Mobility-Assisted and QoS-Aware Resource Allocation for Video Streaming over LTE Femtocell Networks

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ABSTRACT

The interest on enhanced capabilities of femtocell networks is increasing, since it copes with the dynamics of future cellular networks. Thus, innovative approaches and concepts are required to guarantee successful deployment of this new generation of cellular networks for carrying challenging services (e.g. multimedia applications) under complex network conditions. In this context, we propose a novel approach that enhances the capability of LTE-femtocell networks when dealing with downlink variable bit rate video transmission. The idea consists on making a pre-allocation of radio resources (resource blocks and transmit power) based on the knowledge of future required video traffic of connected users. We also make our approach capable of supporting efficient mobility management through an optimized handover policy. In fact a coordination entity is proposed to select the target cell which is more capable to support future video traffic delivery based on a multi-criteria utility function. Simulation results prove the effectiveness of the scheme. The frame loss ratio and transmit power are, respectively 4 and 5 times, lower than in random allocation. Besides, the inter-handover period is increased by more than 120% compared to traditional handover. This means that the journey time in the cell is efficiently maximized thus minimizing delays related to unnecessary handovers and avoiding disconnections.

Keywords: Femtocells, VBR video streaming, resource management, interference mitigation, power control, handover, QoS.

1. INTRODUCTION

The rapid development of enhanced mobile devices (such as Smartphones, tablets, etc.) over the last few years has led to a sharp increase in the consumer demands for rich multimedia applications. Indeed, according to Cisco, mobile video traffic generated from bandwidth demanding applications (such as video streaming, video-conferencing, video gaming, etc.) is expected to increase 14-folds between 2013 and 2018, accounting for 69% of the total mobile data traffic by 2018 [1]. This fact has motivated the third generation partnership project organization (3GPP) to work on the Long Term Evolution (LTE) and LTE-Advanced standards to ensure competitiveness in a longer time frame, thus LTE/LTE-Advanced are considered as one of the major steps in radio communication. However this technology alone cannot meet the expected requirements. This is why, femtocell networks [2] have emerged bringing complementary advancements to LTE. They represent a ubiquitous and cost-effective solution for enhancing spectrum efficiency and improving the Quality of Service (QoS) of end users. But at the meantime, femtocell deployments are accompanied with additional technical issues. Among the most important ones is inter-cell interference related to frequency reuse and which can dramatically degrade the perceived quality especially for real-time applications. This has lead researchers to investigate new resource management techniques to cope with this problem. However they didnâĂŹt propose effective solutions dealing with video streaming application.

On the other hand, most of the existing works on resource allocation for video streaming have not directly addressed the problem of interference and its impact on this sensitive type of applications. However in dense femtocell based networks this poses a real problem because the system can suffer from high levels of inter-cell interference which will dramatically degrade the perceived QoS.

Furthermore, the interest on green technology and energy saving is increasing and represents an important necessity for the future of communication technologies. Femtocell networks are one of the taken measures towards this end, but this is not sufficient given the exponential increase of traffic loads and QoS requirements. Thus energy-efficient solutions are inevitable.

In this work a novel large scale resource management scheme for interference-limited femtocell networks is proposed. It considers the variability of video traffic related to the encoding process, the playout buffer of the end user and the availability of radio resources in the system. Our approach is oriented principally for Variable Bit Rate (VBR) video services and assumes the knowledge of encoded video

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frames. For stored video sequences, knowledge is obtained through transmitting a message from the server to the Femtocell Base Station (FBS) during the initial setup phase to inform it about the video frame sizes, while for non-stored videos this information can be communicated on the fly before the server sends video frames to the FBS or it can be obtained through prediction.

Our resource allocation procedure is performed by the serving nodes in two steps. First, based on the knowledge of the future frame sizes as well as a dynamically updated information about resource reservation results of neighboring cells, it reserves network resources for each user in a manner that satisfies user's requirements on one hand and guarantees a minimal inter-cell interference on the other hand. Then resource allocation is performed based on reservation result. The main objectives are to enhance the spectrum efficiency and the perceived QoS of end users.

Also, given the importance of mobility in femtocell networks and its stringent impact on perceived QoS, we propose an optimized handover management approach based on an effective handover decision combining the instantaneous and the future network conditions for a long-term QoS guarantee to end users.

The remainder of this paper is organized as follows. Section 2 gives the state of the art on resource allocation and video streaming over wireless and cellular networks. Section 3 provides problem statement where we present the network and video system models as well as the formulation of the problem. In section 4, we present our proposed power and resource block allocation framework. In section 5, we complement our proposed resource allocation scheme with a new mobility management policy. Section 6 presents the numerical results and performance evaluation. Finally, section 7 concludes the paper.

2. STATE OF THE ART

Several works have dealt with the problem of resource allocation in femtocell networks ([3],[4],[14]-[16]) aiming mainly to avoid or reduce interference, and/or manage power consumption. Among the different proposed approaches, a great interest was attributed to distributed management schemes as well as cognitive radio approaches since they represent the key solutions to deal with dense and randomly deployed femtocell networks. For example, in [3] authors propose a new fractional frequency reuse (FFR) scheme adapted to interference limitations of femtocell networks. The FFR factor is adjusted according to the interference information and femtocell locations. Then, sub channels are allocated to avoid interference. The allocation of transmit power takes place after sub channels allocation based on the received signal strength information (RSSI). Although researchers in this field proposed efficient solutions for spectrum management and interference mitigation in femtocell networks, they didn't consider application specificities. However, for video streaming applications especially VBR video transmission, to guarantee the required video quality, resource allocation should take into consideration the traffic dynamics related to video streaming.

On the other hand, few works have been devoted to study resource allocation problem for video streaming over wireless networks. For instance, in [5] authors formulated the problem of power allocation for VBR video streaming over multi-cell wireless networks as an optimization problem where the delivered video data is to be maximized under peak transmit power constraint and playout buffer requirements. Even thought, their solution provides a good trade-off between power consumption and buffer utilization, it is mainly based on power management without optimizing channel utilization which may be inefficient in systems limited by spectrum scarcity.

In [10], the concept of "rebuffering outage capacity" is introduced. In fact, authors defined a new metric consisting on the threshold of rebuffering percentage above which users will be considered in outage. They also proposed a resource management framework for downlink scheduling considering both the Quality of Experience (QoE) of the consumers and their playback buffer status. However this scheme doesnâĂŹt work for realtime streaming traffic since it is based on the rebuffering concept which is applied only for stored videos.

Some other works were interested in cross-layer approaches ([9], [11]) which seem very promising. For instance, authors in [9] proposed a cross-layer optimized system to dynamically determine modulation and coding scheme (MCS) and codec parameters based on the radio resource allocation result and the instantaneous channel conditions of resource blocks. In [11], authors propose a new version of the stop-and wait automatic repeat request (SW-ARQ) protocol to make it energy-efficient by adapting transmission according to the wireless channel status. Furthermore, they combine this with a rate controller that adapts the transmission bit rate of video source in order to maintain a convenient queue status (avoiding buffer underflow and overflow). The main limitation of these works ([9],[11]) is that researchers didn't address the problem of traffic congestion in a multi-cell system presenting important inter-cell interference.

In [8], authors investigated the problem of resource allocation for video streaming applications (multicast/broadcast services (MBSs)) over cellular networks together with non-MBS traffic. They propose a spectrum allocation scheme to efficiently manage bandwidth allocation among the two classes of traffic based on the QoS requirements. Their solution enhances the capacity of the system to carry MBS video calls together with other traffic calls, however

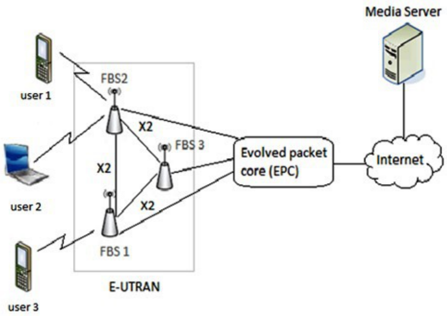

Fig.1: *Video streaming system over an LTE- femtocell network.*

the perceived QoS for both MBS and non-MBS services is degraded under high traffic load conditions as the authors stated.

In [6], a frequency-time scheduling scheme is formulated by introducing new QoS metrics including Channel Quality Indicator (CQI), the ratio between arrival and departure rates of packets and the normalized packets delay. Authors focused on guaranteeing a trade-off between capacity and fairness for streaming applications over Orthogonal Frequency Division Multiple Access (OFDMA) systems under delay constraints. They decomposed the process of packet scheduling into two steps: first resource allocation to determine the amount of required resources for each user, then resource assignment to map the available resources to users conforming to the resource allocation output.

Table 1 summarizes the strengths and weaknesses of the different schemes and compares them to our approach. The comparison is based on criteria related to the effectiveness of a scheme in terms of buffer control, interference mitigation, and power management. Also we examined the ability of each scheme to support real-time (RT) video traffic as well as its capacity enhancement by supporting high traffic loads. Finally we point out that our approach outperforms the others by proposing an intelligent handover (HO) adaptation which works jointly with the resource allocation framework.

3. PROBLEM STATEMENT

3.1 System Model and Assumptions

3.1.1 Network Model

However, this work as well as the previously cited ones didn't propose a mobility-assisted solution, whereas, maintaining a good QoS of users experiencing handover is of a great importance.

We consider a dense LTE-based femtocell network composed of interfering FBSs. Each FBS streams video content to mobile users in the cell. Fig. 1 presents the overall architecture of a video streaming system over an LTE-based femtocell network. The most relevant components in this architecture are the following:

- The media server which contains the encoded video sequence then transmits the video frames to the FBS over the Evolved Packet Core (EPC).
- The FBS for which the main task is to allocate physical resources (bandwidth and power) to ensure the transmission of video frames to the end user.
- The User Equipment (UE) which is characterized by a playout buffer to maintain a continuous playout of the video sequence.

Conforming to 3GPP LTE systems, the radio access interface for downlink transmission uses OFDMA. We assume that the system uses full frequency reuse, thus the interference perceived by one user is mainly caused by the concurrent downlink transmissions of neighboring femtocells on the same resource block.

3.1.2 Video Traffic Model

The transmitted video traffic consists of VBR encoded videos. Contrary to CBR videos, VBR encoded videos maintain a stable visual quality of the frames at the expense of high deviations in bit rate related to the variations in frame sizes. One approach to model VBR video traffic is statistic modelling. However, it is very difficult to characterize the variability of VBR video traffics for various video sources using that approach. That is why, we opt for a deterministic model that considers video frame sizes and users' playout buffers to capture the variation of VBR video traffic. The advantage of this model is that it provides a common way to capture VBR video traffic variations through a cumulative representation of video frame sizes. This model assumes the knowledge of future frame sizes and their display times.

We assume that the connection between the media server and the serving FBS has sufficient bandwidth providing reliable transmission, whereas the radio path between the FBS and the served UE represents the bottleneck of the end-to-end video delivery. Each UE in the femtocell network is associated to one video sequence, so for simplicity we denote by s the video sequence watched by user s. We assume that the frame rate ρ_s for video sequence s is constant and $\theta_s = 1/\rho_s$ as the average inter-display time of consecutive frames. We define the inter-display period [i,i+1] as the period of length θ_s and during which the i^{th} video frame (or group of video frames in the case of realtime video traffic) is displayed. Thus, given the equality between inter-display periods, we denote by $d_s(i)$ the size of the video frame (or group of video frames for realtime video traffic) watched during [i,i+1]. For the sake of clarity, we note that in the rest of this paper the period [i,i+1] will also be considered as the allocation (or reservation) period. Let $D_s(t)$ be the cumulative amount of bits

Table 1: Comparison of the Proposed Scheme to the Other Resource Allocation Methods.

Method \ Criteria of effectiveness	Buffer flow control	Interference	Power control	RT traffic support	High traffic support	HO adaptation
"Downlink Power Control for Multi-User VBR Video Streaming in Cellular Networks" [5]	Yes	Yes	Yes	Yes	Yes	No
Rebuffering [10]	Yes	Yes	No	No	Yes	No
Cross Layer ([9],[11])	Yes	No	No	Yes	No	No
" Radio Resource Allocation for Scalable Video Services Over Wireless Cellular Networks" [8]	Yes	No	No	Yes	No	No
Frequency-time scheduler [6]	Yes	Yes	Yes	Yes	Yes	No
Our scheme	Yes	Yes	Yes	Yes	Yes	Yes

consumed by the decoder of user s up to the period [i,i+1], and $B_s(i)$ the cumulative number of bits received up to the period [i,i+1] without overflowing the playout buffer of user s. We denote by b_s the size of the playout buffer of user s and λ_s the total number of frames in the video sequence s. $D_s(i)$ and $B_s(i)$ are defined by equations (1) and (2), respectively

$$D_s(i) = D_s(i-1) + d_s(i) \tag{1}$$

$$B_s(i) = minD_s(i-1) + b_s,\ D_s(\lambda_s) \tag{2}$$

Let $X_s(i)$ be the cumulative number of bits transmitted to user s from the beginning of video transmission up to the period [i,i+1]. In fact, $X_s(i)$ should be upper bounded by $B_s(i)$ and lower bounded by $D_s(i)$. The aim of this is to smoothen the transmission rate of video frames so that the user's buffer is neither overflowed nor underflowed. In the next subsection, we give the mathematical formulation of $X_s(i)$ as well as the resource allocation problem.

3.2 Problem Formulation

The allocation unit on the LTE air interface is the Physical Resource Block (PRB). We denote by $PRB(t,c)$ the PRB corresponding to time slot t and subchannel c. We denote by $C_{k,s}(t,c)$ the downlink capacity of FBS k on $PRB(t,c)$ for serving user s. This capacity depends on the Signal-to-Interference-plus-Noise Ratio (SINR) denoted $\gamma_{k,s}$(t,c), which is received by user s from FBS k on $PRB(t,c)$. The SINR is given by

$$\gamma_{k,s}(t,c) = \frac{p^{rec}_{k,s}(t,c)}{I_s(t,c) + \eta_s} \tag{3}$$

In fact, the SINR is the ratio of the received power denoted $p^{rec}_{k,s}(t,c)$, to the sum of the noise power η_s at user s and the intercell interference $I_s(t,c)$ perceived by that user on $PRB(t,c)$. The intercell interference on a particular resource block $PRB(t,c)$ is given by

$$I_s(t,c) = \sum_{m \neq k} \left(p^{rec}_{m,s}(t,c)\right) \tag{4}$$

It consists on the aggregation of interferences caused by every FBS m other than the serving FBS k. The interference level related to one interfering FBS is nothing other than the power received from that FBS. Equation (5) computes the received power from a FBS m to a user s on $PRB(t,c)$ by subtracting the path loss, denoted $L_{m,s}$, from FBS m to user s, from the transmit power $p^{tr}_m(t,c)$ of that FBS on $PRB(t,c)$

$$p^{rec}_{m,s}(t,c) = p^{tr}_m(t,c) - L_{m,s} \tag{5}$$

We assume that the pathloss follows a log-distance model. Thus it can be computed using the well-known pathloss expression given by

$$L_{m,s} = 10 \times n \times \log_{10}(d_{m,s}) + cst \tag{6}$$

where, n and cst denote respectively the path loss exponent and a constant, both of them depend on the physical characteristics of the transmission environment; $d_{m,s}$ refers to the distance between FBS m and user s.

The downlink capacity $C_{k,s}(t,c)$ also depends on the subchannel bandwidth B. We calculate it using the Shannon Capacity formula as follows

$$C_{k,s}(t,c) = B \times \log_2\left(1 + \gamma_{k,s}(t,c)\right) \tag{7}$$

Once the capacities on allocated PRBs are determined, the total number of bits $s_{k,s}$ to be delivered to user s by FBS k during the period [i,i+1] can be deduced as follows

$$S_{k,s} = \sum_t \sum_c a_{k,s}(t,c) \times C_{k,s}(t,c) \times \tau \tag{8}$$

In fact, the number of bits delivered by $PRB(t,c)$ is $C_{k,s}(t,c) \times \tau$ where τ is the duration of one time slot which is fixed to 1ms in LTE. The allocated PRBs vary in the time and frequency domains. The time slot t and subchannel c defining a particular $PRB(t,c)$ vary, respectively, in the period of time [i,i+1], and the set of sub-channels available in system bandwidth. $a_{k,s}(t,c)$ is a Boolean variable that takes 1 when $PRB(t,c)$ is allocated by FBS k to user s, and 0 otherwise. Thus, the cumulative amount of bits transmitted to user s up to the period [i,i+1] can be deduced by equation (9), with $X_s(0) = 0$

$$X_s(i) = X_s(i-1) + \sum_t \sum_c a_{k,s}(t,c) \times C_{k,s}(t,c) \times \tau \quad (9)$$

The resource allocation problem can be viewed as a combination of sub-optimization problems for each user. Each sub-optimization problem aims at maximizing the rate achieved by one user under some constraints. The first constraint concerns the minimum requirement in terms of SINR as imposed by the transceiver design. We reformulate it in terms of minimum transmit power. The second is related to the buffer control. In fact, the high variability of frame sizes of VBR video traffic may cause buffer overflow or underflow if transmission is not adaptively controlled. Thus it is essential to adjust the input bit rate of the user buffer in order to fit this variability. Let p_{max} be the upper bound of the FBS transmit power imposed by the FBS manufacturer. The sub-optimization problem for user s is formulated as follows:

Maximize $X_s(i)$

Subject to

$$\begin{cases} p_{\max} \geq p_k^{tr}(t,c) \geq p_{s,\min}(t,c) & (10) \\ D_s(i) - X_s(i-1) \leq S_{k,s} \leq B_s(i) - X_s(i-1) & (11) \end{cases}$$

In fact, on one hand the SINR $\gamma_{k,s}$(t,c) on a physical resource block $PRB(t,c)$ should be higher than a threshold value Γ_{th} ($\gamma_{k,s}(t,c) \geq \Gamma_{th}$). Consequently, the minimum power required by user s on $PRB(t,c)$, which we denote $p_{s,min}(t,c)$ can be deduced by

$$p_{s,\min}(t,c) = \Gamma_{th} \times (I_s(t,c) + \eta_s) + L_{k,s} \quad (12)$$

It consists on the power that permits to achieve an SINR equal to the threshold value. On the other hand, to ensure the transmission of bits, in the transmission period [i,i+1], without causing neither buffer underflow nor buffer overflow, the following condition should be satisfied

$$D_s(i) \leq X_s(i) \leq B_s(i) \quad (13)$$

In order to guarantee a reliable transmission of video frames for user s, the serving FBS k should allocate, in each period [i,i+1], a number of PRBs as well as their corresponding transmit powers while satisfying the two conditions (10) and 11). However, in a highly dense network (in terms of users) and/or due to the huge resource requirement imposed by the video traffic, there may be insufficient resources to meet the lower bound condition in (11) which may lead to frame loss and consequently to video interruption.

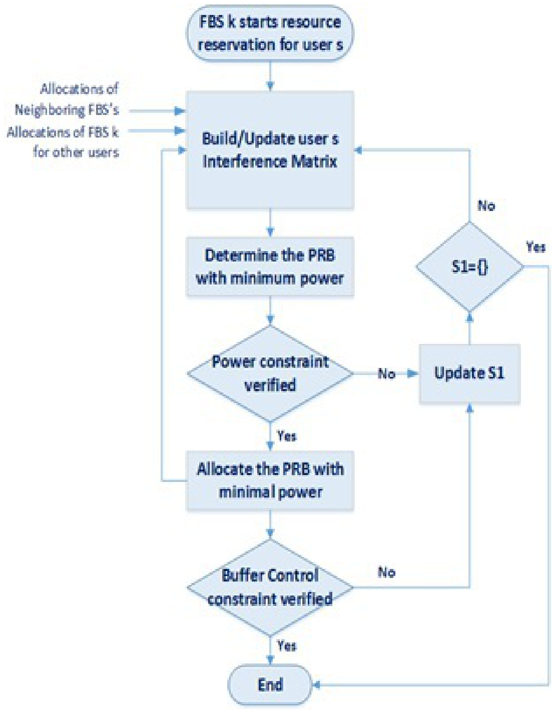

Fig.2: *PRBs and downlink transmit power allocation procedure performed by the FBS for a given UE.*

4. PROPOSED RESOURCE RESERVATION SCHEME

In this section, we are interested in the resource allocation for a short period of time so that users remain attached to the same serving femtocell. In other words, we assume that there is no handover during the resource allocation period. The proposed resource allocation mechanism aims at adaptively allocating the required amount of PRBs needed by each user for the reception of the video frame, so that neither buffer underflow nor buffer overflow are caused. In this allocation, we take into consideration the mitigation of inter-cell interference. In fact, we propose that each FBS calculates an interference matrix based on neighbors' information, and then selects the resource block with minimal interference. Furthermore, PRBs which are requiring minimal power while satisfying the power constraint condition are prioritized. We note that interference mitigation and power minimization are interdependent. In fact, the more interference is minimized the less power is required to achieve the target SINR value.

As aforementioned, the allocation period is the same as the inter-display period denoted [i,i+1] when the i^{th} frame (or group of frames for realtime video) is to be displayed. So for user s, the reservation period is of length θ_s which is calculated in terms of Transmission Time Interval (TTI). Also, we assume that the resource reservation algorithm is always computed before the FBS receives the user request. Let's consider the reservation of radio resources in the period [i,i+1] to user s attached to FBS k. For each reservation period, corresponds a set S_1 of available PRBs. In fact, S_1 refers to the set of PRBs which are not reserved by FBS k so that they can be allocated to user s. S_1 is updated after each reservation of one PRB by omitting that PRB from the sets of available PRBs of other users attached to the same FBS. An interference matrix $M(s)$ is associated to each user s. It contains the values of interferences $I_s(t, c)$ on each $PRB(t, c)$ inside the set S_1 and which are caused by nearby cells using the same PRB. First, for each PRB in the set S_1 the FBS k randomly associates a transmit power between a minimum transmit power value p_{min} and the maximum transmit power of the base station p_{max}. Then FBS k determines the resource block, denoted $PRB(t', c')$, with the minimum transmit power $p_k(t', c')$. If $PRB(t', c')$ fulfils the power transmission constraint defined in (10) (i.e. $p_{\max} \geq p_k(t', c') \geq p_{s,\min}(t', c')$) then it is allocated. Otherwise the set S_1 is updated by omitting $PRB(t', c')$; in this case, if there still are some available PRBs in the set S_1, the FBS repeats the process of determining and checking the power constraint for the resource block with minimum power. The constraint (11) which concerns the transmission capacity (in terms of number of bits) in relation to the two boundary conditions on the buffer is dynamically checked after each assignment of one physical resource block. Based on the checking result, the FBS has two possible decisions to make. In fact, if constraint (11) is verified, reservation is stopped in order to avoid buffer overflow. Otherwise the resource allocation process is repeated until attaining condition (11) or there is no available resource blocks (i.e. $S_1 = \{\}$). Also, we note that after each assignment the FBS broadcasts a message to its neighboring FBSs to update their interference matrices.

As it can be realized, the allocation mechanism adjusts the allocated physical resource blocks and the transmit powers in a way that satisfies the dynamicity of the VBR video traffic. In fact, the allocation is governed by the buffer control constraint. Subsequently, it permits to tackle the variability of frame sizes without causing buffer overflow or underflow. Furthermore, in some periods the VBR video traffic may require important resources. The proposed mechanism guarantees this since it provides very efficient resource management which permits to satisfy the instantaneous requirements of that traffic. Fig. 2 resumes the resource reservation mechanism.

5. MOBILITY MANAGEMENT

5.1 QoS-Adapted Handover Policy

Compared to traditional cellular networks, open access femtocell networks induce more challenges related to handover. In fact, given the small coverage areas of femtocells as well as the presence of many overlapping zones due to the randomness of FBSs' de-

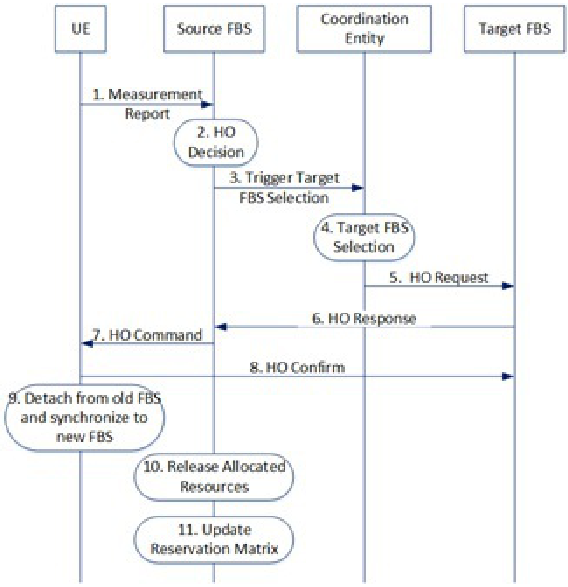

Fig.3: *Sequential diagram of the proposed handover policy.*

ployment, mobile users in this type of networks may experience more frequent handovers. As a result a dramatic degradation of the perceived QoS of real-time multimedia applications especially VBR video streaming may occur.

In this section, a novel handover policy is proposed to deal with VBR video streaming applications. In fact, the resource allocation scheme presented in the previous section is adapted to the mobility-assisted environment where handovers may be frequent so that seamless handovers are required. We propose to use a utility function based policy to make the handover decision. In fact, several works have used the utility theory to manage handovers between access points belonging to the same network ([17]) or to different network systems ([18]-[19]). In our approach, given the large scale aspect of our resource allocation procedure, we adjust the handover utility function taking into account the future traffic dynamics together with the estimation of the required radio resources in the target FBS versus the available resources. This is obtained as output of the resource allocation process as described in the previous section. Moreover, the proposed handover policy involves a Coordination Entity (CE). This CE intends for an entity connected to neighboring FBSs and communicating with them to decide on the choice of the target FBS.

Fig. 3 presents the sequential diagram of the proposed handover policy. The handover is initiated by the current serving FBS (also called source FBS) based on the information provided by the measurement report indicating that the SINR of connected user s falls down a critical value. Then, the source FBS sends a signalling message to trigger the search for target FBS by the CE. We assume that the reservation outputs of the different FBSs are communicated to their corresponding CE after each reservation event so that their reservation matrices are dynamically updated at the CE. Furthermore, we consider a predefined trajectory (a linear trajectory for example) as well as velocity of the mobile user so that its future time journey in the coverage of a neighboring FBS is easily predictable. Given these information (reservation matrices and time journey), the CE selects the best target FBS based on a multi-criteria utility function as will be described in the following paragraphs. After target cell selection, the source FBS releases its resources allocated to user s as well as reserved ones.

The main difference of the proposed HO policy as compared to the traditional HO consists on the introduction of a CE which makes the HO decision instead of the serving FBS. In traditional HO, the decision is based only on the quality of the signal perceived by the UE, particularly the Received Signal Strength Indicator (RSSI) or Signal-to-Interference-plus-Noise Ratio (SINR). In our approach, the CE permits to consider all potential target FBSs and select the best one according to a multi-criteria utility function that takes into consideration the mobility pattern of users as well as the capability of the FBS as will be detailed in the next subsection. This is achieved by making the CE aware of the resource allocation results of those FBSs. The advantage of that consists on the selection the FBS achieving a long-term QoS guarantee. Consequently the inter-handover periods would be increased contrary to the traditional approach which is based only on the SINR and thus may result in many unnecessary handovers and Ping-Pong HO effect responsible of serious delay impact.

5.2 Handover Utility Function: Two Alternatives

Let's consider a handover initiated by the source FBS during the transmission period [i,i+1]. We give below two alternatives for the HO utility function. A comparison of the advantages and limits of each one are provided in subsection 5.3.

5.2.1 Power and Capacity-focused Alternative

The utility function is an aggregation of the following single criterion utility functions:

- Power utility function corresponding to target femtocell k: it is defined by equation (14) with $P_{k,s}$ being the total expected transmit power needed by FBS k to serve user s if this FBS is selected for HO during the considered transmission period

$$f^{p}_{k,s} = \frac{1}{P_{k,s}} \tag{14}$$

This function gives more priority to FBSs with lower transmit power consumption, since it increases as the expected transmit power decreases.

- Transmission capacity utility function $f^{\tilde{X}}_{k,s}$: it defines how much the transmission condition defined in (11) remains satisfied when user s is handed over to femtocell k. To this end, we define in equation (15) the metric $\tilde{X}$ for user s and resource allocation period [i,i+1], and which represents the expected amount of bits that can be transmitted by a potential target FBS k during the remaining time in the current allocation period [i,i+1]

$$\tilde{X}_{k,s}(i) = x_{current}(i) + x_k(i) \tag{15}$$

The terms $x_{current}(i)$ and $x_k(i)$ represent respectively the number of bits already transmitted to user s by the current serving FBS and the number of bits to be transmitted by the target FBS k (if it is selected for HO) during the allocation period [i,i+1], $x_k(i)$ is determined by computing the resource reservation algorithm assuming that user s is attached to femtocell k. Then $f^{\tilde{X}}_{k,s}$ is defined by

$$f^{\tilde{X}}_{k,s} = \begin{cases} 1 \quad if \ \ D(i) \leq \tilde{X}_{k,s}(i) \leq B(i) \\ \frac{1}{e^{D(i)-\tilde{X}_{k,s}(i)}} if \tilde{X}_{k,s}(i) < D(i) \\ \frac{1}{e^{\tilde{X}_{k,s}(i)-B(i)}} if \tilde{X}_{k,s}(i) > B(i) \end{cases} \tag{16}$$

This utility function permits to take into consideration the buffer status variation. It remains constant (equal to 1) as long as $\tilde{X}_{k,s}(i)$ is in the interval $[D(i), B(i)]$ (D(i) and B(i) as defined in equations (1) and (2) respectively), which means that the buffer-related transmission constraint defined in (13) is verified. On the other hand, if this is not the case (i.e. $\tilde{X}_{k,s}(i) < D(i)$ or $\tilde{X}_{k,s}(i) > B(i)$), there will be a reduction of the utility. We choose an exponential expression in the denominator to induce a very rapid decrease of the utility as we go far from the required constraint in (13).

- Time journey utility function $J_{k,s}(v_s)$ which refers to the expected time journey of user s in femtocell k in function of user s velocity (v_s). This utility function is determined by the FBS based on the mobility pattern of user s.

Finally, the aggregate utility function for FBS k to hand over user s is defined by

$$U^{(1)}_{k,s} = (SINR_{k,s} + J_{k,s}(v_s)) \times (\alpha_{\tilde{X}} \times f^{\tilde{X}}_{k,s} + \alpha_p \times f^{p}_{k,s}) \tag{17}$$

where $\alpha_{\tilde{X}}$ and α_p are two weight coefficients in the interval]0,1[and satisfying $\alpha_{\tilde{X}} + \alpha_p = 1$. They define the preferences of the handover parameters for respectively the transmission capacity utility function and the power utility function.

5.2.2 Load-focused Alternative

In this alternative, instead of the transmission capacity utility function and the power utility function defined in the first alternative, we use a traffic utility function $f_k^{traffic}$ defined for a target femtocell k based on the traffic load in terms of video frame sizes d_s of all connected users. $f_k^{traffic}$ is given by

$$f_k^{traffic} = \frac{1}{\sum_s d_s(i)} \tag{18}$$

where, s refers to a user connected to femtocell k and i is the index of the video frame to be transmitted to the handed over user.

Thus the second alternative of aggregate utility function for femtocell k to handover user s is defined by

$$U_{k,s}^{(2)} = (SINR_{k,s} + J_{k,s}(v_s)) \times f_k^{traffic} \tag{19}$$

where $J_{k,s}(v_s)$ is the time journey utility function as defined in the first alternative and $SINR_{k,s}$ is the signal to interference plus noise ratio perceived by user s by a potential serving FBS k. This aggregated utility function ($U_{k,s}^{(2)}$) represents the sum of the SINR criterion and the journey utility function, all normalized with respect to the femtocell traffic load. So, the more the femtocell is charged the less will be its utility output.

5.3 A Comparative Overview of the Two Alternatives

The difference between the two alternatives resides in the second term of the utility function. The first alternative (power and capacity-focused alternative) permits to get more accurate information on the capability of the FBS to satisfy user long term demand. As a result, the user may experience less number of handovers because of the accuracy of the target femtocell selection. The disadvantage of this alternative is that it involves much more complexity as compared to the load-focused alternative, so more time will be needed to process. This induced handover period may be transparent to the end user because of the accuracy in the selection of the target cell. Indeed, the capacity utility function permits to select the femtocell which satisfy better the buffer control criterion, and as a result to avoid disconnection of the video display. Obviously the handover period is tolerated at a certain extend. In this case a disconnection of the video display will occur since the user doesn't receive video frames during that period which causes the buffer to be empty. On the other hand, the second alternative seems to be advantageous in that it involves less complexity to select the best target FBS, as consequence it involves less time for handover decision processing. But it isn't as much accurate as the first alternative in terms of buffer control criterion.

The best alternative would be the one that offers a tradeoff between the resulting handover latency and the decision accuracy. The former is evaluated as a consequence of the complexity involved in the handover process, whereas the latter can be evaluated through the number of initiated handovers and the average inter-handover period. In fact, the more the decision function is accurate the less is the number of handovers and the larger is the inter-handover period. Moreover, a misguided handover decision may cause outage of the connection due to potential bandwidth shortage. If either latency or accuracy requirements are not satisfied, discontinuity of the video playback may be experienced by the end user. Also, guaranteeing the continuity of the video becomes more challenging when the velocity of mobile users is augmented.

6. PERFORMANCE EVALUATION

In this section, we present the simulation results obtained using MATLAB to illustrate the performance of the proposed approach. For the network settings, we consider 10 FBSs randomly distributed in an area of 1Km×1Km; femtocell users are randomly distributed in this area, their number varies between 4 and 100 users. For the video settings, we adopt the video trace of the sequence "Sony Demo" provided by the video library site http://trace.eas.asu.edu/. The considered trace is characterized by H.264 SVC as video codec [13], a frame rate equal to 30fps, 17 Bytes as minimum frame size and 104148 Bytes as maximum frame size. A part of the video sequence of length 30 seconds (which is equivalent to 900 video frames) is used for the simulations. In fact a chunk of 900 frames is sufficient to reflect the dynamicity of the VBR video traffic and thus evaluate the allocation mechanism accordingly. We assume that the size of playout buffer for each user is equal to three times the maximum frame size. The downlink capacity of the system was evaluated for an air interface configuration of 10MHz carrier bandwidth along with Frequency-division duplex (FDD), and a Gaussian channel model. The maximum transmit power of the femtocell base stations is of 20dBm (100mW). Also, an SINR threshold of -6dB is used.

The resource allocation scheme is evaluated in terms of Frame Loss Ratio and the average transmit power per FBS as function of the total number of video consumers in the network. Fig. 4 illustrates the variation of the average Frame Loss Ratio (FLR) as function of the traffic load (i.e. number of users in the network) and compares it to the random allocation method. It is clear that the proposed scheme is highly efficient. It provides a FLR which is 4 times lower. This gain is expected for two facts. On one hand, the control of the buffer flow (condition in equation (8)) implies less frame loss. On the other hand, PRBs are allocated while minimizing inter-cell interference thus gaining in terms of channel capacity, as a result the system is more capable to carry high traffic load with minimal frame loss. Fig. 5 shows the variation

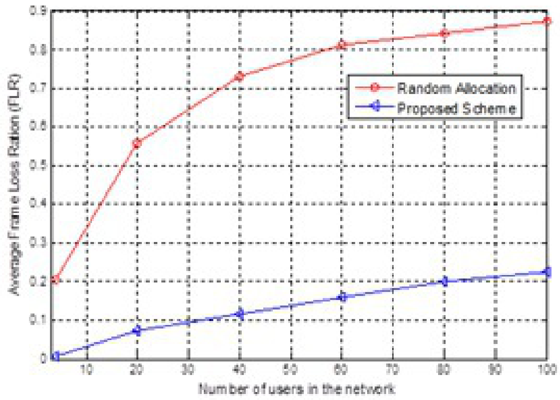

Fig.4: *Evolution of the average FLR when the number of users in the network increases.*

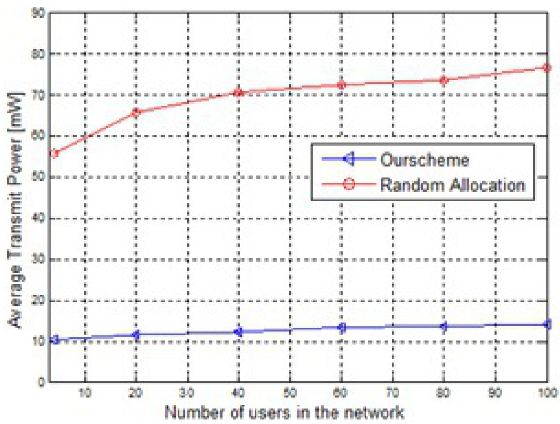

Fig.5: *Average FBS transmit power when the number of users in the network increases.*

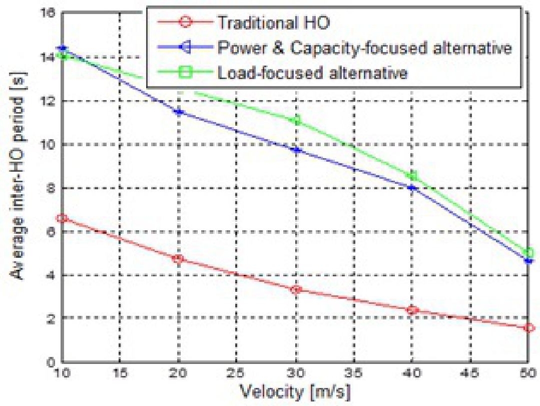

Fig.6: *Variation of the average inter-handover period when the velocity of users increases.*

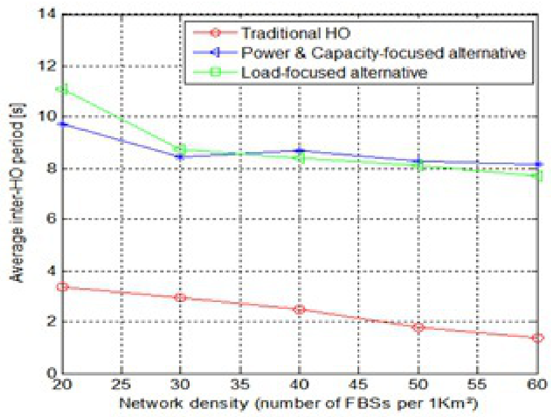

Fig.7: *Variation of the average inter-handover period when the number of FBSs in the network increases.*

of the transmit power when the number of users is increased. We remark that thanks to our scheme, the average transmit power per FBS is considerably decreased (it reduces power 5 times as compared to the random allocation) and remains very low for higher traffic load. This is expected because the proposed power management scheme is based on allocating the PRB which requires the minimum transmit power. Thus we can conclude that our scheme is very energy efficient, and can support high traffic loads with minimal energy consumption.

Also, numerical results are conducted to illustrate the effectiveness of the proposed handover policy. To do so, we examined the average inter-handover period as function of the velocity of users and the density of the network. Fig. 6 shows the variation of the average time between two consecutive handovers in function of the velocity of users. We compare the proposed alternatives with the traditional handover mechanism where the target FBS is the FBS with the maximum SINR value. According to numerical results, the two proposed alternatives have nearly the same performance and they outperform the traditional handover policy by increasing the inter-HO period by more than 120%. This can be explained by the fact that the proposed utility functions take into consideration the expected journey time as well as the capacity of the target femtocell which optimizes the choice of the target FBS and consequently decreases the number of performed handovers then increases the inter-HO period. Fig. 7 illustrates the variation of the inter-HO period in function of the network density. The velocity of mobile users is maintained constant (30m/s) while the number of FBS in an area of $1Km^2$ is varied from 20 to 60. We can see that for the traditional HO, the inter-HO period is very short and it decreases rapidly, while in the proposed scheme the inter-HO period is larger by about 120% as compared to the traditional HO. We also remark that our scheme have tendency to stabilize the inter-HO period as the network density augments. This is due to the optimization of the target FBS choice which takes into consideration the capability of the target FBS to satisfy the future requirement of the

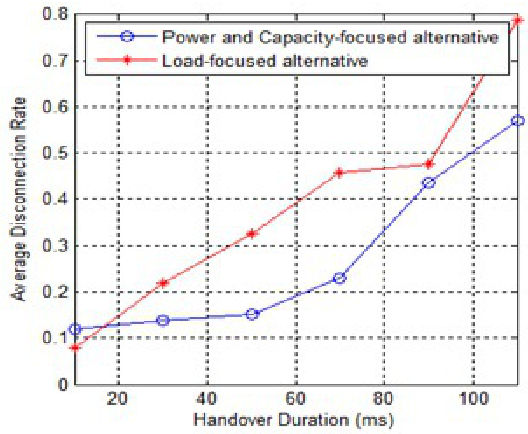

Fig.8: *Variation of the average disconnection rate per user when the handover duration increases.*

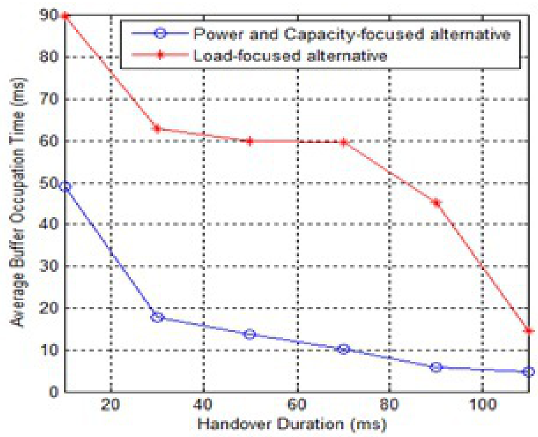

Fig.9: *Variation of the average buffer occupation time per user when the handover period increases.*

handing-over user thus minimizing unnecessary handovers and efficiently maximizing the journey time in the cell. Fig. 8 gives the variation of the average disconnection rate in function of the handover period. For the two alternatives, this rate increases when the handover period increases. This is expected because the more the handover period is high the more there is a chance that the frames in the buffer get displayed before the end of the handover processing (knowing that the buffer does not include more than 3 frames), which causes the buffer to be empty and then a disconnection is perceived by the end user. We remark also, that the first alternative outperforms the second one, since it results in a lower disconnection rate.

We also examined the average buffer occupation time, which is the average time for a video frames to remain blocked in the buffer before being displayed. Fig. 9 illustrates this fact. It is clear that when the handover period increases the buffer occupation period decreases. This can be explained by the fact that, during handover, no more frames are received by the user; this restrains the time between frame reception and frame display.

For real time video streaming, the transmission of video frames is subject to significant fluctuations in time and quantity. We consider a transmission period of 100ms. Unlike stored video streaming where the server sends frames uniformly, frame transmission for real time video is non-uniform. For this case, we evaluate the frame loss rate in function of the surplus of frames transmitted within that period. It is worthy to note that this surplus is calculated as the number of frames in excess regarding the mean number of frames that are supposed to be transmitted during a transmission period. In order to cope with the unexpected variation of the number of transmitted frames, we consider a larger size of the buffer (4 times the maximum frame size). Fig. 10 depicts the obtained variation of the average frame loss rate in function of the surplus in transmitted frames as previously defined. The number of users in the network is fixed to 40. The higher the standard deviation is (i.e. the surplus of frames transmitted per period is much higher than average), the higher is the FLR. The results prove the efficiency of the scheme to handle the variations related to realtime video transmission since it keeps the FLR 5 times lower than in random allocation.

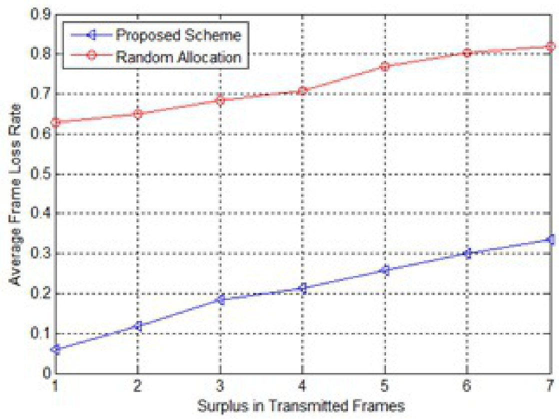

Fig.10: *Variation of the average FLR for realtime video streaming in function of the surplus in transmitted frames .*

7. CONCLUSION

In this paper we investigated a novel approach of resource management with two HO utility functions for efficient VBR video delivery over dense femtocell networks. On one hand, a capacity related inequality is formulated to avoid both buffer underflow and overflow. On the other hand, collaboration of neighboring FBSs enables each FBS to allocate resources while minimizing inter-cell interference. Power control is also considered since the FBS always allocates the resource block requiring minimum transmit power that matches the SINR threshold. The effectiveness of our scheme was proven through simulations since very high gains are obtained in terms of FLR, transmit power as well as inter-HO period. Thus the proposed scheme enhances the capacity of dense femtocell networks to support video streaming applications.

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