AN OPTIMIZATION MODEL FOR ALLOCATION OF NETWORK USERS IN MACRO-FEMTO NETWORKS

An Approach based on Energy Efficiency and Quality of Service

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Keywords: Femtocell, Mobile, Optimized Allocation, Markov Decision Process, Quality of Service.

Abstract: The femtocell concept aims to combine fixed-line broadband access with mobile telephony using the deployment of low-cost, low-power third generation (3G) base stations in the subscribers' homes. While the self-configuration of femtocells is a plus, it can limit the quality of users and reduce the efficiency of the network, based on outdated allocation parameters such as signal power level. To this end, this paper presents a proposal for optimized allocation of users on a macro-femto network, aiming to minimize the consumption of battery without affecting the quality of service of applications. Markov Decision Process Theory is used to model the system, which is modeled as observed by the user's side. So, when the user needs to connect to make a voice call or a data call, the mobile phone has to decide in which network to connect, using the information of number of connections, the quality of service parameters and the signal power level of each network.

1 INTRODUCTION

Studies conducted in recent years have revealed the explosive growth of wireless communications raised by technological advances in the telecommunication industry.

The femtocell technology obtained much attention from researchers, especially focusing on how they can be used to improve voice services in coverage limited locations (Chandrasekhar *et* al., 2008); however, broadband data services are an increasingly significant source and percentage of the mobile operator's business.

Femtocells have a strong potential to improve the capacity of next generation wireless systems since they offer better link qualities and wider spectrum resources for connected users. Scheduling in femtocell networks involves more complications due to involvement of multiple (typically co-channel) small-size cells, as well as the macro-cell. In addition, associating users to appropriate frequency bands for achieving high capacity and fairness, intelligent assignment of users to different cells is also required. These unique problems in femtocell networks require intelligent scheduling algorithms that can present a good compromise between maximization of the fairness and the sum-rate (Ertürk *et* al., 2010).

This problem becomes more complex when the battery consumption of client nodes and the QoS (Quality of Service) requirements are considered to decide in which cell the client should connect. Traditionally, the decision is based on the signal power (connect on the cell with higher signal power, whether it is a macro cell or femtocell) without considering if the output meets the minimum QoS requirements.

This proposal also targets Green Networking, which is the practice of selecting energy-efficient networking technologies and products, and minimizing resource use whenever possible (SearchNetworking, 2009). It should be noted that maximizing the energy efficiency of the nodes is a key factor, however this is not the only one that should be considered; The maximization of user satisfaction should also be pursued.

In such context, planning for the allocation of users by operators in their cells, macro or femto, carries critical importance for minimizing

Cardoso D., Silva M., Santana A., Francês C., Carvalho S. and Vijaykumar N..
AN OPTIMIZATION MODEL FOR ALLOCATION OF NETWORK USERS IN MACRO-FEMTO NETWORKS - An Approach based on Energy Efficiency and Quality of Service.
DOI: 10.5220/0003953202090214
In *Proceedings of the 1st International Conference on Smart Grids and Green IT Systems* (SMARTGREENS-2012), pages 209-214
ISBN: 978-989-8565-09-9

interference, maximizing the system capacity, achieving fairness in femtocell networks and maximizing network utilization (Ertürk *et* al., 2010).

Several works in literature has already proposed how to achieve high capacities with fair scheduling techniques for conventional cellular architectures. For example, (Zhang and Letaief, 2004) aims to maximize the sum-rate of all the users within a cellular network; however, fairness issues have not been considered. A maximum fairness technique has been discussed in (Rhee and Cioffi, 2000), which essentially tries to maximize the capacity of the user that has the lowest data rate and achieve similar data rates for all users.

In terms of capacity overflow, some proposed architectures and schedulers have been proposed. In (Chung and Lee, 2005) and (Hu and Rappaport, 1995.), models based on Markov-modulated Poisson Process (MMPP) were employed for representing multiservice overflow traffic. However, extensive computations are required by a MMPP method to solve multi-dimensional Markov chains for large scale systems.

Relative to Green communication it can be highlighted (Liao and Yen, 2009), where it is proposed the power-saving scheduling of base stations (BS) considering QoS requirements (delay and jitter) of the real-time communications in WiMAX network. Also in (Han *et* al., 2010) several radio management scheduling algorithms are evaluated for the long term evolution (LTE) BSs, and effectively exploits multi-user diversity in the time, frequency and space domains for LTE networks. The works in the area were found to focused mainly on the energy efficiency of macro cells and core network, with no much attention devoted to maximizing the use of battery of client nodes, considering aspects of QoS and signal level.

2 FEMTOCELL

2.1 Definition and Characteristics

Femtocells are devices used to improve mobile network coverage in small areas, connected locally to mobile phones and similar devices through their 2G (GSM), 3G (UMTS) or 4G (WIMAX or LTE) connections, and then route the connections over a broadband internet connection back to the carrier, bypassing the normal cell towers (ERBs or nodeBs).

This technology creates a bridge between mobile and personal wired networks, using a high speed internet connection (either personal or enterprise) to link to the operators macro-network. Doing this, it is easier to extend access to mobile network, providing better coverage for the population (especially in areas where there was no signal or weak signal arrived), and providing high bandwidth to users.

2.2 Problem Description

Femtocells are typically installed by non-expert users, which do not consider the network's performance; simply connecting a Femtocell Acess Point to DSL (Digital Subscriber Line) and turning it on. Femtocell Acess point self-organizes its radio and system operational parameters (Holger *et* al., 2008)(John and Holger, 2009). The node client automatically tries to associate the Femtocell Acess Point with strongest signal, however this choice becomes unfair in two aspects:

1. Considering the capacity of the Femtocell Access Point, which can become overcrowded and can not serve new users, maintaining the quality of service. This can lead to an unbalanced load, overloading a femtocell against each other;

2. Given the choice of allocation by the customer, the network setting only by the signal power level may not meet the quality requirements of the user, which could obtain a better service through another network near, even at a higher cost battery. This fact is aggravated when considering the diversity of existing applications, which have different requirements for quality of service.

3 MARKOVIAN MODEL

3.1 Markov Decision Process

The problem is formulated as a Continuous Time MDP (CTMDP), since it considers that the times (between requests arrival and that a request stay in the system) follow an exponential probability distribution. Also, the problem is formulated as an Infinite Horizon problem, since it can perform for a long, undefined period of time.

Briefly, to model a problem as a CTMDP, it is necessary to define (Puterman, 1994):

- The state space S: the set of all possible conditions of the system;
- The sets of actions $\{A(s) \mid s \in S\}$: for each state $s \in S$, there is a set of possible actions $A(s)$, in which the operator must choose a single action at every decision time;

- The set of costs $\{c(s, a) \mid s \in S, a \in A(s)\}$: where $c(s, a)$ is the cost entailed to the system when it is in $s \in S$ and the action $a \in A(s)$ is chosen;
- A set of transitions probabilities $\{p_{sz}(a) \mid s,z \in S, a \in A(s)\}$: where $p_{sz}(a)$ is the probability that, in the next decision time, the system is in state $z \in S$, given that action $a \in A(s)$ is chosen when it is in the state $s \in S$;
- $\{\tau(s,a) \mid s \in S, a \in A(s)\}$: expected time until the next decision time if the action $a \in A(s)$ is chosen in state $s \in S$.

Using these five elements, the stationary optimal policy R^* that minimizes the long-run average cost per time unity can be calculated by some classical techniques, e.g. Value Iteration Algorithm and Policy Iteration Algorithm (Tijms, 1994).

3.2 Network Architectures and Traffic Assumptions

A typical femto-macro mobile network, with cells providing wireless access for mobile users through macrocell or femtocell access points, is assumed. The architecture used is shown in Figure 1.

The arrivals of calls can be answered by both networks, which have different distances for the mobile nodes, different bandwidths, different losses and different maximum users that can be connected. When a new call arrives to the system, parameters such as the energy consumption when connected, the available bandwidth and packet loss probability of each networks, are used to decide which network should be chosen to serve the call. If new calls are blocked due to capacity limitation, they overflow to the other network for possible service.

Two service classes access the network: voice and data. These are formed by new calls and handoff calls. The requests arrive in the system according to two Poisson processes, with parameters λvn and λdn, for voice and data respectively; where n indicates if the request is to connect to macrocell or femtocell, or if it is a request that have to be decided to which cell it should connect.

The service times of voice calls and data packets follow exponential distributions with parameters μvn and μdn, respectively. Also, there is no differentiation between voice and data channels.

It is important to clarify that the system is modeled as observed by the user. So, when the user needs to connect to make a voice or a data call, the mobile phone has to decide in which network to connect, using the information of number of connections, the quality of service parameters and the signal power level of each network. The signal power level can be obtained directly, but the other variables need to be enquired to the system

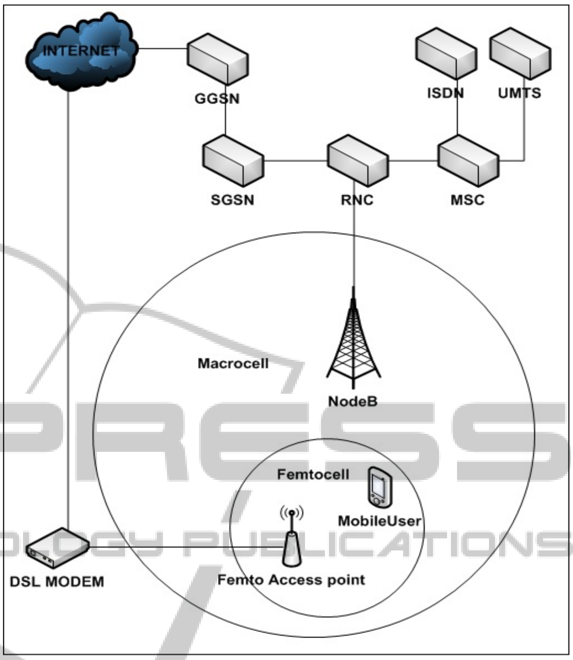

Figure 1: Typical macro-femto scenario that is being taken into consideration.

3.3 Model Formulation

Each state $s \in S$ is defined as:

$$
\begin{aligned}
& s = (v_1, d_1, v_2, d_2, c, k, ev) \\
& \textit{subject to} \\
& \quad v_1, d_1 \in \{0,1,2, ..., MaxCR_1\} \\
& \quad v_2, d_2 \in \{0,1,2, ..., MaxCR_2\} \\
& \quad c \in \{desc, C1, C2\} \\
& \quad k \in \{desc, VOICE, DATA\} \\
& \quad ev \in \{\lambda_{v1}, \lambda_{d1}, \lambda_{v2}, \lambda_{d2}, \lambda_{vu}, \lambda_{du}, \mu_{v1}, \mu_{d1}, \mu_{v2}, \mu_{d2}, \mu_{vu}, \mu_{du}\} \\
& \quad v_1 + d_1 < MaxCR_1 \\
& \quad v_2 + d_2 < MaxCR_2 \\
& \quad \textit{if } c = desc \textit{ then } k = desc \\
& \quad \textit{if } c \neq desc \textit{ then } k = VOICE \textit{ or } DATA \\
& \quad \textit{if } k = VOICE \textit{ then } ev \neq \lambda_{vu} \textit{ and } \lambda_{du} \textit{ and } \mu_{du} \\
& \quad \textit{if } k = DATA \textit{ then } ev \neq \lambda_{vu} \textit{ and } \lambda_{du} \textit{ and } \mu_{vu} \\
& \quad \textit{if } c = C1 \textit{ AND } k = VOICE \textit{ then } v_1 > 0 \\
& \quad \textit{if } c = C1 \textit{ AND } k = DATA \textit{ then } d_1 > 0 \\
& \quad \textit{if } c = C2 \textit{ AND } k = VOICE \textit{ then } v_2 > 0 \\
& \quad \textit{if } c = C2 \textit{ AND } k = DATA \textit{ then } d_2 > 0
\end{aligned}
$$

$$
\begin{aligned}
&\text{if } ev = \mu_{v1} \text{ then } (v_1 = 1 \, AND \, (c = desc \, OR \, c = C2 \, OR \, k = DATA)) \\
&\qquad\qquad OR \, v_1 > 1 \\
&\text{if } ev = \mu_{d1} \text{ then } (d_1 = 1 \, AND \, (c = desc \, OR \, c = C2 \, OR \, k = VOICE)) \\
&\qquad\qquad OR \, d_1 > 1 \\
&\text{if } ev = \mu_{v2} \text{ then } (v_2 = 1 \, AND \, (c = desc \, OR \, c = C1 \, OR \, k = DATA)) \\
&\qquad\qquad OR \, v_2 > 1 \\
&\text{if } ev = \mu_{d2} \text{ then } (d_2 = 1 \, AND \, (c = desc \, OR \, c = C1 \, OR \, k = VOICE)) \\
&\qquad\qquad OR \, d_2 > 1 \\
&\text{if } ev = \mu_{vu} \text{ then } k = VOICE \\
&\text{if } ev = \mu_{du} \text{ then } k = DATA
\end{aligned}
$$

Where:

- v_1 and d_1 are the number of voice and data connections, respectively, on macrocell;
- v_2 and d_2 are the number of voice and data connections, respectively, on fentocell;
- c indicates if the user is disconnected or connected to a macrocell or fentocell;
- k is the type of applications;
- ev is the last event;
- $MaxCR_1$ and $MaxCR_2$ are the maximum number of connections in the macrocell and femtocell, respectively;
- λv_1 *and* λv_2 are the voice calls arrival rates in macrocell and femtocell, respectively.
- λd_1 *and* λd_2 are the data calls arrival rates in macrocell and femtocell, respectively.
- λv_u *and* λv_u are the user arrival rates for voice and data, respectively, which have to be decide if connect on macrocell or femtocell.
- μv_1, μv_2, μv_u are the service rates of voice calls in macrocell, femtocell and that was allocated by the user, respectively.
- μd_1, μd_2, μd_u are the service rates of data requests in in macrocell, femtocell and that was allocated by the user, respectively.

The set of possible actions $A(s)$ for each state $s \in S$ is:

$$
A(v_1, d_1, v_2, d_2, c, k, ev) =
\begin{cases}
0 & \text{if } ev \notin \{\lambda vu, \lambda du\} \\
 & OR \text{ if } ev \in \{\lambda vu, \lambda du\} \; AND \; (v1 + d1 = MaxCR_1) \; AND \; (v2 + d2 = MaxCR_2) \\
1, 2 & \text{if } ev \in \{\lambda vu, \lambda du\} \; AND \; (v1 + d1 < MaxCR_1) \; AND \; (v2 + d2 < MaxCR_2) \\
1 & \text{if } ev \in \{\lambda vu, \lambda du\} \; AND \; (v1 + d1 < MaxCR_1) \; AND \; (v2 + d2 = MaxCR_2) \\
2 & \text{if } ev \in \{\lambda vu, \lambda du\} \; AND \; (v1 + d1 = MaxCR_1) \; AND \; (v2 + d2 < MaxCR_2)
\end{cases}
$$

Where:

- *0* indicates that there is no action to choose. In this case, if the last event is not a request from the user ($ev \notin \{\lambda vu, \lambda du\}$), the decision is to connect while there is at least one free channel. Otherwise, if the last event is a request from the user ($ev \in \{\lambda vu, \lambda du\}$), but both networks are full, then reject the request;
- *1* indicates that the user should connect to the macrocell;
- *2* indicates that the user should connect to the femtocell.

To compute the expected time until the next decision epoch, transitions probabilities and the costs, the following algorithm can be used:

```
Algorithm CalcTransitionProbabilities
Input: state sf and action a.
Output: τ - expect time until the next
        decision epoch;
        psfst(a) - the probability to move
        from state sf to each state st;
        cost – the cost entailed when
        action a is chosen in state sf.
Begin
   pd←0; τ ← 0; cost ← 0;
   v1←sf.v1; d1←sf.d1; v2←sf.v2;
   d2←sf.d2; c←sf.c; k←sf.k; ev←sf.ev;
   if (ev=λv1) AND (v1+d1<MaxCR1) then v1++;
   if (ev=λd1) AND (v1+d1<MaxCR1) then d1++;
   if (ev=λv2) AND (v2+d2<MaxCR2) then v2++;
   if (ev=λd2) AND (v2+d2<MaxCR2) then d2++;
   if (ev=λvu) then
      if (a=1) then v1++; c←C1; k←VOICE;
      if (a=2) then v2++; c←C2; k←VOICE;
   if (ev=λdu) then
      if (a=1) then d1++; c←C1; k←DATA;
      if (a=2) then d2++; c←C2; k←DATA;
   if (ev=μv1) then v1--;
   if (ev=μd1) then d1--;
   if (ev=μv2) then v2--;
   if (ev=μd2) then d2--;
   if (ev=μvu) AND (c=C1) then
      v1--; c←desc; k←desc;
   if (ev=μvu) AND (c=C2) then
      v2--; c←desc; k←desc;
   pd←pd+λv1+λd1+λv2+λd2;
   if (c=desc) then pd←pd+λvu+λdu;
   if ((v1=1) AND (c=desc OR c=C2 OR
   k=DATA)) OR (v1>1) then
      Nmu←v1;
      if (c=C1) AND (k=VOICE) then Nmu--;
      pd ← pd + Nmu*μv1;
   if ((d1=1) AND (c=desc OR c=C2 OR
   k=VOICE)) OR (d1>1) then
      Nmu←d1;
      if (c=C1) AND (k=DATA) then Nmu--;
      pd ← pd + Nmu*μd1;
   if ((v2=1) AND (c=desc OR c=C1 OR
   k=DATA)) OR (v2>1) then
      Nmu←v2;
      if (c=C2) AND (k=VOICE) then Nmu--;
      pd ← pd + Nmu*μv2;
   if ((d2=1) AND (c=desc OR c=C1 OR
   k=VOICE)) OR (d2>1) then
      Nmu←d2;
      if (c=C2) AND (k=DATA) then Nmu--;
      pd ← pd + Nmu*μd2;
   if (k=VOICE) then pd ← pd + μvu;
   if (k=DATA) then pd ← pd + μdu;
```

```
τ←1/pd;
for each state st∈S do
   if (v1=st.v1) AND (d1=st.d1) AND
   (v2=st.v2) AND (d2=st.d2) AND (c=st.c)
   AND (k=st.k) then
      switch (st.ev)
         case λv1: psfst(a)←λv1/pd; break;
         case λd1: psfst(a)←λd1/pd; break;
         case λv2: psfst(a)←λv2/pd; break;
         case λd2: psfst(a)←λd2/pd; break;
         case λvu: psfst(a)←λvu/pd; break;
         case λdu: psfst(a)←λdu/pd; break;
         case μv1: psfst(a)←μv1/pd; break;
         case μd1: psfst(a)←μd1/pd; break;
         case μv2: psfst(a)←μv2/pd; break;
         case μd2: psfst(a)←μd2/pd; break;
         case μvu: psfst(a)←μvu/pd; break;
         case μdu: psfst(a)←μdu/pd; break;
         default: psfst(a)←0;
for i←1 until 2 then
  if (c=Ci) then
   cost ← cost + energyi*Ecost/SR(st,a);
   if (k=VOICE) then
      cost ← cost + Li*LVcost/SR(st,a);
      if (ABi < vi*BV + di*BD) then
         cost ← cost + BVcost/SR(st,a);
   else if (k=DATA) then
      cost ← cost + Li*LDcost/ SR(st,a);
      if (AB1 < vi*BV + di*BD) then
         cost ← cost + BDcost/SR(st,a);
End
```

Where:

- *energy1* and *energy2* are the energy consumptions when connected to macrocell or femtocell, respectively;
- *Ecost* is the energy costs per time unit;
- *L1* and *L2* are the losses in the macrocell and femtocell, respectively;
- *LVcost* and *LDcost* are the loss costs for voice and data applications, respectively;
- *AB1* and *AB2* are the total available bandwidths in the macrocell and femtocell, respectively;
- *BV* and *BD* are bandwidths used for one voice and data connection, respectively;
- *BVcost* and *BDcost* are the voice and data costs, respectively, entailed when the total number of connections need more bandwidth than what is available.

4 NUMERICAL RESULTS

Table 1 shows the numerical values used to perform the experiments.

Observe that the costs are dimensionless, since for losses and bandwidth overhead it is not possible to define monetary costs. These costs are used to weigh what parameter is more critical.

Table 1: Parameters and numerical values.

Parameter	Value
MaxCR1	10 connections
MaxCR2	5 connections
energy1	10.8 J
energy2	7.6 J
Ecost	20
L1	0.5 %
L2	2 %
LVcost	40 - 70
LDcost	20
AB1	1 Mbits/s
AB2	5 Mbits/s
BV	12.2 kbytes/s
BD	144 kbytes/s
BVcost	70
BDcost	30
λv_1	2 requests/s
λd_1	10 requests/s
λv_2	1 request/s
λd_2	5 requests/s
λv_u	0.5 requests/s
λd_u	1 request/s
$\mu v_1 = \mu v_2 = \mu v_u$	0.25 requests/s
$\mu d_1 = \mu d_2 = \mu d_u$	2 requests/s

In this paper, the energy cost was set to 20, while the cost for voice losses was set for a value between 40 and 70. However, it is important to note that the energy cost will be multiplied by the value of energy consumption and the losses cost will be multiplied by the amount of loss observed. The total weight for energy sums to 216 for the macrocell and 152 for the femtocell, while the total weigh for losses on voice connections will be a value between 80 and 140. The same analysis can be performed for others costs, which shows that the energy has been used as the most critical parameter.

Analyzing the optimal policy it is observed that when the voice loss cost is 40 (lower value) all requests from the user (voice or data) should be serviced by the femtocell; only when the femtocell is full the requests should be serviced by macrocell.

Increasing the loss cost it is observed that the data connections should be serviced by the femtocell and the voice calls should be serviced according the femtocell congestion. While the congestion is low, the connection is preferred, otherwise, connection to macrocell is preferred.

For a loss cost of 70 (the highest value observed) the optimal policy indicates that voice and data should be connected to macrocell. Only for congestion exceeding 80% the data requests should be serviced by femtocell.

Increasing the loss cost means reducing the battery consumption importance. However, Figure 2 shows that the average battery consumption has a limit, increasing up to 20%.

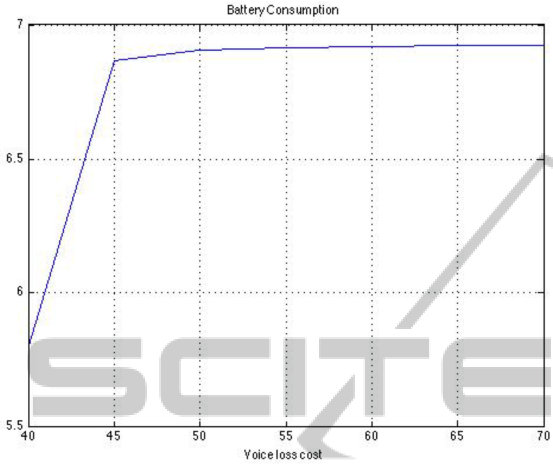

Figure 2: Average battery consumption X voice loss cost.

5 CONCLUSIONS

Through an optimized allocation, this work sought to provide users the minimum levels of service quality, maximizing battery lifetime at client node. However, one must consider that the traffic used (voice and data) have specific characteristics (such as bandwidth, minimum levels of QoS, transmission cost), which generates different behavior at the time of transmission.

It can be seen, from the results, that voice connections should be designed to macrocells, which, despite having smaller bandwidths, can meet a higher number of voice calls, have a greater coverage area and lower levels of loss (due to congestion and interference). The data traffic should be directed to the femtocells, which have higher bandwidth, and that, even with a loss of data, can meet the minimum QoS of this particular application; mainly due to existing correction protocols in TCP/IP.

Thus, the following contributions can be seen as results of this work: (a) the proposal of a Markov optimization model for optimal allocation of users in macro-femto network, considering the type of traffic to be transmitted, (b) different from studies in literature, the model was built considering crosslayer aspects (bandwidth, signal strength) and energy efficiency (battery level);

As limitations, it is emphasized that the model was implemented in a general way, not realizing specific studies, such as (a) Costs associated with handoffs (between macro and femto cell), (b) Cost associated, with each new call, to choose which network to connect.

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