QoS/QoE Predictions-based Admission Control for Femto Communications

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Abstract—**Due to their numerous advantages, current trends show a growing number of femtocell deployments. However, femtocells would become less attractive to the general consumers if they cannot keep up with the service quality that the macro cellular network should provide. Given the fact that the quality of mobile services provided at femtocells depends largely on the level of congestion on the backhaul link, this paper introduces a flow mobility/handover admission control method that makes decisions on layer-three handovers from macro network to femtocell network and/or on entire or partial flow mobility between the two networks based on predicted QoS taking into account metrics such as network load/congestion indications and based on predicted QoE metrics. The performance of the proposed admission control is evaluated via simulations and encouraging results are obtained.**

I. INTRODUCTION

A Femto Access Point (FAP), also known as Home Base Station (HBS), Home Node B (HNB), or Home e-Node B (HeNB) in the 3GPP terminology, constitutes the main technology enabler for providing Radio Access Network (RAN) functionality in indoor environments such as shopping malls and large enterprises forming the so-called femtocell networks. A FAP is defined as a low power and low cost cellular base station, operating in licensed spectrum and providing coverage ranges in the order of tens of meters. FAPs connect mobile terminals, or User Equipments in the 3GPP terminology, to a mobile operators core network through the so-called H(e)NB Gateway, using fixed broadband access networks (e.g., broadband digital subscriber line (DSL), cable, or fiber to the home (FTTH) technology) as backhaul. Current trends show a growing number of femtocell deployments, and that is mainly due to their numerous benefits. Indeed, femtocells assure better indoor voice and data coverage, increase the peak bit rate in low coverage areas and ultimately improve the macro network reliability in such areas. Above all, they represent a cost effective solution to the bandwidth limitation and coverage issues of mobile networks. Femtocells represent also a viable way to offload significant amounts of traffic and alleviate congestion at macro network [1]. This is mainly interesting in case of dense-urban high-traffic load areas, such as an enterprise building or a down-town business district. Generally speaking, femtocells would become less attractive if the fixed broadband connection cannot keep up with the Quality of Service (QoS) that the cellular network should provide. Femtocells would indeed become a step down in performance in scenarios whereby a potential number of users simultaneously connect to a FAP or to a set of different FAPs (e.g., in a residential area) whilst the communication path, in the backhaul (e.g., to the same Digital Subscriber Line Access Multiplexer (DSLAM), to the HeNB gateway, or to other relevant potential nodes) is congested or is about to get severely congested. Indeed, as the number of FAPs and the number of users connected to these FAPs increase, e.g., in a residential area, coupled with the fact that FAP users will not use only smartphones, but also laptops with cellular modems launching multiple bandwidth-intensive applications simultaneously, congestion at DSLAMs or relevant nodes becomes highly possible in the absence of an agile admission control. Needless to say that this congestion, if not avoided, degrades QoS and ultimately impacts the Quality of Experience (QoE) of users. Therefore, the quality of mobile services provided at FAPs depends not only on the radio link quality from the UEs to the FAPs, but also on the level of congestion on the backhaul link. A solution to the backhaul segment may deceptively appear simple by increasing the backhaul capacity, e.g., on busiest sites, i.e., by having the mobile network operator overprovision the dedicated resources (e.g., maximum bandwidth) at DSLAMs or other relevant nodes. through well-defined Service Level Agreements (SLAs) with the Internet Service Provider (ISP). However, resource overprovisioning is certainly not a cost-efficient solution mainly in developing markets where wireless is amazingly less expensive than cable or DSL [2]. An agile admission control mechanism that anticipates QoS/QoE degradation and proactively defines policies for admitting UEs handing-in from the macro network to the femtocell network and also enables IP flow mobility between femtocell and macro networks would be of vital importance. This defines the focus of this paper.

The remainder of this paper is structured as follows. Section II highlights some research work pertaining to femtocells and admission control at femto networks. Section III presents the key components of the envisioned network architecture, describes the proposed admission control approach, and highlights the distinct operations that it incorporates. Section IV portrays the simulation philosophy and discusses the simulation results. Finally, the paper concludes in Section V.

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II. RELATED WORK

Regarding femtocell networks, several research works have been conducted in the recent literature. Many of them have dealt with mobility management issues, and that is in both the Open Subscriber Group (OSG) case and the Close Subscriber Group (CSG) case [3][4]. Cell search and reselection, mainly when moving from macro network to femto network, is also of a concern that has been investigated somehow in the area of femto networking. Solutions to this issue were in the form of predicting the user movement, comparing the FAPs that have been visited to those stored in the local cache, and then selecting the ones that a user should more likely connect to [5]. Again to support mobility between macro network and femtocell, the work in [6] proposes a mobility management scheme based on QoS, traffic type (e.g., real time vs. non-real time), and UEs' speed considering three velocity ranges, namely low, medium, and high.

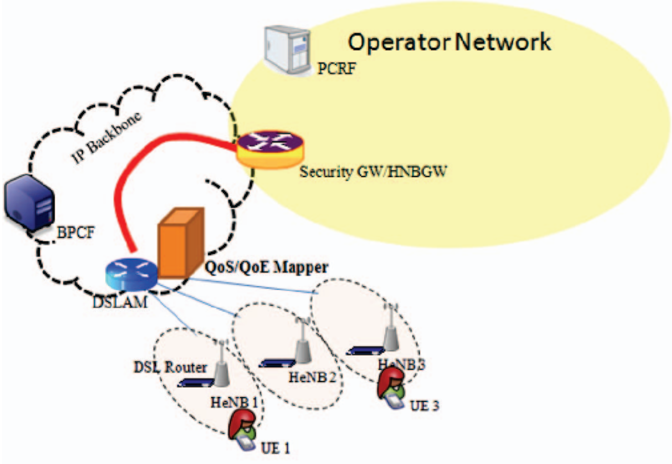

Fig. 1. A typical femtocell network deployment.

As mentioned earlier, assuring acceptable QoS over IP backhaul is of vital importance for femtocell networks, especially for delay-sensitive traffic. This becomes a challenge, mainly when the mobile network and the broadband network are operated independently. One solution to this problem is by implementing admission control mechanisms at femtocells; a research area which is still fertile with a few contributions in the literature. The authors of [7] propose a distributed admission control mechanism for traffic load balancing among sub-carriers when there are multiple QoS classes. In [8], an admission control and resource allocation mechanism is provided to avoid resource overloading and call quality degradation at DSLAMs to support femto communications. In this admission control, the voice quality measurements are made at the HeNB GW and the call admission decisions are made based on measurements taken from actual ongoing VoIP calls rather than voice probing streams and that is considering a modified variant of the ITU-Ts E-Model algorithm. In [9], a whole study is conducted by 3GPP defining policies for interworking between 3GPP networks and fixed broadband networks. The work in [9] focuses mainly on the architecture aspects addressing system architecture impacts to support broadband network access interworking and covering aspects such as basic connectivity, mobility, authentication and authorization, policy and QoS aspects, and traffic offload.

III. PROPOSED QOS/QOE-BASED ADMISSION CONTROL

A typical femtocell network deployment is shown in Fig. 1. The shown network architecture comprises a number of femtocells, covering multiple households/small offices in a wide residential area or forming an enterprise or a hotspot femtocell network (e.g. shopping mall). The multiple femtocells are provided by the same mobile network operator and connected through the same DSLAM (or another node relevant to the used fixed access technology) to the mobile operators core network via (optionally) a security gateway and a HNB gateway. Whilst the figure shows the case of a single mobile operator network operating femtocells and utilizing the fixed broadband networks DSLAM, the DSLAM can be also shared by femtocells operated by different mobile operators. In this case, DSLAMs are assumed to have the capacity to individually identify the different mobile operators using one or more suitable methods. The problem that we aim solving in this paper is as follows. A mobile user enters an area serviced by a femtocell network and covered also by the mobile operators macro network. In case a link along the path from the femtocells (or the DSLAM or other relevant node) to the HNB GW (or to another relevant point of mobile traffic concentration) is congested or is about to get congested, if the user handovers from the mobile operators macro network to the femtocell network, the service quality may get downgraded. Furthermore, due to the handover of the new user to the femto network, the quality of services received by other existing users may get also downgraded, or worse enough, aggravated. As a solution to this issue, this paper presents a mechanism that i) predicts and assesses the variation of QoS metrics in the future such as network load/congestion indications, ii) predicts and assesses the impact of QoS variation on users' QoE, iii) and based on these two predictions, defines policies for admitting UEs wishing to handover from the macro network into the femtocell network and enforcing IP flow mobility (including multi-homing) between femtocell and macro networks as a proactive measure to encounter any possible degradation in QoS/QoE. In this mechanism, QoE is assessed in the form of a metric that indicates average user satisfaction level (i.e., Mean Opinion Score MOS). Information on user satisfaction is collected explicitly from users when they hand-out from the femtocell network. A users satisfaction level can be, for example, a score from ω_{min} to ω_{max}, with ω_{max} indicating an excellent perceived quality and ω_{min} indicating a poor service. Satisfaction levels can be collected, from a randomly selected group of users, for instance using short message service (SMS), through a web portal, or through a dedicated application. Incentives could be given to users that scored their service satisfaction levels. It should be noted that for many mobile operators, using femtocells for data offload, providing mobile services, or other purposes is still a new service or yet to be launched service and operators may then want to evaluate the satisfaction of their customers at an initial phase of the service to assess and ensure an adequate deployment of resources. In the envisioned architecture depicted in Fig1, a new entity, called QoS/QoE mapper, is collocated with the DSLAM. In case of an enterprise network or a shopping mall, it can be collocated at the gateway of the enterprise local network to the ISP network. This QoS/QoE mapper can be also collocated with the HeNB GW or at another appropriate location. It can be a physically independent and new node or a function at an existing node. The QoS/QoE mapper is in charge of monitoring the bandwidth variation of the link between the femtocell network and the operators HNB gateway, using one or more suitable bandwidth probing techniques. The link bandwidth may vary during different periods of a day. For instance, the link may be accessed heavily during the day and not so much at night. To inflict these variations, the QoS/QoE mapper develops a statistical profile over time of the link bandwidth variation. This statistical profile is constantly updated over a long period of time, in the order of days or weeks. This statistical profile is referred to as link bandwidth profile. The QoS/QoE mapper keeps also track of another statistical profile, called QoS/QoE profile hereunder, whereby QoE in terms of the satisfaction level of users, averaged over a short and predetermined period of time Δ, is mapped to QoS in terms of average link utilization and total number of users connected to the femtocell network during the time period Δ. The QoS/QoE profile is constantly updated through learning. There may be different ways for computing the average user satisfaction level using any function that takes the following metrics as inputs, namely the score ω_i indicated by a customer i, the duration θ_i during which the user was connected to the femtocell network, the types of applications/services received by the customer, and the average throughput λ_i achieved by the customer while being connected to the femtocell network. In the initial stage of the system deployment, the database of the QoS/QoE profile is empty. During the femtocell network service time, the QoS/QoE mapper uses the customer satisfaction levels, explicitly indicated by users, to build the QoS/QoE profile, which actually forms an online profile that learns the non-linear relation between user satisfaction and QoS parameters using machine learning (e.g., neural networks, Bayesian inference, supervised learning, etc). The online QoS/QoE profile may be categorized into multiple profiles that are specific to an application type.There could be different ways for the QoS/QoE mapper to collect feedback from users upon performing handoff out of a specific femtocell network. In one approach, it could be that the mobility management entity (MME) is acquired with a specific policy, following which it decides whether a user needs to be contacted to provide feedback on the service or not. These policies can be provided by the QoS/QoE mapper or by any other mobile network node (e.g. PCRF). When a UE performs handoff from a femtocell network to the macro network, MME becomes aware of this handoff (regardless whether it is a S1-based handoff or a X2-based handoff [11]). MME then runs the policy logic to decide if the UE needs to be contacted for scoring the service or not. If yes, the MME may trigger the QoS/QoE mapper or another node to SMS the UE. Feedback on the femtocell network service is then sent from the UE to the QoS/QoE mapper. In this paper, we restrict the QoS parameters to the available bandwidth of the IP backhaul link to the HNB GW and the total number of users connecting through the femtocell network. However, other metrics that could be used for QoS assessment may be access delay and packet error rate at the IP backhaul.

Fig.2 depicts the major steps behind our proposed admission control. Decisions on the admission control policies to be sent to femtocells are run periodically. For the sake of simplicity and with no other purposes in mind, we set the periodicity of the admission control policy determination equal to Δ, the time over which IP backhaul link bandwidth and the user satisfaction levels are averaged. At the beginning of each period $\Delta(k)$, the QoS/QoE mapper predicts the average link bandwidth from the relevant link band-width statistical profile. The accuracy of the prediction can be assessed by comparing the predicted values and the actual values measured during a number of previous time periods. The correlation between the predicted link bandwidth value and the actual one measured during a time period $\Delta(j)$ is denoted by $\Phi(j)$. Knowing the total number of users connected to the femtocell network and using the predicted average link bandwidth, the QoS/QoE mapper refers to the QoS/QoE profile (or a particular profile such as QoS Class Identifier QCI-specific) to predict the user satisfaction level $S_p(k)$ during the upcoming time period $\Delta(k)$. In Step 3 as shown in Fig. 2, the system assesses this prediction by comparing the predicted user satisfaction values $S_p(j; j < k)$ and the actual satisfaction values $S_a(j; j < k)$ measured during a number of previous time periods $\Delta(j; j < k)$. The correlation between the predicted user satisfaction value and the actual one measured during a time period $\Delta(j)$ is denoted by $\Psi(j)$. Strong correlations between the predicted values and the actual ones, in other words, high values of $\Phi(j; j < k)$ and $\Psi(j; j < k)$ indicate that in the current round $\Delta(k)$ there is a high probability to have the IP backhaul link experience traffic dynamics as predicted

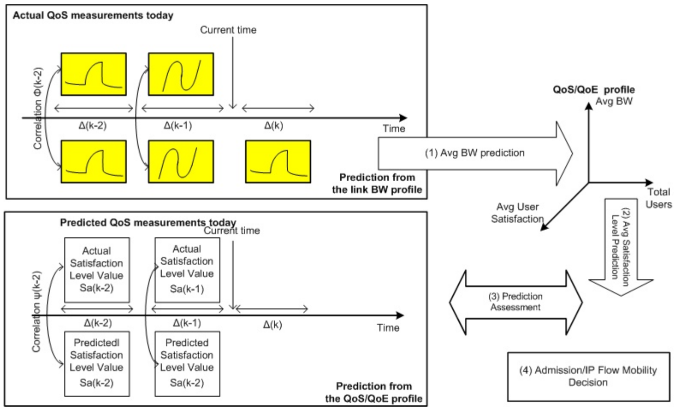

Fig. 2. Major steps behind the proposed admission control mechanism.

from the link BW statistical profile and also to experience a user satisfaction level similar to the value $S_p(k)$ predicted from the QoS/QoE statistical profile. If the satisfaction level is predicted to be low, the QoS/QoE mapper defines an admission control policy that shall be enforced at femtocells, to ultimately increase the satisfaction level to an acceptable value, e.g., by decreasing the total number of users connected to the femtocell network to a certain value according to the QoS/QoE statistical profile and that is via IP flow mobility between macro and femtocell networks (assuming UEs with dual cellular radios capability), by declining requests from new users to handover from the macro network to the femtocell network, etc. Indeed, a user, currently connected to the femtocell network, may be requested to move a set of his IP flows to the macro network. In another scenario, a user may be requested to split the traffic of the same IP flow between the macro network and the femtocell network, i.e., have a certain percentage of the IP flow traffic serviced via the femtocell network while the remaining portion of the IP flow traffic is moved to the macro network. After being admitted to the femtocell network, and at a certain point in time, a user may experience degradation in QoS. Degradation of the QoS can be (e.g., visually) perceived by the user or automatically detected by the user equipment using one or more suitable QoE models and considering one or more QoS metrics such as delay, delay variation, jitter, packet drops, etc. Note that the QoE assessment we refer to here is conducted by the UE using different QoE models, whereas at the QoS/QoE mapper, the QoE assessment is based on the feedback received from users, duration of connection to femtocell network, average throughput of users, etc. In such case, if the QoS degradation lasts for a time longer than a predetermined period of time and/or reaches a certain level (e.g., specific values of the considered QoS metrics), the user may manually trigger a handoff request and/or flow mobility from the femtocell network to the macro network. Alternatively, the user equipment may be configured to do so without user intervention.

IV. PERFORMANCE EVALUATION

A. Simulation settings

Due to lack of real-life femtocell network data from operators (due to customer privacy and unavailability of such data at first place given the novelty of the service), we use Pseudo-Subjective Quality Assessment (PSQA) tool [10] in order to reproduce user perception in terms of QoE. PSQA is an automatic QoE evaluation tool for multimedia services based on Random Neuronal Network. It learns the non-linear relationship between parameters impacting the service quality and the user perceived QoE. Note that, the PSQA version we use in these simulations is dedicated to video quality evaluation, while the NN used in our proposal solution concerns all kinds of services. To estimate the user QoE, PSQA takes as input the loss rate and the mean loss burst size observed by the video flow. The obtained output gives a Mean Opinion Score (MOS) value between 0 and 10. 10 and 0 represent the highest video quality and the worst quality, respectively. We implemented the proposed solution in the NS3 simulator. The simulated architecture consists of one P-GW, one S-GW, one eNB, one HeNB and n UEs connected to the HeNB. Whilst the femtocell network can be easily extended to the case of multiple m HeNBs serving (e.g., $m * n$) UEs, we focus here on the case of one HeNB serving n UEs as the fundamental observations about the proposed scheme are independent of the femtocell network architecture. All UEs have access at the same time to the femtocell network and the macro network of the mobile operator. We consider that the channel is operating under good conditions. All UEs are downloading an H.264 video stream of 320 Kbps from a remote server. Both eNB and HeNBs are based on the LTE specifications regarding the Uplink and Downlink physical characteristics. In our envisioned net-work architecture, we deliberately set the bottleneck link to the ADSL down link (i.e., link between DSLAM and femtocell network gateway) whereby a link of four Mbps is used.

B. Results

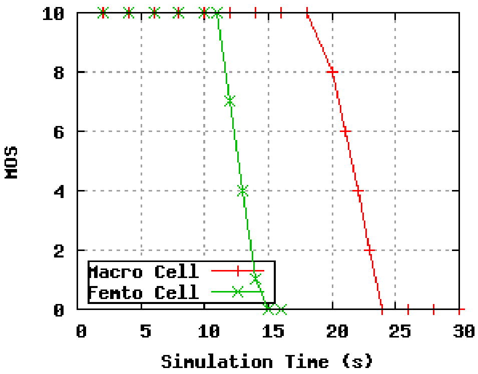

Fig. 3. The mean MOS perceived by users when using the macro network and the femtocell network for different numbers of active UEs.

The first experiment aims at showing the impact of the number of active users on the evolution of the user profile (QoE). Fig. 3 shows the mean MOS perceived by users for different numbers of active UEs. The results relate to both the macro and femtocell networks. We notice clearly that the number of connected active users affects the QoE, particularly at the femtocell network. If no admission is applied, QoE degrades rapidly when the number of UEs increases. Since PSQA is relying on the loss rate to estimate QoE, this degradation is mainly due to the excessive packet drops at the bottleneck link. Here, we observe that the femto cells cannot accept more than 12 stations without degrading users QoE. This clearly proves the need for an admission control to manage handoff operations between the macro and femtocell networks. Based on the results obtained in Fig. 3, we assume that the mobile operator has enough information to build the QoS/QoE statistical profile. By using our proposed admission control (AC), it is able to decide for each UE, to offload or not its traffic through the femto cell. In order to show the effectiveness of our solution, we simulate two scenarios: (i) in one scenario, all incoming traffic is offloaded through the femto cell until QoE begins to decrease, when the proposed

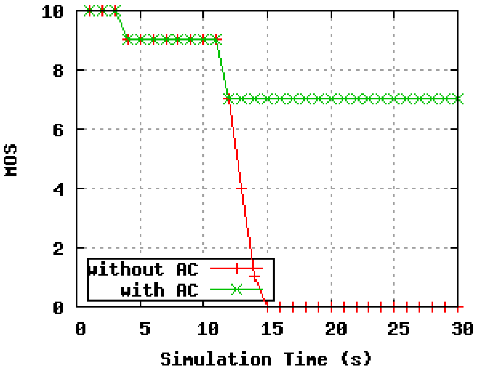

Fig. 4. MOS as perceived by user of UE1 (Scenario 1).

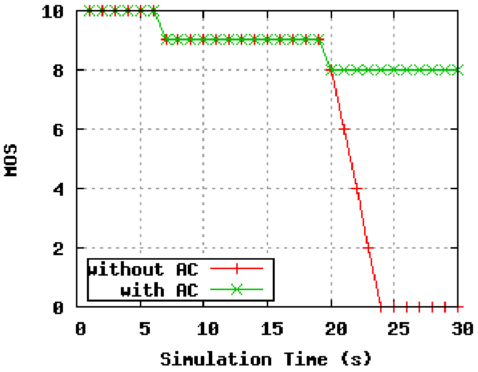

Fig. 5. MOS as perceived by user of UE1 (Scenario 2).

admission control begins to redirect the coming flows through the macro cell; (ii) in the second scenario, all incoming flows are using the macro cell until the QoE offered by this macro network is lower than the one offered by the femtocell network. For both scenarios, 25 flows are introduced every one second. After that, we compare the results obtained by an active UE, when the proposed admission control is used and when no admission control is in place.

Fig. 3 shows MOS as perceived by the user of UE1, in the first scenario. This UE was initiated at $t = 1sec$ and attached to the HeNB throughout the simulation. The two figures indicate that with the usage of the proposed admission control, the mobile operator manages better handoffs into the femtocell network: it accepts handovers to the femtocell network as long as flows of existing users are not compromised. In fact, when the proposed admission control is used, from $t = 12s$ requests from users to handoff from the macro network to the femtocell network are declined as QoE is expected to decrease to lower values according to the adopted NN approach. When no admission control is in place, all the handoff requests to the femtocell network are accepted; a fact that largely impacts the users perceived QoE. Fig. 5 plots MOS as perceived by the user of UE1, in the second scenario. Recall that in this scenario, UEs are attached to the macro network until our proposed NN approach detects that the femtocell can ensure higher QoE. From the results of Fig. 5, it becomes clear that the proposed admission control reacts quickly to any changes in the perceived QoE. From the time instant $t = 20s$, the proposed admission control admits incoming flows through the femtocell network aiming at maintaining acceptable QoE (around 8/10) at the macro network while ensuring good QoE for the flows admitted in the femtocell network. Similar to the first scenario, we notice that the proposed admission control allows the mobile operator to optimize the usage of its resources at both the macro and femtocell networks while maintaining an acceptable QoE at both networks. It is also worth mentioning that when the proposed admission control is in use, the aggregate traffic from all simulated UEs, accepted without degrading QoE at both macro and femtocell networks, is higher and that is in the case of both scenarios.

V. CONCLUDING REMARKS

In this paper, we proposed a QoS/QoE-based admission control mechanism that helps mobile operator to cope with handover decision process between macro and femtocell networks. The admission control mechanism relies on feedback from a new entity, called QoS/QoE mapper, which predicts users QoE based on feedback collected a priori from users on the deployed service. These users feedbacks help the QoS/QoE mapper to build an online neuronal network (NN) that learns the relation between user satisfaction and current QoS conditions of a cell (data rate mainly). Based on this online NN, the proposed admission control decides for each hand-in/flow if it should be accepted within the femtocell network or not. The performance of the proposed admission control was evaluated through simulations and the obtained results were encouraging. They demonstrate the fundamental design goals of the proposed scheme, in accommodating high amount of traffic without compromising users perceived QoE.

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