} = \mathrm{N}_{bs}\sum_{j=1}^{N_j} R_j\bar{\varphi}_j. \tag{10}$$

IV. OPTIMIZATION PROBLEM

In each time t we optimize the network by maximization of the overall users satisfaction and the number of users connected. To do this, for each active user, we connect the user to an access point (with binary variables $\theta^t_{i,j,k}$, $\theta^t_{i,j,k,r}$) and allocate the optimal number of resources (with the variable $\lambda^t_{i,j,k}$) to maximize user satisfacton. We optimize successively at each instant t. Some of our models take into account the previous result (at $t-1$) to optimize at t. As in [9], the optimization is under linear constraints (user activity, resource management, network capacity, cells coverage).

A. Decision Variables

Decisions variables are:

$$\theta^t_{i,j,k} = \begin{cases} 1 & \text{if UE}_k \text{ is associated on BS}_i \\ & \text{over RAT}_j \text{ at } t \\ 0 & \text{otherwise,} \end{cases} \tag{11}$$

$$\theta^t_{i,j,k,r} = \begin{cases} 1 & \text{if UE}_k \text{ is associated on BS}_i \\ & \text{over RAT}_j \text{ with } r \text{ RUs at } t \\ 0 & \text{otherwise,} \end{cases} \tag{12}$$

and $\lambda^t_{i,j,k}$ is the number of resources allocated at t to UE$_k$, which is associated on BS$_i$ over RAT$_j$

B. Objective Function

We choose to maximize both the overall user utility and the number of users connected, the objective function is:

$$\text{Max} \sum_{i,j,k,r} u_{i,j,k,r}\theta^t_{i,j,k,r} + \beta \sum_{i,j,k} \theta^t_{i,j,k}, \tag{13}$$

where $u_{i,j,k,r} = U_k(r\ \varphi_{i,j,k})$ is the utility value if UE$_k$ is associated with BS$_i$ over RAT$_j$ with r RU.

The first part is the utility sum which represents the global users' satisfaction. The second part allows having a solution with a higher level of users connected. This formulation attempts to make the best trade-off between users' utility and the number of users connected. Indeed, having a lot of users connected decreases the overall users' satisfaction (in situation of congestion of the network). Parameter $\beta \geq 0$ is a weighting term that gives an importance to the first or the second part of the objective function. After a sensitivity analysis on β we use $\beta = 1$, this allows all users to be served and have a high level of satisfaction.

C. Constraints

This maximization is under some constraints. Let $\rho_{i,j,k}$ be the coverage parameter. It is equal to 1 if user k is covered by BS$_i$ over RAT$_j$, 0 otherwise. Constraints are:

$$\sum_{i,j} \theta^t_{i,j,k} \leq \Phi^t_k \qquad , \forall k \in K \tag{14}$$

$$\sum_{k} \lambda^t_{i,j,k} \leq R_j \qquad , \forall\ i \in I,\ j \in J \tag{15}$$

$$\theta^t_{i,j,k} \leq \lambda^t_{i,j,k} \qquad , \forall\ k \in K\ ,\ i \in I,\ j \in J \tag{16}$$

$$\lambda^t_{i,j,k} \leq R_j \theta^t_{i,j,k} \qquad , \forall\ k \in K, i \in I,\ j \in J \tag{17}$$

$$\lambda^t_{i,j,k} = \sum_{r=1}^{R_j} r\ \theta^t_{i,j,k,r} \qquad , \forall\ k \in K, i \in I, j \in J \tag{18}$$

$$\theta^t_{i,j,k,r} \leq \theta^t_{i,j,k}\ , \forall k \in K\ ,\ i \in I\ ,\ j \in J,\ r \in \mathbb{N} \tag{19}$$

$$\theta^t_{i,j,k}\ \leq \rho^t_{i,j,k}\ \ , \forall\ k \in K\ ,\ i \in I,\ j \in J \tag{20}$$

$$\theta^t_{i,j,k} \in \{0,1\}\ ,\ \theta^t_{i,j,k,r} \in \{0,1\}\ ,\ \lambda^t_{i,j,k} \in \mathbb{N} \tag{21}$$

Constraint (14) guarantees that a user can be connected to no more than one access point if he is active. Constraints (15) to (17) ensure that a UE cannot be assigned to more resources than available on an access point. Constraint (18) makes the variable $\lambda^t_{i,j,k}$ and the index r equal. Constraint (19) couples the variable $\theta^t_{i,j,k}$ to $\theta^t_{i,j,k,r}$. If $\theta^t_{i,j,k}$ is equal to 0, the constraint force $\theta^t_{i,j,k,r}$ to be equal to 0 too (for all r). Constraints (20) allows to connect UE only if they are covered by a BS/RAT.

Having a linear formulation is an important task to solve effectively the problem with classic solvers. In general, Linear Problems are solved using a linear-programming based on branch-and-bound approach [12].

D. Different Model of Optimization

1) Users Association, Resources Allocation Problem: **UARAP** is our basic optimization model which will be the reference for comparison:

$$\text{Max} \sum_{i,j,k,r} u_{i,j,k,r}\theta^t_{i,j,k,r} + \sum_{i,j,k} \theta^t_{i,j,k} \tag{22}$$

subject to: (14) to (21)

This model consists of optimizing each instant t independently of the previous result at $t-1$. There is no restriction in terms of handover or drop of session.

*2) Users Association, Resources Allocation and no Drop - **UARAD**:* This model guarantees that when a user is connected, he will have connection to an access point during all of the session. We have to add a new constraint to UARAP:

$$\sum_{i,j} \theta^t_{i,j,k} \geq \Phi^t_k \sum_{i,j} \theta^{t-1}_{i,j,k} \qquad , \forall\ k \in K \tag{23}$$

If a user is active at t ($\Phi^t_k = 1$) and was connected at $t-1$ constraint (23) becomes $\sum_{i,j} \theta^t_{i,j,k} \geq 1$. With constraint (14) we have the equality of the constraint to 1. Thus, the user has to be connected to the network. Priority is given to the users that have already been served. In case of important load on the network, the new arrival users wait to start the session, but when they are served, they are then guaranteed to be served until the end of their active period. For the user experience, in particular for RT users, guarantee to connect along the session is important. This model allows the handover.

3) Users Association, Resources Allocation, no Handover and no Drop - ***UARAHD****:* This model gives the same guarantee as UARAD and prevents the possibility of handover. We have to add some new constraints to UARAD:

$$\theta^t_{i,j,k} \geq \Phi^t_k \; \theta^{t-1}_{i,j,k} \qquad , \forall i \in I, \; j \in J, \; k \in K \tag{24}$$

For a giver user, if he was not connected at $t-1$ constraint (24) becomes $\theta^t_{i,j,k} \geq 0$ thus, $\theta^t_{i,j,k}$ is not constrained. If the user was connected at $t-1$ and active at t constraint (24) becomes $\theta^t_{i,j,k} \geq \theta^{t-1}_{i,j,k}$, which forces the user to be connected to the same access point as at $t-1$. Thus during a whole session, the user is always connected (no drop of session) and those at the same access point (no handover).

V. PERFORMANCE EVALUATION

A. Legacy Approach

We use the Highest Received Power (HRP) strategy as reference to assess our model of optimization. With HRP strategy, UEs try to be connected to the BS on RAT that delivers the highest received power. UEs are preferably served on the most recent RAT (4G is preferred). Furthermore, RUs are distributed equitably between all UE connected to a BS/RAT. The HRP model works as follows:

- For RAT$_j$, the UE measures the received power from each base station and makes a sorted list of BS, in descending order.
- The UE is served by BS/RAT$_j$ that accepts its request.
- If no BS of RAT$_j$ accepts the UE, the same procedure is executed on RAT$_{j+1}$.

B. Network Topology and Setting

We use the positioning of Orange's operator base stations in the 14th district of Paris. This consists of 18 base stations with two co-localized technologies namely, LTE ($j = 1$) and HSDPA ($j = 2$). In each cell, UEs are placed using a random uniform distribution. Table I summarize the simulation parameters.

TABLE I
SIMULATION PARAMETERS

	Class NRT	Class RT
User Repartition		
Regular Premium	$\alpha_{\mathrm{R}}^{\mathrm{NRT}}$ = 0.40 $\alpha_{\mathrm{P}}^{\mathrm{NRT}}$ = 0.20	$\alpha_{\mathrm{R}}^{\mathrm{RT}}$ = 0.10 $\alpha_{\mathrm{P}}^{\mathrm{RT}}$ = 0.30
Throughput		
Regular Premium	$\gamma^c = 1.0$ $\gamma^c = 2.0$	$\gamma^a = 3.0$ $\gamma^a = 4.0$
	4G	3G
Number of RUs	48	14
Carrier frequency (in MHz)	2000	1900
Bandwidth (in MHz)	10	5
Orthogonality factor (a)	0	0.5
Occupied resources (π_j)	80 %	90%
Transmit power (in Watt)	10	10
Antenna gain G$_t$ (in dBi)	15	15
Noise Figure (in dB)	9	9
Shadowing Deviation (in dB)	10	10
Cells Radius (in meter)	700	500

C. Experimentation and Results

Different instances of the problems UARAP, UARAD and UARAHD are solved using CPLEX V12.6.0.0 solver. An instance is a random distribution of the users position and traffic. Each instance simulate 300 seconds of network activity ($N_T = 300$). We also generate different instances with different loads L from 30 % to 140 % of the capacity C^{Net}. All of the presented solutions are average solutions. First, for each instance we compute the average on time. Then we compute the average of the different instances for each load. We consider that there is a handover if a user is active at $t-1$ and at t and he is connected to a different access point between $t-1$ and t. Through simulations we present a comparison between the different models and the legacy approach (HRP). We discuss the impact of the optimization in terms of user satisfaction, handover, resource management and computation time.

1) Users' satisfaction: Fig. 4 shows that our models allow us to achieve a higher level of satisfaction compare to HRP. Indeed, the average utility decreases sharply with HRP when the load increase. Thanks to a better resources management, this decrease is less important with our models. The average gap between HRP and our optimization is more then 15% when the network's load increase. We also note that giving priority to the previous users or preventing the handover doesn't impact heavily the user utility (less then 5%).

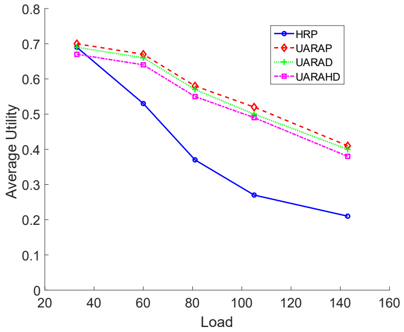

Fig. 4. Average User Utility in term of network load.

To refine our analysis, we plot the average utility by group of users (contract and service). As shown in Fig. 5, our optimization doesn't create an important gap between different groups of users (less then 10 %). Further we note that streaming premium users have the highest satisfaction, this could correspond to an operator strategy for its customers. We can conclude that our optimization has better resource management given that we take into account the user's needs.

2) Handovers: Fig. 6 shows that UARAP and UARAD create an important number of handover with an average 15% of handover. We note that they create a close level of handover. This important number handover can have an important impact in terms of user experience (specifically for RT users). However, Fig. 7 shows that the majority of users have a fewer number of handovers. Accordingly, handovers are

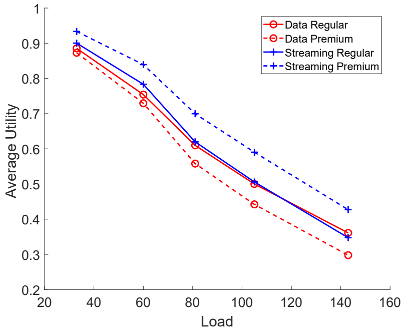

Fig. 5. Average Users Utility per group with UARAP.

focused on some users which will have a lot of handovers. This represents an average of 3 handovers per session for a session of 30 seconds. However, some users have 20 handovers in 30 seconds. Finally, UARAHD allows to ban handovers while guaranteeing a high level of satisfaction and ban the session drop.

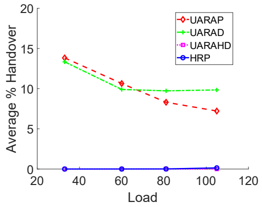

Fig. 6. Average Handover per Model.

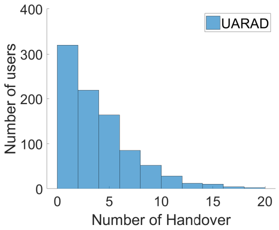

Fig. 7. Number of handover per session for load 60%.

3) Computation Time: We compute the optimal solution of the different models using the CPLEX solver running on a computer equipped with an Intel(R)Xenon(R)CPU L5630, 4 cores.

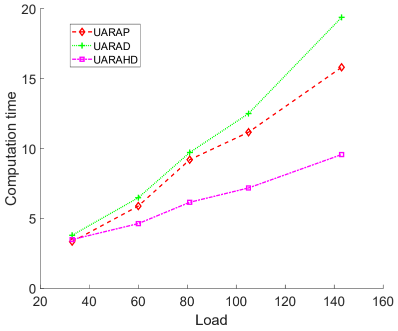

Fig. 8. Computation time.

As we can see in Fig. 8, the average computation time varies between 5 to 20 seconds in terms of the load. In spite of the important combinatorial due to the important choice of RAT for a each user, CPU time is relatively stable and acceptable for an optimization problem. However, for telecommunication implementation it is still huge. We note that UARAHD has a computation time smaller than others models. Indeed adding the constraint (24) reduces greatly the number of access points possible for the users and thus the size of the problem is reduced too. This is an encouraging result.

VI. CONCLUSION

In this work, we presented an optimization approach for cellular RAT selection while taking into account user needs and network capacity. Through simulations using a realistic network model, compared to a legacy approach, our optimization models give a better network performance in terms of user satisfaction. More precisely, UARAHD solution gives a high level of satisfaction, bans the handovers for statics users and has a computation time less then the others. For future work, we will study the problem of selection with a dynamic traffic source model and taking into account users mobility that could provide more handovers. We propose adding some other technologies like Wi-Fi. Using some optimization techniques or with heuristics, we plan to reduce the computation time.

REFERENCES

[1] C. V. N. I. Cisco, “Global mobile data traffic forecast update, 2013–2018,” *white paper*, 2014.

[2] L. Wang and G.-S. G. Kuo, “Mathematical modeling for network selection in heterogeneous wireless networksa tutorial,” *IEEE Communications Surveys & Tutorials*, vol. 15, no. 1, pp. 271–292, 2013.

[3] P. Naghavi, S. H. Rastegar, V. Shah-Mansouri, and H. Kebriaei, “Learning rat selection game in 5g heterogeneous networks,” *IEEE Wireless Communications Letters*, vol. 5, no. 1, pp. 52–55, 2016.

[4] A. Keshavarz-Haddad, E. Aryafar, M. Wang, and M. Chiang, “Hetnets selection by clients: convergence, efficiency, and practicality,” *IEEE/ACM Transactions on Networking*, vol. 25, no. 1, pp. 406–419, 2017.

[5] J. Choque, R. Agüero, and L. Muñoz, “Optimum selection of access networks within heterogeneous wireless environments based on linear programming techniques,” *Mobile Networks and Applications*, vol. 16, no. 4, pp. 412–423, 2011.

[6] Y.-J. Liang, “Dynamic resource allocation in mobile heterogeneous cellular networks,” *Wireless Networks*, pp. 1–13, 2017.

[7] F. Moety, M. Bouhtou, T. En-Najjary, and R. Nasri, “Joint optimization of user association and user satisfaction in heterogeneous cellular networks,” in *Teletraffic Congress (ITC 28), 2016 28th International*, vol. 1, pp. 78–86, IEEE, 2016.

[8] N. Zarin and A. Agarwal, “A hybrid network selection scheme for heterogeneous wireless access network,” in *Personal, Indoor, and Mobile Radio Communications (PIMRC), 2017 IEEE 28th Annual International Symposium on*, pp. 1–6, IEEE, 2017.

[9] I. Ben Dhia, M. Bouhtou, T. En-Najjary, S. Lahoud, and X. Lagrange, “Optimization of access points selection and resource allocation in heterogeneous wireless network,” in *Personal, Indoor, and Mobile Radio Communications (PIMRC), 2017 IEEE 28th Annual International Symposium on*, pp. 1–7, IEEE, 2017.

[10] R. Nasri and A. Jaziri, “On the analytical tractability of hexagonal network model with random traffic distribution,” *CoRR*, 2015.

[11] A. Campbell, G. Coulson, and D. Hutchison, “A quality of service architecture,” *ACM SIGCOMM Computer Communication Review*, vol. 24, no. 2, pp. 6–27, 1994.

[12] J. Clausen, “Branch and bound algorithms-principles and examples,” *Department of Computer Science, University of Copenhagen*, pp. 1–30, 1999.