Optimization Framework for Uplink Video Transmission in HetNets

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ABSTRACT

To deal with the explosion of mobile traffic, network operators deploy heterogeneous networks (HetNet), a combination of macro and pico eNodeBs. In this paper, we propose an optimization framework for the study of the optimal performances of HetNet on the uplink. We focus on video traffic because technologies like WebRTC allow mobile users to upload live video streams in cellular networks. Optimization model for uplink is much more complex than for downlink, for which previous works exist. Our model integrates both network management (radio resource allocation, user-cell association, interference management) and video (encoding bit-rate, QoE metrics). We apply our framework on an use case and reveal the complexity of HetNet management due to the interplay between several parameters.

Categories and Subject Descriptors

H.5.1 [**Information Interfaces and Presentation**]: Multimedia Information Systems—*Video*; C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*Wireless Communication*

1. INTRODUCTION

To deal with the explosion of data traffic in cellular networks, 3GPP promotes *heterogeneous networks* (in short HetNet) with the ambition to increase the available capacity in a cell [1]. The main idea behind HetNet is to deploy pico Evolved Node B (eNodeB) within the coverage area of a macro eNodeB. The management of HetNet is however much more complicated than in regular homogeneous cellular networks since four management processes interplay: user-cell association, radio resource allocation, terminal power control and interference management [4, 5].

MoVid '14, March 19, 2014, Singapore.

The scientific community has studied HetNet management with two approaches: (*i*) practical management algorithms have been designed and evaluated by the mean of simulations [2, 13], and (*ii*) optimization models have been formulated to study the theoretical performances of HetNet [4, 12]. To the best of our knowledge, all previous works related to the latter approach have studied HetNet for *downlink*, where the transmission power of both macro and pico eNodeBs are fixed and known. In this paper, we propose an optimization model for the *uplink* of HetNet. Modelling the optimal performances of HetNet on the uplink is especially challenging because the use of the uplink power control changes the interference according to the cell association.

The importance of uplink performances in cellular networks has grown significantly in the recent years due to the development of technologies like WebRTC, which allows end-users to upload live video streams, either directly to other end-users, e.g. in videoconferencing, or to application servers, e.g. in crowdsourced journalism [10]. The improvement of video capture devices integrated in smartphones also sustains the demand for bandwidth in the uplink. Users are interested in sending live high-definition videos through cellular networks. These recent developments call for a closer attention to uplink in cellular networks and for the integration of video Quality of Experience (QoE) in the performance evaluation of HetNet management strategies.

The contribution in this paper is twofold:

- We present an optimization framework to evaluate the performance of radio resource strategies in uplink for HetNets, with regard to both the interferences and a proper power control algorithm. This framework takes in input a snapshot of the system (user deployment and channel gains) as well as video characteristics. Like other optimization frameworks, it enables offline study of the performances of a HetNet, which is especially useful for network operators that deploy HetNet. To the best of our knowledge, this optimization framework is the first one for video uplink in HetNet.

- We identify some characteristics of video uploading in HetNet by applying our framework on a specific use case. This study illustrates the benefits of our optimization framework. Indeed, we observe that there is no obvious best practice in the deployment of HetNet, so network operators need a framework to study each deployment context. We highlight that the interplay of several parameters makes the analysis of performances difficult. Typically, the increase of the number of pico eNodeBs has different impact according to the video resolutions and the density of users.

The remainder of this paper is organized as follows. The system model and the optimization problem are introduced in Section 2. Numerical results are provided in Section 3. Section 4 presents the related works. Finally, conclusions and future works are discussed in Section 5.

2. PROBLEM FORMULATION

2.1 Video Model

We consider a set of users $\mathcal{U}$ who concurrently upload video streams while located in the same cell. We define a set of possible encoding bit-rates $\mathcal{R}$ for each spatial resolution of the streaming content generated by the users. We denote by T_r the value (in kbps) of the encoding rate r. Each resolution admits encoding bit-rates $r \in \mathcal{R}$ within the range from $T_{\min}$ to $T_{\max}$. Each user emits a stream to the maximum bit-rate smaller to her uplink throughput (with respect to the maximum possible encoding bit-rate $T_{\max}$), but higher than a minimum admissible bit-rate represented by $T_{\min}$. In other words, we assume an ideal implementation of webRTC at each mobile device since the uploaded video bit-rate matches the actually available uplink throughput.

Our optimization framework aims at maximizing the average satisfaction of the set of users $\mathcal{U}$.[1] To set the satisfaction of an uploading user $u \in \mathcal{U}$, we estimate the QoE of the video uploaded by u (as if u watched its own video). The satisfaction is denoted by f_r since it is an increasing function of the encoding bit-rate r. Without loss of generality, the satisfaction f_r ranges from 0 to 1, where f_r is equal to 1 when $T_r = T_{\max}$. Typically, f_r can be computed from VQM scores on the video [8]. Note that the same rate might lead to a different satisfaction for the same video content but displayed at different resolutions. For sake of clarity in the notation, we assume hereafter that all users encode their video stream in the same spatial resolution.

2.2 Network Model

We deal with the four components of HetNet management. The *user-cell association* decides to which pico or macro eNodeB each user should be associated. The *radio resource allocation* mechanism decides the way in which the spectrum available at each eNodeB is shared between the mobile devices attached to them. The *terminal power control* determines the amount of power allocated to each scheduled mobile device over its allocated resources. The *interference management* is due to the fact that pico eNodeBs may utilize a part of the spectrum that is allocated to the macro eNodeBs.

The cell is covered by a set $\mathcal{B}$ of eNodeBs, including one macro eNodeB (cell $b = 1$), overlaid with $B-1$ pico eNodeB (cells $b = 2, \ldots, B$), which are identical in terms of antenna gain and backhaul capacity. The spectrum available at each eNodeB is divided into M resource blocks (RBs) with a 180 kHz bandwidth (W). The set of RBs is denoted by $\mathcal{M}$.

[1] Various other objectives can be formulated, including the ones that reinforce fairness

Like other optimization frameworks related to HetNet [4], we associate each user $u \in \mathcal{U}$ with only one eNodeB in $\mathcal{B}$, which should provide u with some RBs. To conform state-of-the-art schedulers for LTE uplink, we consider long-term periods in the order of seconds. Therefore our goal is to determine the average resource share of each user.

For the path loss between users and eNodeBs (L_{ub}), we use models from [6]. The channel gain G_{ub} is:

$$G_{ub} = \begin{cases} g_d \times g_m \times L_{ub}, & \text{if } b = 1, \\ g_d \times g_p \times L_{ub}, & \text{if } b \neq 1, \end{cases} \quad \forall u \in \mathcal{U}, \qquad (1)$$

where g_d is the mobile device antenna gain, and g_m and g_p are the macro and pico antenna gains, respectively.

The Signal to Interference plus Noise Ratio (SINR) of user u at eNodeB b on each RB (c) can be written as:

$$\gamma_{ub}^{(c)} = \frac{P_{ub}^{(c)} \times G_{ub}}{N_0 + I_b^{(c)}}, \ \forall u \in \mathcal{U}, \forall b \in \mathcal{B}, \text{ and } \forall c \in \mathcal{M}, \qquad (2)$$

where N_0 is the additive white Gaussian noise power, $I_b^{(c)}$ is the interference level on uplink RB (c) of eNodeB b, and $P_{ub}^{(c)}$ is the transmission power on RB (c) of user u towards eNodeB b. At this point, two important assumptions are made: first, the total transmission power of a user is shared equally among all its allocated RBs, which is a common practice; and second, the level of interferences over the set of RBs of a eNodeB is uniform. This latter assumption is the result of the frequency hopping technique in LTE uplink [3], which provides frequency diversity and interference averaging. For these reasons the SINR $\gamma_{ub}^{(c)}$ does not depend on the RB (c), therefore we refer hereafter to it as γ_{ub}.

In 3GPP LTE, the Fractional Path Loss Compensation Power Control (FPC) mechanism is used for uplink power control. In this work, we use the same simplified approach as in [13] and we ignore the closed-loop corrections in the FPC power control mechanism. Thus, the total transmission power of user u towards eNodeB b is:

$$P_{ub} = min\{P_{max}, P_0 + 10log_{10} m_{ub} + \beta L_{ub}\} \qquad (3)$$

where P_{max} is the maximum UE (User Equipment) transmission power level, P_0 is a cell specific parameter that defines the UE minimum transmission power, m_{ub} is the amount of RBs that are allocated to user u, L_{ub} is the downlink propagation loss that is measured by the mobile device and β represents a compensation factor for the path loss.

In a scenario where path losses do not saturate the maximum transmission power allowed to each RB (i.e., $P_{ub}^{(c)} \leq P_{max}/m_{ub}$), $P_{ub}^{(c)}$ is calculated as follows:

$$P_{ub}^{(c)} = P_0 + \beta L_{ub} \qquad (4)$$

We compute the average level of interferences with regard to the interference management policy, and to the decisions for user-cell association and radio resource allocation. We consider both *Orthogonal Deployment (OD)* and *Co-Channel Deployment (CCD)* as proposed in 3GPP [1]. In short, OD allocates $n = M - p$ RBs to the macro eNodeB, while pico eNodeBs share the other p RBs among them. On the other hand, in CCD all eNodeBs use all the available M RBs. Both deployments have been studied for HetNet in downlink [4].

Once we know the value of the SINR (γ_{ub}), the channel capacity per RB can be calculated using the Shannon-Hartley

Notation	
$T_r \in \mathbb{R}^+$	Value in *kbps* of the streaming rate r
$T_{\min} \in \mathbb{R}^+$	Value in *kbps* of the lowest streaming rate
$f_r \in \mathbb{R}^+$	Satisfaction level at streaming rate r
$K_{ub} \in \mathbb{R}^+$	Value in *kbps* of the capacity per RB at the uplink from user u to eNodeB b
$P_{ub}^{lin} \in \mathbb{R}^+$	Transmission power per RB in linear units at the uplink from user u to eNodeB b
$P_{max}^{lin} \in \mathbb{R}^+$	Maximum UE transmission power level in linear units
$M \in \mathbb{Z}^+$	Number of RBs in the system

Table 1: Notation adopted in the MILP formulation.

Mixed Integer Linear Programming formulation

$$\max_{\{x,y,z,n,p\}} \sum_{u\in\mathcal{U}} \sum_{r\in\mathcal{R}} f_r \cdot y_{ur} \tag{6a}$$

$$\text{s.t.} \sum_{r\in\mathcal{R}} T_r \cdot y_{ur} \leq \sum_{b\in\mathcal{B}} K_{ub} \cdot z_{ub}, \quad u \in \mathcal{U} \tag{6b}$$

$$\sum_{r\in\mathcal{R}} T_r \cdot y_{ur} \geq \sum_{r\in\mathcal{R}} T_{min} \cdot y_{ur}, \quad u \in \mathcal{U} \tag{6c}$$

$$\sum_{r\in\mathcal{R}} y_{ur} \leq 1, \quad u \in \mathcal{U} \tag{6d}$$

$$\sum_{b\in\mathcal{B}} P_{ub}^{lin} \cdot z_{ub} \leq P_{max}^{lin}, \quad u \in \mathcal{U} \tag{6e}$$

$$z_{ub} \leq M \cdot x_{ub}, \quad u \in \mathcal{U}, b \in \mathcal{B} \tag{6f}$$

$$\sum_{b\in\mathcal{B}} x_{ub} \leq 1, \quad u \in \mathcal{U} \tag{6g}$$

$$\sum_{u\in\mathcal{U}} z_{ub} \leq \begin{cases} n, \text{ if } b = 1, \\ p, \text{ if } b \in \mathcal{B} - 1, \end{cases} \quad b \in \mathcal{B} \tag{6h}$$

$$n + p = M, \tag{6i}$$

$$x_{ub} \in \{0, 1\}, \quad u \in \mathcal{U}, b \in \mathcal{B} \tag{6j}$$

$$y_{ur} \in \{0, 1\}, \quad u \in \mathcal{U}, r \in \mathcal{R} \tag{6k}$$

$$z_{ub} \in \mathbb{R}_{\geq 0}, \quad u \in \mathcal{U}, b \in \mathcal{B} \tag{6l}$$

$$n \in \mathbb{R}_{\geq 0}, \tag{6m}$$

$$p \in \mathbb{R}_{\geq 0}, \tag{6n}$$

theorem as:

$$K_{ub} = W \times log_2(1 + \gamma_{ub}),\ \forall u \in \mathcal{U},\ \text{and}\ \forall b \in \mathcal{B}. \tag{5}$$

2.3 MILP Model

We now describe the proposed MILP. The main notations introduced up to here are summarized in Table 1. The decision variables in the model are:

$$x_{ub} = \begin{cases} 1, & \text{if user } u \text{ is associated to eNodeB } b \\ 0, & \text{otherwise.} \end{cases}$$

$$y_{ur} = \begin{cases} 1, & \text{if user } u \text{ is associated to rate } r \\ 0, & \text{otherwise.} \end{cases}$$

$z_{ub} \in \mathbb{R}_{\geq 0}$ is the average number of RBs used in the uplink from user u to eNodeB b (see the aforementioned long-term period assumption).

$n \in \mathbb{R}_{\geq 0}$: Number of RBs assigned to the macro eNodeB $b = 1$.

$p \in \mathbb{R}_{\geq 0}$: Number of RBs assigned to the pico eNodeBs $b \in \{2, \ldots, B\}$.

Then, the optimization problem can be formulated as shown in (6). The objective function (6a) maximizes the overall satisfaction of users that will watch the video content generated by the mobile devices. The constraints (6b), (6c) and (6d) are related to the bit-rate selection for each user. Each uploading user will try to emit a stream to the maximum bit-rate smaller than her uplink throughput (6b), but higher than a minimum admissible bit-rate (6c). Constraint (6e) is related to power management. A consistent relation between the decision variables x_{ub} and z_{ub} is set up by (6f). The constraint (6g) forbids associating a mobile user to more than one eNodeB. Finally, the constraints (6h) and (6i) set up the *Orthogonal Deployment* as interference management policy. Conversely, if the interference management is implemented by the *Co-Channel Deployment*, then these constraints are replaced by equation (7):

$$\sum_{u\in\mathcal{U}} z_{ub} \leq M,\ b \in \mathcal{B} \tag{7}$$

2.4 Iterative Interference Estimation

One of the parameters that we need as an input to solve the MILP is the channel capacity per RB (K_{ub}). Yet, we need to previously calculate the average level of interferences at each eNodeB (I_b) to obtain these values. However, as previously said, the average level of interferences at an eNodeB depends on the interference management policy (either *CCD* or *OD*), the user-cell association and the radio resource allocation, i.e., x_{ub} and z_{ub}. Hence we need to make some assumptions to obtain proper values for K_{ub}.

To solve this egg-chicken problem, we propose an iterative process. The initial values of x_{ub} are set such that each mobile device is associated with the eNodeB whose signal is received with the largest average strength (it is the default user-cell association in HetNet and homogeneous networks). Furthermore, similarly as [12], we assume equal sharing of RBs among users connected to the same eNodeB, in order to obtain the initial values of z_{ub}. From these initial default values, an estimation denoted as $K_{ub}^{(i)}$ is obtained.

We solve the MILP using any generic solver and obtain, among others, the optimal values for x_{ub} and z_{ub} with regard to $K_{ub}^{(i)}$. With these new x_{ub} and z_{ub}, we compute a second estimation of K_{ub}, denoted now as $K_{ub}^{(ii)}$, and we compare it with the initial one $K_{ub}^{(i)}$. If the difference between $K_{ub}^{(i)}$ and $K_{ub}^{(ii)}$ is not small enough, the MILP is solved again considering $K_{ub}^{(ii)}$ as an input. This process is iteratively repeated until the difference between consecutive values for K_{ub} is below a predefined threshold. To compute the difference between consecutive values of K_{ub} the mean squared error (MSE) criterion is used. During our tests, we used a threshold value of 0.001.

3. ANALYSIS OF AN USE CASE

We now apply our optimization framework on a specific use case and present some numerical results. Our goal is *not* to derive definitive conclusions about the prevalence of a deployment strategy or a management policy over another. We do not aim at being comprehensive, but rather at highlighting the usefulness of our theoretical framework for network operators. We show in the following the non-trivial interplay between the characteristics of a specific scenario, the deploy-

Noise Power (N_0)	-162 dBm/Hz	RB Bandwidth (W)	180 kHz
P_{macro}	46 dBm	P_{pico}	30 dBm
Macro Ant. Gain (g_m)	15 dBi	Pico Ant. Gain (g_p)	5 dBi
$P_{\max}$	23 dBm	UE Ant. Gain (g_d)	0 dB
P_0	-90 dBm	β	0.8
Path Loss Pico	$L_{ub} = 140.7 + 36.7log_{10}(d_{ub}/1000)$		
Path Loss Macro	$L_{ub} = 128 + 37.6log_{10}(d_{ub}/1000)$		

Table 2: Physical layer parameters.

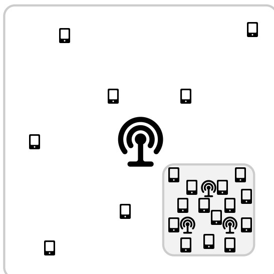

Figure 1: Macro and pico eNodeB location. Results correspond to the average values of ten different random placements of users in the system area.

ment decisions and the quality of the videos generated by the mobile users.

3.1 Use Case Description

Network. We consider a square region of length 2000 meters, which is covered by one macro eNodeB (cell $b = 1$). Within this region, there exists a specific *hot spot*, which is a square area of length 500 meters, where the users are more concentrated. This use case is typically a localized temporal event where network operators would like to study the opportunity to deploy pico eNodeBs. One of the main questions is the total number B of eNodeBs to deploy. In our study, values from $B = 1$ (no additional pico eNodeBs) to $B = 10$ will be evaluated. The physical layer parameters used in our experiments are based on the 3GPP evaluation methodology document [6] used for HetNets in LTE. These parameters are shown in Table 2.

Population. We consider a fixed number U of users in the cell. Two thirds of them are located in the hot spot. In the hot spot as well as outside the hot spot, users are randomly located (uniform distribution). Figure 1 is an illustration of the case where $B = 4$ and $U = 21$.

Video. For simplicity, the video content that is streamed by users is the same. We obtained a satisfaction curve from VQM score [8] evaluated on one test sequence from [9] at three different resolutions. Since the VQM score ranges from 0 to 1, representing the best and the worst QoE, respectively, user satisfaction level is computed as $(1 - \text{VQM})$ score. The empirical measures obtained from evaluating the aforementioned sequence are depicted as circles in Fig. 2. From these measures, we derived a satisfaction function by curve fitting. In this extrapolated function, the satisfaction level for a video at rate r is modeled as follows

$$f_r = a * T_r^b + c. \qquad (8)$$

where the values of parameters a, b, and c for each resolution are given in Table 3. The steps between consecutive possible encoding bit-rates are set to 25 kbps for the 224p and 360p resolutions, and to 60 kbps for 720p. Satisfaction curves

Resolution	a	b	c	$T_{\min}$ kbps	$T_{\max}$ kbps
224p: 440x224	-88.612999	-1.057453	1.03	75	1925
360p: 640x360	-56.653398	-0.893399	1.06	250	2100
720p: 1280x720	-775052.600233	-2.118902	1.01	860	5300

Table 3: Parameters for the QoE model.

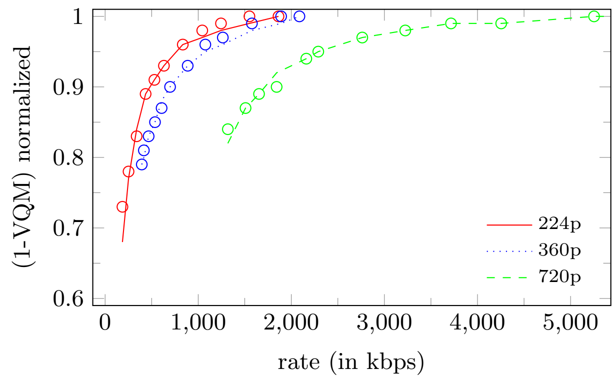

Figure 2: Curve fitting for the three considered resolutions. The circles are real measures taken from the video while the lines reflect the model.

evaluated from Eq. 8 are plotted as continuous lines in Fig. 2.

Framework Implementation. For each evaluated scenario, we compute the average values for ten instances, which corresponds to the random placement of the U users in the cell.We solve the MILP model by the generic solver IBM ILOG CPLEX [7]. CPLEX was able to solve the MILP model in the order of a few minutes in an Intel(R) Xeon(R) CPU E5640 @ 2.67GHz with 24 GB of RAM.

3.2 Numerical Analysis

We try in the following to answer three questions that network operators have to consider before dimensioning and deploying pico eNodeBs.

What is the best interference management policy?

This questions was central in [4] for the downlink. In Figure 3, we show the gain in terms of average user satisfaction when we increase the number of pico eNodeBs with respect to a network without pico eNodeB. We study both co-channel and orthogonal deployments, which are the two main options for the interference management. Our answer to the question is that it depends on the number of pico eNodeBs that are deployed, even for one specific instance (here 100 users and 360p videos).

According to the number of pico eNodeBs, one deployment clearly outperforms the other. We distinguish two main families. When a small number of pico eNodeBs are deployed, the best interference management policy is the co-channel deployment. Orthogonal deployment has an especially bad behavior, typically less than 5% gain with three pico eNodeBs. On the contrary, when the number of pico eNodeBs increases, orthogonal deployment becomes more attractive. For example, the average satisfaction can be 24% better with nine additional pico eNodeBs when orthogonal deployment is chosen although it is less than 20% with co-channel deployment. Yet these gains come at the cost of deploying eNodeBs at ideal locations, either where data re-

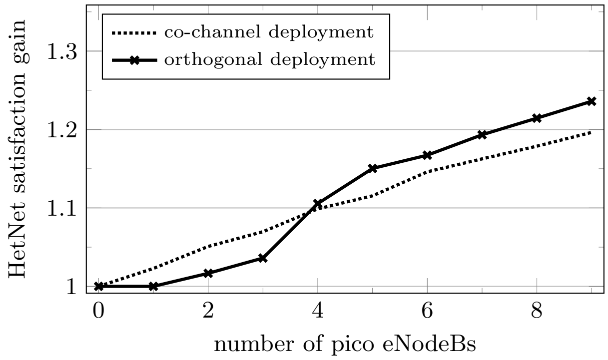

Figure 3: HetNet satisfaction gain is the ratio of avg. satisfaction to the avg. satisfaction in homogeneous network. Optimal performances of both intereference management policy with regard to the number of pico eNodeBs. The number of users is $U = 100$. The video resolution is 360p.

quirements are high or where macrocell performance is low. However, it is very difficult to predict the optimal locations of these nodes [11].

What is the actual impact of adding more pico eNodeBs on user satisfaction?

We start in Figure 4 with one specific instance, with $U =$ 400 users and the orthogonal deployment. We represent here the Cumulative Distribution Function (CDF) of user satisfaction for three typical cellular networks: homogeneous network, a HetNet with a small number of pico eNodeBs, and a HetNet with a large number of pico eNodeBs. Please note that, due to the high number of users, not all users can upload video stream, even in the most favorable scenario (nine pico eNodeBs and 224p video).

We study Figure 4 in two ways. First by observing the rightest point of lines. From the left (no pico eNodeB) to the right (nine pico eNodeBs), we show an increase in the percentage of users who can upload, for example, from 10% to 40% of users for 720p videos. It means that adding more pico eNodeBs has an impact in the sense that *more users can actually upload video stream*. Another way to study Figure 4 is by looking at the user satisfaction. From the left to the right, we show an increase in the range of user satisfactions and also in the maximum values that can be reached. For example, when there are nine pico eNodeBs some users have a satisfaction greater than 0.8 in every resolution. It means in practice that adding more pico eNodeBs has an impact in the sense that *some users can enjoy a better QoE*. The angular shape of 360p videos in homogeneous networks is due to the fact that the user satisfaction corresponding to the $T_{\min}$ value associated to this video resolution is 0.65.

How does the average user satisfaction evolve when the number of users grows?

We highlight again the complex interplay between parameters in HetNet management in Figure 5 where we show the average satisfaction experienced by the subset of users who are able to upload a video when the population grows. We explain the angular shape of the satisfaction as follows. For a low number of users, everybody is satisfied. When the number of users increases, the optimal performances are obtained when the user satisfaction decreases. It is the price to pay to serve all users, until the maximum capacity of the cell is reached. Then, the average satisfaction is stable, which means that the increase of the population is at the price of a lower ratio of users being able to upload.

As we have seen in Figure 4, adding more pico eNodeBs increases both the number of users that can upload a video stream and the maximum user satisfaction that can be reached. These two properties are translated in an increment of the average satisfaction experienced by the user who are able to upload a video, as can be seen in all the results shown for 9 pico eNodeBs in Figure 5. If we focus on the results for 360p with 0 and 3 pico eNodeBs, the average satisfaction stabilizes to the value associated to $T_{\min}$ (~ 0.65), from 150 users. However, with 9 pico eNodeBs this parameter stabilizes to a higher value (~ 0.73), from 200 users.

4. RELATED WORKS

An optimization model to solve the user-cell association on the downlink is studied in [4, 12]. The downlink scenario is easier to solve due to the fact that the transmission powers of eNodeBs are constant values, which simplifies the computation of the interferences. Furthermore, the objective of both works is to achieve load balancing, and some level of fairness among the users. They do not take into account the characteristics of video traffic. With a closer look at the model, our work is closer to [4], where radio resource allocation and interference managements are also solved. Other works are less complete. In [12] the resource allocation is simplified, while in [1] authors consider neither user-cell association nor radio resource allocation.

So far, only sub-optimal algorithms have been studied for uplink HetNet. An algorithm to solve the cell association is introduced in [2]. Authors consider the uplink power control algorithm and take into account the uplink interferences, however they do not consider the direct effect that these interferences can have over the user perceived bit-rate. Moreover neither resource allocation strategy nor interference management are considered. In [13], authors propose a stochastic algorithm to solve the resource allocation problem for both the downlink and the uplink of HetNet. This algorithm allocates the resources of pico eNodeBs probabilistically to keep the interference levels under control. The performance of the proposed algorithm is evaluated by means of simulation. No cell association strategy is studied.

5. CONCLUSIONS

We present in this paper the first optimization model for the study of the uplink in HetNet. Moreover, we focus on video uploading, which is an especially challenging issue for network operators. By applying our framework to an use case, we showed the complex interplay between strategies and parameters in HetNet. Such study reinforces our motivation for a framework that let network operators study each HetNet deployment carefully.

For future works, we would like to explore two topics. First, we are interested in studying another theoretical approach to reach the optimal computation of the uplink interferences. In parallel, we would like to develop a scheduler that considers both the special characteristics of HetNets and the quality of the generated videos, in order to prioritize some RBs to mobile users.

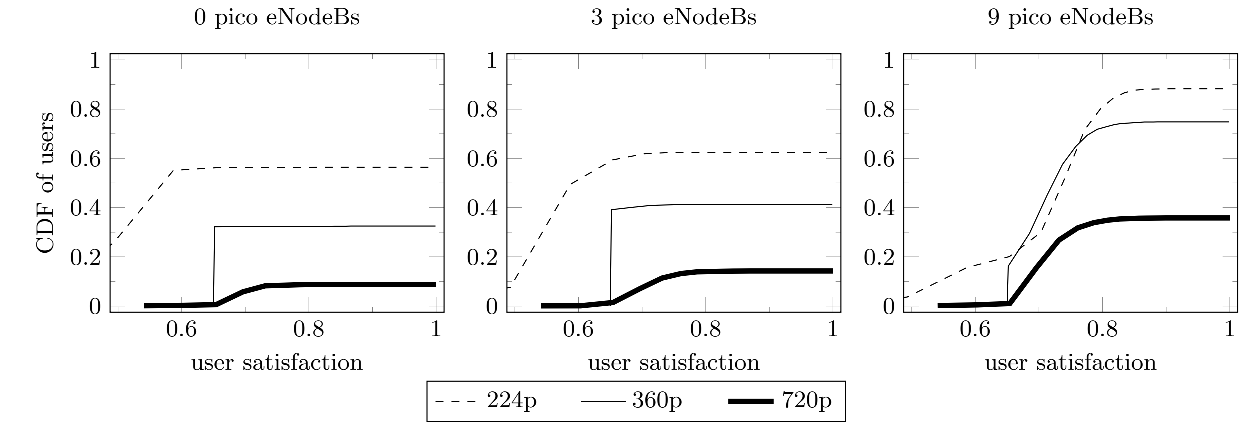

Figure 4: CDF of user satisfaction for three different numbers of pico eNodeBs. The number of users is $U = 400$ and the interference management policy is Orthogonal Deployment.

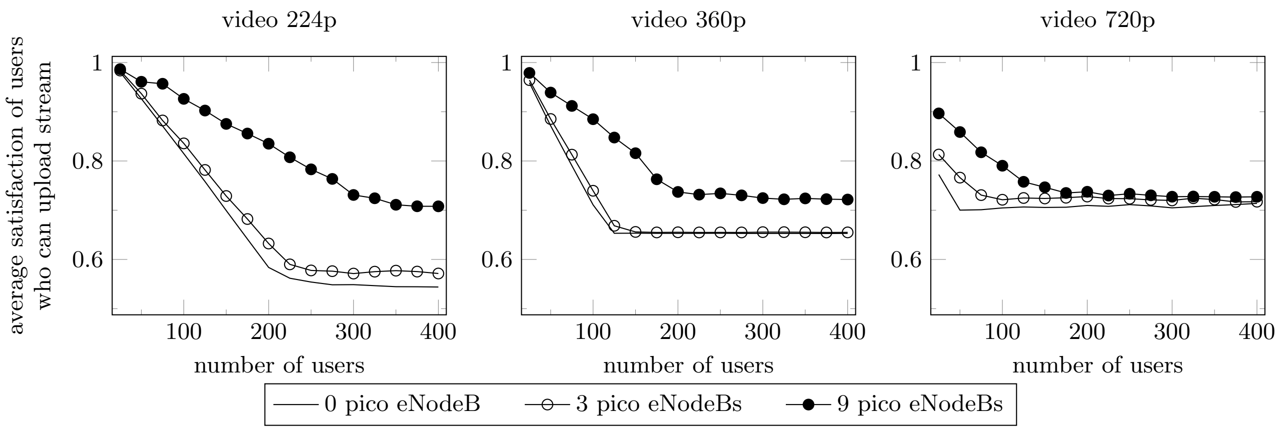

Figure 5: Evolution of the average satisfaction of users (only those who are able to upload) when the total number of users increases. The interference management policy is Orthogonal Deployment.

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