Exploiting User Context Information for Energy Management in Enterprise Femtocell Networks

Konstantinos Samdanis, Marcus Schoeller
NEC Europe Ltd, Germany
samdanis@neclab.eu

Abstract— **Enterprise femtocell networks provide connectivity for indoor users supporting enhanced capacity given traffic and Quality-of-Service (QoS) provision requirements. Their deployment is usually dense with the objective to serve peak hour demands. However, users do not enter or leave an indoor environment at the same time or use extensively the network resources on a constant basis. During times where the network is underutilized, energy is wasted depending on the degree of mismatch between the offered capacity and user demand. This paper aims to resolve this problem by introducing autonomous power-aware femtocell operation based on the user context information. A set of energy management strategies and algorithms are introduced based on the user location, femtocell coverage, per user resource demand and other context information associated with users entering/leaving times and electronic calendar entries. Our results demonstrate that adopting user context information can improve significantly the energy expenditure of enterprise femtocell networks.**

I. INTRODUCTION

Ubiquitous connectivity for mobile users has been promised for many years. Using 3G network technologies it is achieved in many areas, but maintaining connectivity when users enter buildings is still challenging. Femtocells, small and easy to deploy cellular base stations, are designed to improve indoor coverage and to provide increased capacity to mobile users. Recently femtocells are increasingly deployed in enterprise environments forming networks that serve many users in large buildings [1]. In such environments, femtocells provide cellular connectivity and Internet access complementing the limited coverage of macro-cell networks. Usually over provisioned, i.e. densely deployed, enterprise femtocell networks ensure an adequate service to a potentially higher than the expected number of users. Effectively though, such over provisioned capacity is rarely used in practice as pointed out in [2].

In fact, peak hour capacity is only exploited at specific periods, as users enter and leave the enterprise network at different times. Hence, energy efficiency may be realized by dynamically dimensioning the offered network resources according to the varying traffic demand, considering user context information. Our proposal is based on the observation that individual users often follow a strict daily routine but that this routine can vary significantly amongst the employee base considering an office environment. Especially times when individual employees come to work and leave can be quite diverse, simply because they have different responsibilities with not aligned schedules. We envision that such user context may advance the current solutions by providing a more sophisticated femtocell power management. Moreover, additional context information related with users absences and meeting schedules may enhance further the energy efficiency by providing awareness regarding the expected traffic demand.

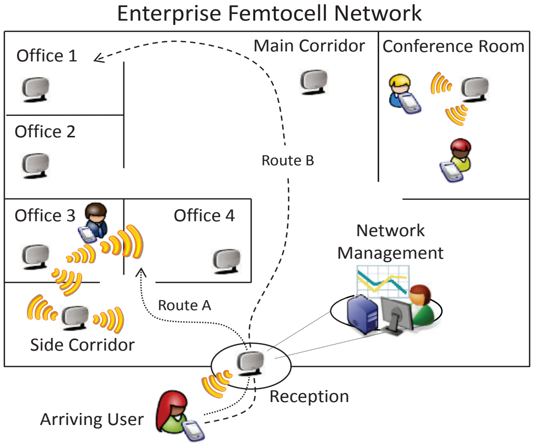


Fig. 1: An example of energy management in enterprise networks.

Our contribution is to explore individual user activity and routine patters, in order to introduce power-awareness in operating a femtocell network. The aim is to enhance current energy management systems enabling autonomous or self-organized functions similar to macro-cellular 3GPP systems [3], assuming that the coverage of certain femtocells is partially overlapping. Likewise macro-cellular networks, the purpose is to maintain the minimum set of femtocells powered-on to serve a specific group of users, while the difference concentrates on the parameters considered. In particular, our proposal considers the sequence of incoming and leaving users as well as electronic calendar entries for appointments and absences, combined with user specific traffic demands, working locations and mobility patterns.

The proposed scheme identifies each approaching and leaving user based on the procedures defined in [4] and from the movement towards the entrance, assuming a reception femtocell is powered-on during network operating times as shown in Fig.1. We envision that the reception femtocell in coordination with the management system can identify the user's office location and the service requirements based on prior user context information, and hence specify the femtocells operating arrangement. The objective is to optimize the energy consumption by selecting to power-on femtocells that may also serve subsequent users keeping the remaining ones powered-off for a longer time.

978-3-901882-50-0 ©2013 IFIP

For example in Fig.1, an incoming user associated with office 4 following route A would introduce no changes on the current power-aware network arrangement, since the side corridor and office 3 femtocells are already powered-on, capable to provide coverage with adequate resources to office 4. Alternatively, if the incoming user's location is office 1, then the femtocell in the main corridor should be powered-on to maintain coverage for route B. Provided that the femtocell in office 2 can serve both users in office 1 and office 3 then from the energy perspective it is the ideal femtocell to be powered-on. The management system should follow such power-awareness, which could be further enriched by the knowledge that the user of office 1 will enter shortly after the one in office 3, selecting to power-on the femtocell of office 2 on the first place. A similar policy could also be applied once users are leaving the network. If all users have a meeting in the conference room, then the management system would power-off all office and side corridor femtocells for the duration of the meeting keeping powered-on the main corridor femtocell in case of an unexpected user move.

The remaining of the paper is organized as follows. Section II presents the related work, while Section III introduces the considered energy management strategies and algorithms. The evaluation and analysis of the proposed solutions is discussed is Section VI. Finally Section V provides the conclusion remarks and the potential further research directions.

II. RELATED WORK

The introduction of femtocells for enterprise environments improve the radio conditions and reduce the transmission distance for indoor users, enhancing energy efficiency as pointed out in [5]. Enterprise networks may also benefit from data offloading policies as specified in [6] reducing further energy consumption. Nevertheless, interference due to the absence of network planning could prove a significant barrier as analyzed in [7], which studies such a problem and provides a set of resource allocation and coordination solutions. A self-organizing framework that complements such interference mitigation scheme by configuring autonomously a set of radio parameters and access control mechanisms is introduced in [8], improving the operation performance and energy efficiency of enterprise femtocell networks. With such energy efficient radio and access control being the current state of the art, we examine further network management proposals.

The simplest form of energy saving management is based on scheduled operations, i.e. fixed time periods where the network access points are fully operational or powered-off. In an enterprise environment these time periods can be aligned with the business hours. A more dynamic femtocell operation is introduced with the aforementioned 3GPP proposal [9], a home centered scenario, which could easily be applied in enterprise cases. Its main idea is to exploit the UE "neighboring context", enabling the network, i.e. MME, to recognize when a UE enters or leaves its home network with the objective to introduce a power-aware operation of the associated femtocell. In an enterprise femtocell scenario the same principle may be applied for users that move away from their typical working locations. Such a method may further be enhanced considering user activity patterns as proposed in [10]. In this way a femtocell may additionally realize energy saving once the associated users remain in idle state.

Since enterprise deployments are usually dense, in where users can be served by several femtocells, more advanced solutions exploiting such flexibility may further enhance energy saving. In [2] a resource on demand strategy and a green clustering algorithm is introduced with the objective to match the offered capacity to the traffic demand, while a similar approach centered on 3GPP macro-cellular networks is also considered in [11]. Such a green clustering approaches specify associations among powered-on and powered-off access points maintaining a constant coverage and QoS provision, while avoiding powering-off and re-powering-on, access points frequently. A simple analytical model, developed in [12] further evaluates such green clustering, introducing also a hysteresis policy for powering-on and off access points according to traffic load variations. An alternative approach based on Integer Linear Programming (ILP) that aims to obtain the optimal power saving arrangement, while ensuring coverage and QoS is presented in [13]. Further coverage adjustment heuristics based on femtocell coordination methods with the objective to save energy by minimizing the transmission power according to user demands are introduced in [14].

Our proposal advances the current approaches by exploiting the user context in specifying autonomous or self-organized energy management solutions. Besides user activity and mobility patterns, our scheme considers user location information to form femtocell power operation practices combined with handover policies, which may further be enriched by considering user entering and leaving patterns as well as electronic calendar details. In this way the energy efficiency is increased due to more sophisticated femtocell power-aware operation.

III. ENERGY SAVING STRATEGIES AND ALGORITHMS

This section presents four distinct energy management strategies including the related algorithms for operating an enterprise femtocell network in an increased complexity order. The first two detail the current conventional methods adopted for use within the enterprise femtocell environment, while the remaining introduce our proposed solutions.

A. Scheduled-based

The simplest way to operate an enterprise network considering energy efficiency is by powering-off all femtocells during idle times, associated with the opening hours of the building. Such a system is controlled by a time based policy that powers on and off the complete femtocell network at scheduled times. Hence, energy is conserved by allowing femtocells to be powered-off at times when the network is idle and users are residing in the building.

B. Location-based

A user-location based approach keeps femtocells powered-off until the associated user, i.e. the employee of a particular office, enters the building. A dedicated femtocell usually in the reception should remain powered-on during the enterprise opening times. As users enter the building and perform a regular handover from the macro-cellular network to the femtocell, the identity of the user is revealed to the system. Based on such identity, the system determines and powers-on the femtocell on user's location and the ones en route, ensuring a seamless service. Once a user leaves the building, the management system checks whether the associated femtocell is still in use by other users, powering-off idle femtocells. Similarly, it checks whether femtocells in halls can be powered-off, once certain employees have left.

Algorithm 1 User-Location based Algorithm

```
 1: $S_{pon} = \emptyset$; $S_{poff} = N_{ent}$; $R(f) = 0, \forall\ f \in N_{ent}$;
 2: while $Ent_{open}$ = true
 3:     $S_{pon} \leftarrow S_{pon} \cup f_R$;
 4:     if $usr_{enter}$ = true
 5:         $usr_{id} \leftarrow (f_o, u_{rs}, u_{pr})$; $f_o(u_{pr}) \leftarrow (P_{f_o})$;
 6:         $R(f_o) = R(f_o) + u_{rs}$;
 7:         if $S_{pon} \cap f_o = \emptyset$
 8:             $S_{pon} \leftarrow S_{pon} \cup f \in (f_o, P_{f_o})$;
 9:         end
10:     elseif $usr_{leave}$ = true
11:         $usr_{id} \leftarrow (f_o, u_{rs}, u_{pr})$; $f_o(u_{pr}) \leftarrow (P_{f_o})$;
12:         $R(f_o) = R(f_o) - u_{rs}$;
13:         if $R(f_o) = 0$
14:             $S_{poff} \leftarrow S_{poff} \cup f \in (f_o, P_{f_o})$;
15:         end
16:     end
17:     if $time < t_{open}$ & $time > t_{close}$
18:         $Ent_{open}$ = false; $S_{poff} \leftarrow S_{poff} \cup f_R$;
19:     end
20: end
```

Algorithm 1 illustrates a pseudocode version of the user-location based algorithm. The algorithm starts considering a set that represents all network femtocells N_{ent} being powered-off, S_{poff}, i.e. the powered-on set $S_{pon}= \emptyset$. Whilst the enterprise operates, i.e. Ent_{open} is true, a reception femtocell f_R is kept powered-on. Once a user enters the network, i.e. usr_{enter} is true, the reception femtocell gets the user id, usr_{id}, which reveals the associated office femtocell f_o, the user resource demand u_{rs} and the network permissions u_{pr}. Based on such permissions, the algorithm specifies the femtocells en route to the users office, P_{fo}. It then increments the resource consumption of the users office femtocell $R(f_o)$, by the resource demand u_{rs} keeping a record. In case the user is the first to enter the office, i.e. $S_{pon} \cap f_o = \emptyset$, such femtocell is powered-on and added to the S_{pon} set.

When a user leaves the building, i.e. usr_{leave} is true, the management system via the usr_{id} the related information and decrease the resources consumption $R(f_o)$ of the associated femtocell by the user demand u_{rs}. In case the user's office femtocell is idle i.e. $R(f_o) = 0$, the algorithm powers it off including the ones en route P_{fo}, not needed to support users in other offices, updating accordingly the S_{poff} record. The algorithm keeps track of the enterprise opening times and declares Ent_{open} as false when time falls outside the predetermined limits, powering-off the reception femtocell.

C. Coverage-Load based Algorithm

The coverage-load based algorithm enhances the priory user-location based one, by considering the overlapping coverage among neighbor femtocells in combination with user activity and network resource availability. A femtocell at the entrance still identifies incoming and leaving users reporting to a management system, which determines the network power operation. The objective of this algorithm is to accommodate incoming users on femtocells already powered-on, slowing down the rate of waking-up additional femtocells and to introduce a handover policy that concentrates users into as less femtocells as possible, once load variations provides such opportunity, preserving always user's QoS.

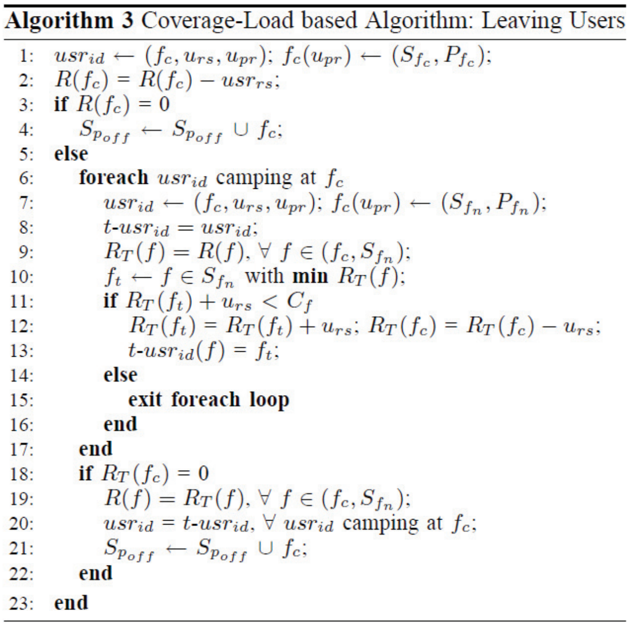
Algorithm 2 Coverage-Load based Algorithm: Entering Users

```
$usr_{id} \leftarrow (f_o, u_{rs}, u_{pr})$; $f_o(u_{pr}) \leftarrow (S_{f_o}, P_{f_o})$;
if $S_{f_o} \cap S_{pon} = \emptyset$
    $R(f_o) = R(f_o) + u_{rs}$;
    $S_{pon} \leftarrow S_{pon} \cup f \in (f_o, P_{f_o})$;
else
    $f_s \leftarrow f \in (S_{f_o} \cup f_o)$ with min $R(f)$;
    if $R(f_s) + u_{rs} < C_f$
        $R(f_s) = R(f_s) + u_{rs}$; $usr_{id}(f) = f_s$;
    else
        if $S_{f_o} - S_{pon} \neq \emptyset$
            $f_s \leftarrow f \in S_{f_o}$ with min dist from $f_o$;
            $usr_{id} \leftarrow (f_s, u_{rs}, u_{pr})$; $f_s(u_{pr}) \leftarrow (S_{f_s}, P_{f_s})$;
            $S_{pon} \leftarrow S_{pon} \cup f \in (f_s, P_{f_s})$;
        else
            foreach $f_n \in S_{f_o}$
                $f_n(u_{pr}) \leftarrow (O_{f_n}, P_{f_n})$;
                $S_R(f_n) = \sum_{f_n \in O_{f_n}} (C_f - R(f_n))$;
            end
            $f_h \leftarrow f \in S_{f_o}$ with max $S_R(f)$;
            while $u_{rs} + R(f_h) > C_f$
                $m\text{-}usr_{id} \leftarrow usr_{id}$ camping at $f_h$ with max $u_{rs}$;
                $f_t \leftarrow f \in O_{f_n}$ with min $R(f)$;
                if $R(f_t) = 0$
                    $f_t(u_{pr}) \leftarrow (S_{f_t}, P_{f_t})$;
                    $S_{pon} \leftarrow S_{pon} \cup f \in (f_t, P_{f_t})$;
                end
                $R(f_h) = R(f_h) - m\text{-}u_{rs}$; $m\text{-}usr_{id}(f) = f_t$;
                $R(f_n) = R(f_n) + m\text{-}u_{rs}$;
            end
            $R(f_h) = R(f_h) + u_{rs}$;
        end
    end
end
```

Algorithm 2, depicts the coverage-load based algorithm for entering users, which enhances Algorithm 1 when usr_{enter} is true replacing lines 5-9. Besides a detailed user profile and network resource availability, the management system maintains a set of coverage overlapping femtocells S_{fo} for each user with respect to the associated office location considering the his network permissions. For incoming users the system retrieves the usr_{id} and all related data before checking whether any of the associated femtocells are already in use. If all powered-off, i.e. $(S_{fo} \cup f_o) \cap S_{pon} = Ø$, the algorithm selects to powers-on the user's office femtocell f_o and performs the related network resource $R(f_o)$ and S_{pon} updates.

In case the $f_o \cup S_{fo}$ set, contains powered-on femtocells, the algorithm tries to accommodate the incoming user on a femtocell f_s with the minimum resource consumption $R(f_s)$, in order to distribute the load. If the resources are adequate for the user demand, i.e. $R(f_s) + u_{rs} < C_f$ are below the upper bound resource limit, the related resource updates are performed and the selected femtocell f_s is stored in usr_{id}, which keeps track of the user's location. Otherwise, the algorithm checks whether there are more femtocells currently powered-off that can accommodate the user, i.e. $(f_o \cup S_{fo}) - S_{pon} \neq Ø$. If that is the case, then the one with the minimum distance from the user's office, which provides radio efficiency is powered-on followed by all related updates.

When none of the potential femtocells that can accommodate the incoming user have sufficient resources, the algorithm needs to shift selected users camping at S_{fo}, towards further overlapping femtocells beyond S_{fo}, creating in this way adequate resources. To accomplish this, the algorithm initially retrieves from each femtocell f_n in S_{fo} the set of its further overlapping neighbors O_{fn} considering also powered-off femtocells to assure a solution, and then calculates the summarized resource availability $S_R(f_n)$, for f_n *in* O_{fn}. The maximum $S_R(f_n)$ femtocell referred to as f_n is selected to shift a part of its camping user load, starting from the maximum resource consumption user, towards a target femtocell f_t with the minimum resource consumption, waking it up first if powered-off. For each handed over user the related resource updates are performed and f_t is stored in usr_{id} to reflect the new user location. This process is carried out until adequate resource are established, i.e. $u_{rs} + R(f_h) > C_f$, and then the associated updates are performed.



Algorithm 3 Coverage-Load based Algorithm: Leaving Users

```
 1: $usr_{id} \leftarrow (f_c, u_{rs}, u_{pr})$; $f_c(u_{pr}) \leftarrow (S_{f_c}, P_{f_c})$;
 2: $R(f_c) = R(f_c) - usr_{rs}$;
 3: if $R(f_c) = 0$
 4:     $S_{p_{off}} \leftarrow S_{p_{off}} \cup f_c$;
 5: else
 6:     foreach $usr_{id}$ camping at $f_c$
 7:         $usr_{id} \leftarrow (f_c, u_{rs}, u_{pr})$; $f_c(u_{pr}) \leftarrow (S_{f_n}, P_{f_n})$;
 8:         $t\text{-}usr_{id} = usr_{id}$;
 9:         $R_T(f) = R(f), \forall f \in (f_c, S_{f_n})$;
10:         $f_t \leftarrow f \in S_{f_n}$ with min $R_T(f)$;
11:         if $R_T(f_t) + u_{rs} < C_f$
12:             $R_T(f_t) = R_T(f_t) + u_{rs}$; $R_T(f_c) = R_T(f_c) - u_{rs}$;
13:             $t\text{-}usr_{id}(f) = f_t$;
14:         else
15:             exit foreach loop
16:         end
17:     end
18:     if $R_T(f_c) = 0$
19:         $R(f) = R_T(f), \forall f \in (f_c, S_{f_n})$;
20:         $usr_{id} = t\text{-}usr_{id}, \forall usr_{id}$ camping at $f_c$;
21:         $S_{p_{off}} \leftarrow S_{p_{off}} \cup f_c$;
22:     end
23: end
```

When a user leaves the building, the management system checks the potential of powering-off the associated femtocell. Algorithm 3 illustrates the coverage-load based algorithm for leaving users that advances Algorithm 1 when usr_{leave} is true, replacing lines 11-15. Once a user leaves the network, the algorithm gets the usr_{id} and related information. It then decreases the resource consumption of the associated femtocell $R(f_c)$ by the user demand u_{rs} and if $R(f_c)=0$, it powers it off. Otherwise, it examines the potential of handing over all currently camping users towards neighbor overlapping femtocells, before fc is powered-off in order to avoid performing a significant amount of handovers without a guarantee benefit.

To explore such a potential, the algorithm introduces temporary variables that aim to hold changes caused by the handover users. Specifically, for each user camping at fc, the algorithm retrieves its usr_{id} and based on that the overlapping femtocells S_{fn} that can accommodate such user. Then it assigns two temporary variables referred to as $t\text{-}usr_{id}$ and $R_T(f)$ to hold the user data and femtcells resource updates respectively. The algorithm then selects as target handover femtocell f_t the one with the minimum resource consumption $R_T(f)$ and as long as its resources can accommodate handover users, the appropriate updates are performed on the temporary variables. Otherwise, upon a single user failure the process is abandoned. In case all users are successfully handed over, the algorithm updates the corresponding usr_{id} and $R(f)$ variables based on the temporary ones. Pre-arranged appointments, where a set of users leave their office for given times gathering into a meeting room, are also exploited in terms of energy saving following the same procedure. In practice, the proposed algorithms should be complemented to handle user deviations by having nearby femtocells along the expected path in a rapid activation mode, i.e. powered-on with reduced radio capabilities.

D. User-Context Based Algorithm

The user-context based approach introduces further enhancements, considering user statistics. The management system monitors daily user actives, i.e. entering and leaving the building, having also access to user's electronic calendar, considering appointments and absences. Based on such statistics, the user-context algorithm derives a sorted sequence or simply a preference for powering-on/off certain femtocells before others, exploiting user specific knowledge in combination with femtocell overlapping coverage. Such a sequence aims to replace the minimum resource consumption or minimum distance femtocell selection criteria introduced in Algorithm 2 lines 6 and 11. For the user leaving scenario, it determines the optimal user camping femtocell before the algorithm execution and guides the handover process replacing the minimum resource selection of Algorithm 3 line 10. Establishing such sorted femtocell sequence is an off-line activity, performed rarely once user statistics change significantly.

Algorithm 4 shows a pseudocode version of the user-content based algorithm that provides the optimal sequence for powering-on the enterpise femtocells considering all potential solutions. The algorithm initiates with an empty solution set *Sol*, with each solution S_{cnt} holding two variables that enable the algorithm to check feasibility and performance. One variable relates to the resource consumption of each femtocell, $S_{R(f)}$, enabling the algorithm to check the solutions feasibility and another referred to as $L_{ft}=(f,t)$ maintains a sorted list of femtocells that were powered-on and a record of the corresponding time used for performance evaluation. Solutions that violate network resource availability are not recorded on the *Sol* set. The management system supplies the algorithm with a sequence of incoming users U_{in}, derived from monitoring statistics, which is essential for determining the sorted list of powering-on the enterprise femtocells.

Algorithm 4 User-Content based Algorithm

```
$Sol = \emptyset$; $S_0 = (S_{R(f)}, L_{ft})$;
$S_{R(f)} = (R(f_1), R(f_2), ...R(f_m)) = (0, 0, ...0)$;
$L_{ft} = (f, t) = \emptyset$; $Sol \leftarrow Sol \cup S_0$;
foreach $usr_{id} \in U_{in}$
    $usr_{id} \leftarrow (f_o, u_{rs}, u_{pr}, u_t)$; $f_o(u_{pr}) \leftarrow (S_{f_o}, P_{f_o})$;
    $N_{Sol} = \emptyset$; $cnt = 0$;
    foreach $S \in Sol$
        foreach $f \in S_{f_o}$
            $cnt = cnt + 1$; $nS_{cnt} = S$;
            if $R(f) + u_{rs} < C_f$
                if $R(f) = 0$
                    $nS_{cnt}(L_{ft}) \leftarrow$ concat $L_{ft}$ $(f, u_t)$;
                end
                $nS_{cnt}(S_{R(f)}) \leftarrow R(f) = R(f) + u_{rs}$;
            end
            $N_{Sol} \leftarrow N_{Sol} \cup nS_{cnt}$, for unique $nS_{cnt}$;
        end
    end
    $Sol = N_{Sol}$;
end
$Opt_{Sol} \leftarrow Sol$ with max $\sum_{S \in Sol} S(L_{ft}(u_t))$;
```

A solution S_0 with the network being idle, i.e. $R(f)$=0, forall f within $S_{R(f)}$ and with L_{ft} being empty is specified as a starting point. For each user in U_{in}, the algorithm retrieves the usr_{id} and hence all related data, including a new variable u_t, which holds the user entering time based on monitoring statistic to compare the performance of different solutions. The algorithm creates an empty solution set N_{Sol} with the same properties as *Sol*, which holds new solutions as evolve based on the previous ones during the consideration of each incoming user and a count variable *cnt*, to distinct them. For each current solution S_{cnt} in *Sol*, the algorithm considers all potential femtocells S_{f_o} and examines whether their resource availability can accommodate the user demand, i.e. $R(f)+u_{rs} < C_f$. A new solution nS_{cnt} based on each current one *S* is created to record the impact of the incoming user.

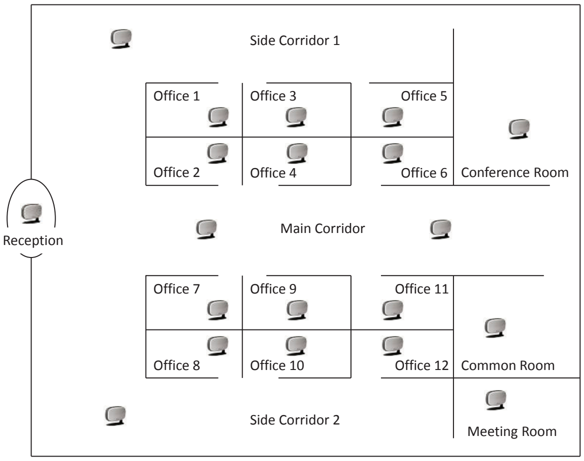
Once a specified femtocell can accommodate the user, the algorithm checks if it is powered-off, i.e. $R(f)$=0, before updating its resources based on the user demand u_{rs}. Newly powered-on femtocells are recorded including the corresponding powered-on time based on u_t, in the L_{ft} variable of the nS_{cnt} solution, concatenated at the end of the list, which is kept in this way sorted. The resources of the femtocell that accommodated the incoming user are then updated according to the user demand and a record is kept at the $S_{R(f)}$ variable of the nS_{cnt} solution. New solutions are then kept at the N_{Sol} set, which maintains non duplicated, but only unique solutions. Once all current solutions are examined, with respect to the incoming user encountering all potential femtcells, the new solution replaces the current, Sol=N_{Sol} and the process continues with the next user until all users are considered. The optimal solution is then specified as the solution in *Sol* with the maximum summarized time $L_{ft}(u_t)$ or higher average delay in powering-on the enterprise femtocells, considering only solutions where all users are accommodated. A similar process is also adopted for the user leaving scenario considering the leaving user sequence and following the same process, with the difference that the optimal solution is the one with the minimum summarized time for smallest operation durations.

IV. SIMULATION SETUP AND ANALYSIS

In order to base our simulations on real energy consumptions measures, we analyzed two state of the art femtocells, from Ubiquitous and Sagem. We measured their respective energy consumption at 12V not accounting for the power loss on the 220V power converter. Once the system is turned on, the measurements vary between 500mA and 650mA. The attachment of UEs to the femtocell show none measurable increase in the power consumption, and user activity, e.g. video streaming, adds about 20mA. Thus, the main source of power consumption is keeping a femtocell powered-on, which shapes the objective of our simulation study.

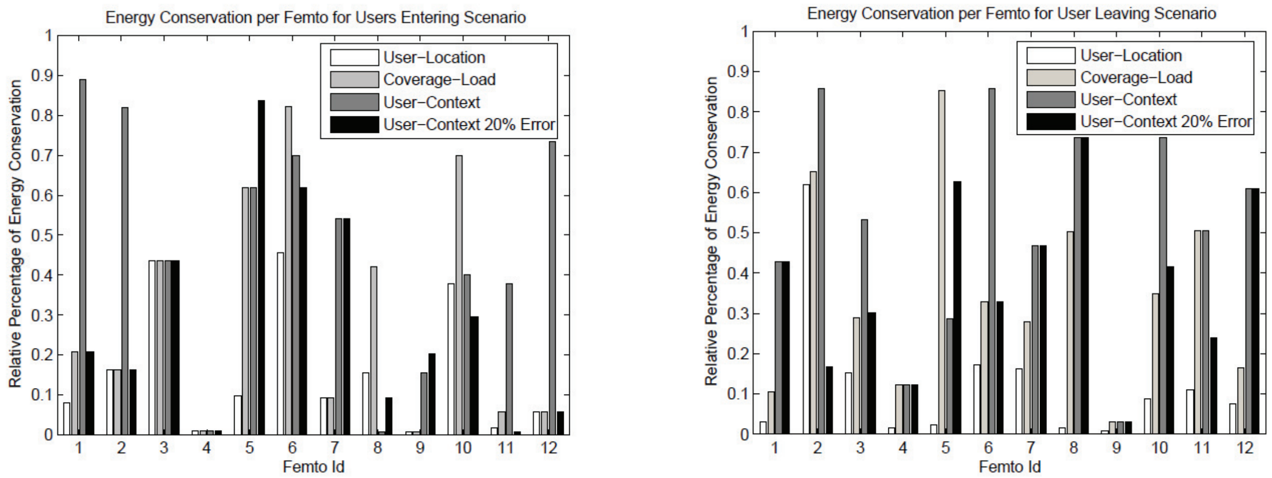
A. Simulation Setup

The simulation study was performed using Matlab employing the femtocell network illustrated in Fig.2, which represents a typical enterprise environment that contains a reception area, three corridors that connect the reception with individual offices as well as a common, meeting and conference room. The reception area is equipped with an always on femtocell that communicates entering or leaving user related information with the energy management system.



Enterprise Femtocell Network

Fig. 2: Simulation Topology



(a) (b)

Fig. 3. Femtocell energy conservation: (a) User entering scenario, (b) User leaving scenario.

The core of the enterprise network consists of twelve offices, each equipped with a femtocell that may accommodate up to four users, forty-eight in total, with individual users being located close to the corner area of every office. Adjacent femtocells are assumed to overlap, allowing users located next to neighboring offices to potentially be served by the corresponding neighboring femtocell with negligible additional cost. Users are also assumed to hold an electronic calendar that indicates their absence and meetings information.

Each femtocell may accommodate a pre-determined upper bound load, which is measured with respect to the number of users for simplicity purposes, four users in particular, assuming that users have equal resource demands. Users may enter and leave the network within a certain times, which correspond to the time when the enterprise building opens until the time when all users have to be in and from the time that users start leaving the building until the time that the building is officially closed. Such a time frame is further referred to as *energy activity period*. We quantize the energy activity period in the interval of [0,1] for each of the entering and leaving scenario separately. Arriving and leaving users are allocated a random time within the energy activity period. We simulated the scenarios where users enter and leave the building considering (i) all users to be present, i.e. no absences, (ii) certain percentage of users being absent and (iii) certain users participating in meetings, assuming that user context information may also be extracted from their electronic calendar entries.

Considering the scheduled-based approach as the base method, the following three different energy saving approaches were studied including: (i) user-location based according to the user office position, (ii) coverage-load based that blends user location, load and coverage and (iii) user-context, which takes additionally into account sequence statistics of entering and leaving users. For the user-context approach we considered a scenario where the user statistics accurately predicts the actual user entering and leaving times and an additional scenario with 20% error, since in practice it is difficult to predict accurately user specific patterns.

B. Results Analysis

To demonstrate in depth the behavior of the proposed schemes, we considered both a particular simulation instant, given a certain entering and leaving sequence of users, and an average case, repeating the process a number of times. Instant performance measures provide a qualified analysis, i.e. how and why one scheme is better than the other, while average measures capture a quantified comparison, i.e. how much better a scheme is with respect to another. We compare the different approaches focusing on the energy saving of office femtocells only, without considering the corridor and common area ones against the following criteria:

- **Relative energy conservation percentage**: the amount of time that a certain femtocell is powered-off with respect to the energy activity period.
- **Update overhead**: indicates the amount of additional handovers during the energy activity period.
- **Complexity**: a measure of time and computing resources for executing each energy saving strategy or algorithm.

Fig.3 depicts the relative energy conservation percentage of each femtocell for a simulation instant considering both user entering and leaving scenario, assuming no user absences. The x-axis represents the femtocell identity of the corresponding office in the simulation topology of Fig.1. The relative percentage of energy conservation, i.e. the y-axis, indicates how much more energy efficient each proposed method is compared to the conventional scheduled-based strategy. Both Fig.3(a) and Fig.3(b) demonstrate the energy conservation of the proposed approaches for each femtocell, verifying the significant contribution of the increased user context information in operating efficiently the enterprise network. Considering the overall energy conservation of the enterprise network, the user context algorithm outperforms the coverage-load, which is followed by the user-location based one.

However, examining each individual femtocell, it is observed that the coverage-load approach always outperforms the user-location based algorithm, while the same is not true for the user-context one, e.g. femto id 6, 8 and 10 Fig.3(a) and femto id 5 Fig.3(b). This demonstrates their fundamental difference, which concentrates on the type of information considered. In particular, the coverage-load reactively manages the energy efficiency, i.e. once a user is about to enter or leaves the building then a decision is made. In contrast, user-context is proactive, i.e. identifies femtocells to power-on/off that can conserve energy for the complete network in the long term, based on prediction information regarding the network resource usage. Thus, although it powers-on/off certain femtocells earlier even than user-location based one, such selection ensures a higher overall energy conservation. Considering the user-context with the 20% error, we observe that its performance is considerably low compared to the ideal user-context case, but still it outperforms the coverage-load based equivalent. The reason behind this is the fact that only errors related to certain key users have a significant effect on the energy performance of the system. Thus, the user-context approach is kind of robust to relatively small errors in predicting the user behavior.

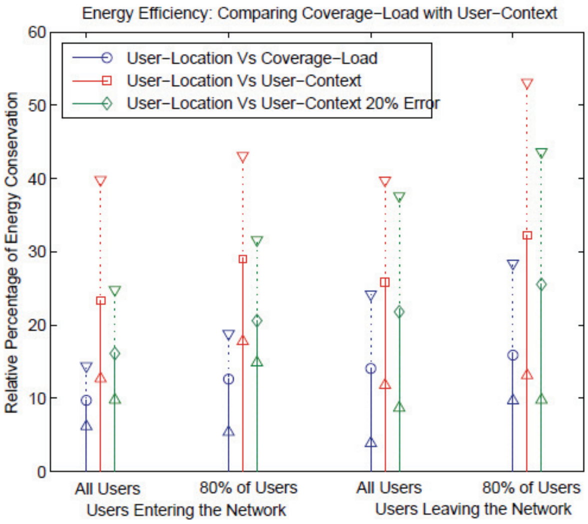


Fig. 4. Average energy saving for entering/leaving scenarios.

The average energy conservation percentage considering 100 samples is depicted in Fig.4, showing also the maximum and minimum range of each proposed method. In this case, the relative energy conservation percentage represents how much more efficient each algorithm is compared to the user-location approach. Both user entering and leaving scenarios are considered with all and 80% of the users being present according to electronic calendar entries. The results clearly demonstrate the superiority of the user-context algorithm under all encountered scenarios and also illustrate that although its performance under 20% error decreases compared to the ideal case, it is still greater than the coverage-load based equivalent. On average considering all scenarios, the user-context algorithm is around 30% more energy efficient compared with the equivalent coverage-load based one, which corresponds to around 2Wh savings per femtocell assuming an energy activity period of 1 hour. In general, the difference between coverage-load and user-context is greater when 80% of the users present. This is because the user-context approach can proactively use the absence information to manage the operation of the network, while the coverage-load based one just uses such information reactively. In addition, the user-context approach may provide better selection for powering-on/off certain femtocells, because it has more long term information regarding the traffic distribution of incoming and leaving users.

We also observe from Fig.4 that the proposed energy management strategies and algorithms are more effective for the leaving scenario compared to the entering, because there is more room for improvement by shifting users among neighboring femtocells. Considering the user-context approach, it is worth noting that the performance difference among ideal and 20% error is greater for the user entering scenario compared to the leaving one. Hence, the entering scenario is more sensitive to errors, which may result in powering-on unnecessarily femtocells, while for the leaving one; errors may slightly delay powering-off certain femtocells because of handing over users towards a sub-optimal location.

The update cost associated with the number of handovers in relation with each proposed energy management strategy and algorithm is summarized in the Table 1 for the entering and leaving scenario assuming no user absences. In the table the entries represent the average amount of handovers in the complete enterprise network. Based on the results it is clear that besides the user-location approach with no update overhead, all the rest introduce a handover cost, with the user-context scheme being the most efficient considering the overall handover amount even when there is a 20% prediction error. It is worth noting that the user-context approach mainly improves the handover cost for the entering scenario, while for leaving one its cost is similar to the coverage-load one.

Sim-Sn	User-Loc	Cov-Loc	User-Cont	20% Error
Enter	0	9.1	3.4	5.8
Leave	0	15.4	16.8	18.7

Table 1: Update cost handover overhead.

Considering the algorithmic complexity, the scheduled based approach introduces no processing, hence zero complexity, while the user-location $O(1)$ to retrieve each user identity. For the incoming users, the coverage-load algorithm needs to examine all potential femtocells V_p introducing $O(V_p)$ complexity, while for each leaving user it checks whether the remaining users can be handed over, a process again with $O(V_p)$ complexity. Considering the user-context algorithm, the femtocell sequence is calculated based on all combinations of potential femtocells with respect to each user u, a process with complexity $O(V_p^u)$. Although high, in practice femtocell groups that overlap with a relatively small number of users are considered independently reducing in this way such complexity. Additionally, the user-context algorithm can be executed as background, relatively infrequently only upon a significant change and whenever convenient.

To evaluate our energy proposed strategies and algorithms against meeting scenarios, we initiate a simulation scenario assuming all users present to their offices and then a certain percentage of users at a short time frame join a pre-determined meeting to the appropriate meeting/common/conference area. Once users move to the corresponding meeting location, we compare the proposed energy saving schemes based on the percentage of powered-off office femtocells. Fig.5 illustrates the energy conservation percentage enhancement of the proposed algorithms compared to the scheduled-based one for a range of different user's percentage participating in a meeting.

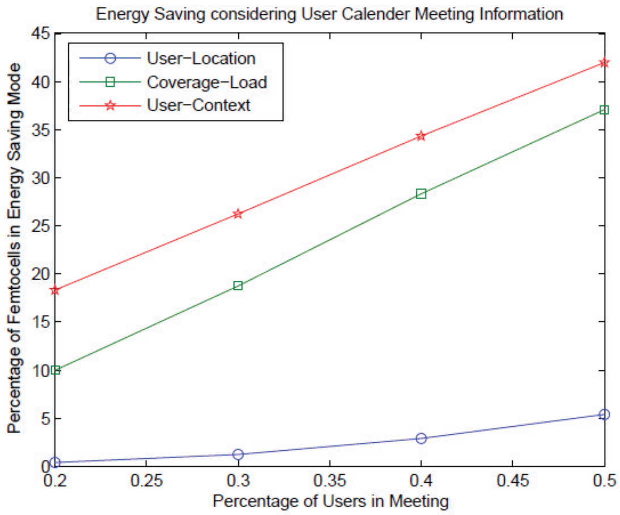


Fig.5: Energy saving under various meeting scenarios.

Once again the user-context algorithm outperforms the remaining, but this time its performance is relatively close to coverage-load one, especially as the percentage of users involved in a meeting grows. The reason behind this is the fact that for smaller user percentages in meetings, the user re-association, i.e. via handover among neighboring femtocells are fewer, hence enhanced information results in higher quality solutions. As the percentage of users in meeting increases and the potential solution options grow, the coverage-load based approach may produce comparable results as the user-context one. It should be noted that the user-location based approach has a poor performance within this scenario mainly because of its inability to handover users towards neighbor office femtocells.

V. CONCLUSIONS

In this paper we introduced an energy management framework for operating an enterprise femtocell network. It utilizes user context information such as user identity, past user behavior statistics and access to electronic calendar information to predict which set of office femtocells should be powered-on to provide indoor users in with continuous connectivity and QoS provision. We deployed four strategies for that framework with different levels of information and assessed their power conservation gains considering also handover and complexity costs. Our simulation study revealed that the higher the amount of information considered the higher the power conservation, at the cost of increased overhead and/or complexity. Specifically, the proposed user-context approach outperforms all others even under inaccurate user prediction circumstances. The main reason behind that is the enhanced user prediction knowledge that allows the management system to perform proactive resource allocation making even better use of electronic calendar entries. Additional simulations studies considering the user varying activity and in building mobility are for further study.

ACKKNOWLEDGEMENT

The research leading to these results has been funded by the European Commission under the grant agreement number ICT-4-248523 (BeFEMTO Project)

REFERENCES

[1] Femtocell Forum, Femtocell Market Status, Dec 2011.

[2] A.P. Jardosh, et .al, "Green WLANs: On-Demand WLAN Infrastructures", ACM/Kluwer MONET, Vol.14, No.6, Dec 2009.

[3] 3GPP TS 32.551, Telecommunication management; Energy Saving Management (ESM); Concepts and Requirements, Mar 2011.

[4] 3GPP TS 23.401, General Packet Radio Service Enhancements for Evolved Universal Terrestrial Radio Access Network Access, Dec 2011.

[5] D. Calin, H. Claussen, H. Uzunalioglu, "On Femto Deployment Architectures and Macrocell Offloading Benefits in Joint Marco-Femto Deployment", IEEE Communication Magazine, Vol.48, No.1, Jan 2010.

[6] K. Samdanis, T. Taleb, S. Schmid, "Traffic Offload Enhancements for eUTRAN", IEEE Communication Surveys and Tutorials, Vol.14 , No.3, Third Quarter 2012.

[7] K. Zheng, Y. Wang, W. Wang, M. Dohler, J. Wang, "Energy-Efficient Wireless In-Home: The Need for Interference-Controlled Femtocells", IEEE Wireless Communications, Vol.18, No.6, Dec 2011.

[8] G. de la Roche, et.al,"Self-Organization for LTE Enterprise Femtocells", Globecom Workshop on Femtocell Networks, Miami, Dec 2010.

[9] 3GPP R3-081174, Solution for Interference Reduction SON Use Case, TSG-RAN WG3#61, Kansas City, May 2008.

[10] I. Ashraf, et.al,"SLEEP Mode Techniques for Small Cell Deployments", IEEE Communication Magazine, Vol.49, No.8, Aug 2011.

[11] K. Samdanis, et.al, "Energy Management SON functions for Cellular Urban Networks", ACM/Kluwer MONET, Vol.17, No.1, Feb 2012.

[12] M.A. Marsan, et.al, "A Simple Analytical Model of Access points in Dense WLANs", e-Energy, Passau, Apr. 2010.

[13] J. Lorincz, A. Capone, D. Begusic, "Optimized network management for energy savings of wireless access networks", Computer Networks, Vol.55, No.3, Feb 2011.

[14] F. Mhiri, et. al., "SOCS: A Self-Optimized Coverage Scheme for Femto-Enterpise Deployment", IFIP Wireless Days, Niagara Falls, Oct 2011.