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Performance Evaluation of a Markovian Policy for Macro/Femto User Allocation Considering Aspects of QoS, QoE and Energy Efficiency

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Abstract: The advancement of wireless networks offers mobile users a diversity connectivity options, but the choice of the best connection should consider classics QoS aspects and, with increasing multimedia applications, should also consider QoE metrics. Another important parameter to choose the best connection is the energy efficiency by reducing the battery consumption of the devices and reducing CO_2 emissions (green network). This paper validates a Markovian policy for distribution of user load balancing in femtocell/macrocell networks considering QoS/QoE and energy consumption providing quality for multimedia applications. The results obtained by simulation proved the benefits.

Key words: Femtocell, Markov, green networks, quality of service, quality of experience.

1. Introduction

The increasing demand for new technologies, services and content are changing the way that users access the Internet. Due to the growing number of mobile users and the need for access to numerous network applications such as videos and social networks, operators are being forced to provide services with high transmission rate and quality. This fact becomes a reality due to the popularization of equipment with wireless interface, such as laptops, smart phones and tablets. According to Ref. [1] as quantitative insights, by 2016, the global IP traffic will grow fourfold, reaching a milestone of 1.3 zettabytes annually. Among IP applications, video communications (video on demand, IPTV (internet protocol television), video conference, etc.) will be14 times larger than the current demand.

Currently, the cost associated with the deployment of cellular systems is high and these networks have coverage problems in indoor environment. In addition, research shows that over 50% of the connections that use the wireless connection and more than 70% of data traffics originated from an indoor environment [2]. Despite the current infrastructure that has a good performance for voice traffic, the profile of service utilization by users is changing and the use of data traffic is growing, which in most cases, cannot be met the current infrastructure.

There are several approaches that can be used to meet the demand for high data rates, the main options to expand the capacity of the network include: improving the performances of eNodeBs (enhanced NodeBs (macrocells)) and complement the network with low power nodes, thus creating a heterogeneous network [3]. Complement macrocells with low power nodes such as picocells and femtocells, is one of the most accepted solutions [3].

Together with these developments, another topic that has been addressed is the concept of green networks which are aimed at saving energy and reducing CO_2 (carbon dioxide) emissions. With regard

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to this, in December 2008, the European Commission set a target to reduce CO_2 emissions by 20% and improve energy efficiency by 20% by 2020 [4].

According to Ref. [5], 57 % of the power consumption of the ICT (information communications and technology) sector is allocated to users and mobile and wireless devices and this percentage is still growing at a very fast rate. Furthermore, the energy savings in mobile communication systems depends on the reduction of energy consumption in BSs (base stations) and MSs (mobile stations) [6].

Thus, it is essential for society to stimulate growth in the provisioning of wireless networks while reducing energy costs and hence, one of the most important objectives of the ICT sector in the coming years.

A number of authors have published models or algorithms of green communication networks for mobile telecommunications. Salem and Reguiga [7] described a policy decision to reduce energy consumption in femtocell, with the primary metric, the number of users connected to the same. Also in Ref. [7], the specific objective is the research and development of innovative methods to reduce the total power required to operate a network radio access and identify the most appropriate radio architectures, and allow a great power in reduction of energy consumption. Moreover, the recent development of hierarchies to allocate users macro/femto wireless access broadband, has attracted the attention of service providers mainly due to their improved indoor coverage.

Kong [8] proposed a reduction of CO_2 emission of a wireless network, enabling and disabling features of the base station via a Markov decision process discrete time for decision making in each season, activating, deactivating or maintaining resources. The proposed policy can reduce up to 50% energy consumption without compromising service quality, which is assessed through the blocking probability.

In Ref. [9], there is a proposal for optimized allocation for users on a macro-femto co-channel network which seeks to maximize the QoS (quality of service) applications and energy efficiency, by searching for the concept of green networks. Thus a fuzzy inference system has been formulated to define which network is used to connect with the mobile device. The results show that, compared with traditional QoS approaches, the proposed approach in Ref. [9] model may improve energy efficiency by 25%.

Most of the literature is focused on the energy efficiency for macro cells and the network core, without much attention being paid to reducing the battery life of the client nodes, by considering aspects of QoS and signal strength in the allocation of users over networks.

Given the above, this work combines two important approaches which can complement each other: An optimal policy for allocation of voice and data calls based in Markov decision process was developed in Ref. [10], which maximized the quality of connections and the battery life of mobile users. Combined with the networks simulator widely used (Network Simulator 2–with the MIH (media independent handover) and the Rakhmatov-Vrudhula battery modules). The idea is to introduce the Makov policy into the simulator to assist the mobile device to empower decision-making during the handover and thus provide optimal power consumption when allocating energy to the user in macrocell/femtocell networks and ensure QoS and QoE (quality of experience).

This article is structured as follows: Section 2 sets out the characteristics of a femtocell; then, Section 3 shows the Markov decision process; in Section 4, the developed model (network architecture, the simulation parameters, the policy developed and MIH module) is outlined; the results are discussed in Section 5; finally, Section 6 shows the final considerations of this work, together with the acknowledgements and bibliographical references.

2. Femtocell

According to Refs. [2, 11], femtocells are small base stations used in the 3rd and 4th generation (3G and 4G) mobile technologies with the same functionality as the macro seasons. However, they only possess enough power to meet a restricted environment (20 meters), and support a small number of users. Thus they are installed by the users for better voice and data reception indoors.

This technology reduces the problem of indoor coverage and has other advantages such as low cost and high energy efficiency. Moreover, it has been proposed by 3GPP (3rd generation partnership project) and applied UMTS (universal mobile telecommunications system) technology network and its LTE—advanced form A (long term evolution advanced) [2].

The femtocell networks have a great potential to improve the capacity of wireless systems for next generation users, as they offer better signal strength indoors. However, the femtocell access points that are installed by users are usually non-specialist, the time of the installation is not considered performance indicator of the network, since it just connects an access point to a DSL (digital subscriber line) and turns it on.

According to Ref. [12], the access point itself sets its own operating parameters and establishes a radio system. This adverse factor is more complex when the battery consumption of the client nodes and the QoS requirements is taken into account so that it can be decided which cell they should connect to. Traditionally, the decision is based on the signal received by the mobile user (by connecting the cell with a higher power signal, either macrocell or femtocell), without considering whether the output meets the minimum requirements of QoS.

3. Markov Decision Process

According to Ref. [10], the MDP (Markov decision process) is a mathematical tool used to analyze reactive complex systems to define the optimal control policy that reduces the system's operational cost (or else maximizes it the rewards).

This can be formulated as a CTMDP (continuous time MDP) problem, since it considers that the times (between the arrival of the request and the time that a request stays in the system) follow an exponential probability distribution. In addition, it is formulated as an infinite horizon problem, since it can last for a long, undefined period of time. Briefly, to model a problem as a CTMDP, it is necessary to define:

- The state space S: the set of all possible conditions (states) of the system (such as the number of requests of each kind of application in each cell);
- Sets of actions {A (s) | s ε S}: for each state sε S, there is a set of possible actions A(s), in which the operator must choose a single action at every decision time;
- A set of costs {c (s, a) | s εS, a ε A(s)}: where c(s, a) is the cost entailed to the system when it is in state s ε S and a action a ε A(s) is chosen;
- A set of transitions probabilities of { p_{sz} (a) | s, z ε S, a εA (s)}: where p_{sz} (a) is the probability that, in the next decision time, the system is in state z ε S, given that action a ε A(s) is chosen when it is in the state sεS;
- {τ (s, a) | s εS, a ε A(s)}: expected time until the next decision time if the action a ε A (s) is chosen in state s ε S.

The stationary optimal policy R*, which reduces the average long-term cost per time unit can be calculated by means of these five elements. There are some classical techniques that can be used for this purpose, e.g., value iteration algorithm, policy iteration algorithm and linear programming.

Fig. 1 shows a diagram representing the transition of states as a time dependent function. An event occurs at a given time t_n; after this event, the system's state changes and, a decision is made simultaneously. Between the instants t_n and t_{n+1}, the system behavior will depend on the state and the decision taken in t_n. In t_{n+1}, a new event that changes the system's state occurs and the process restarts. The optimal policy calculated indicates which decision (action to be chosen) should be made at each instant of time (t_{n-1}, t_n, t_{n+1}, and so on); this decision will be stationary only and depend on the

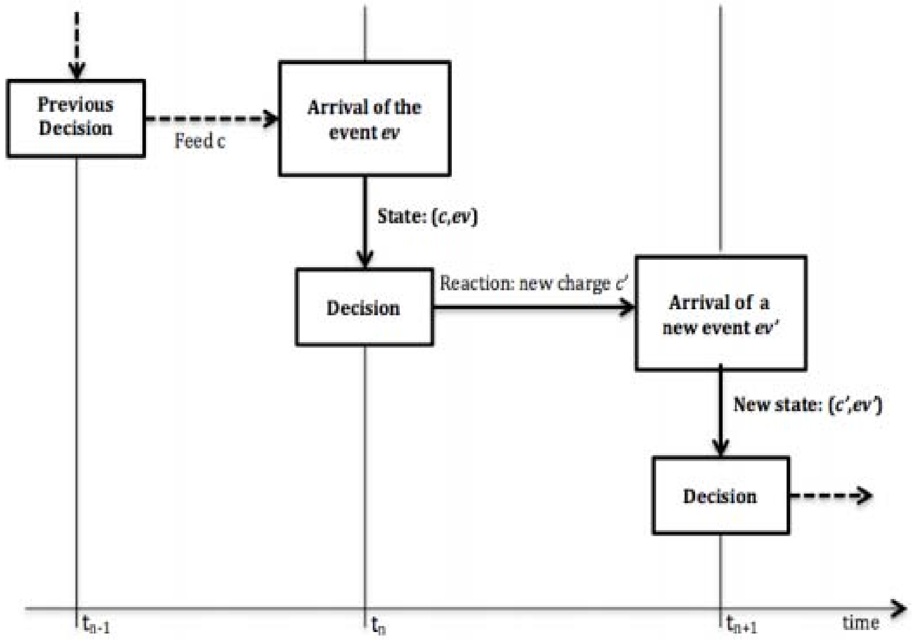

Fig. 1 Diagram representing the state transition over time.

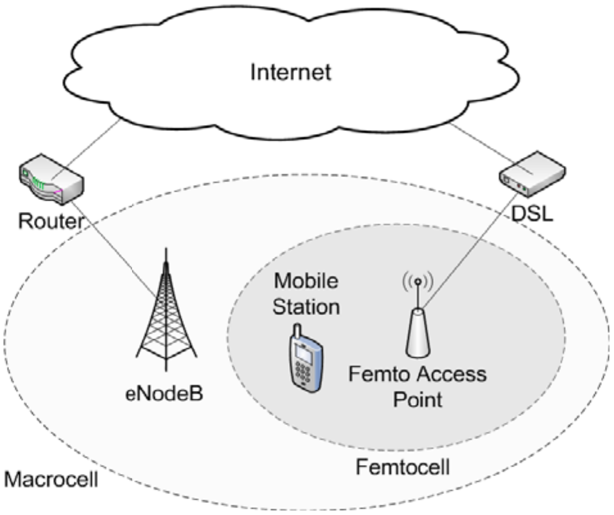

Fig. 2 Macrocell and femtocell, considered scenario.

state of system.

4. The Developed Model

4.1 Network Architecture

A mobile network is assumed to meet the mobile station that communicates with the macrocell and femtocellcells through the femtocell access point and the Node B, which provides wireless access (as shown in Fig. 2). The arrivals of calls can be answered by both networks, which have different distances to the mobile nodes, different bandwidths and different losses and allow a maximum numbers of users to be connected.

When there is a new call, the system parameters such as power consumption, the available bandwidth and packet loss probability of each network are used to decide which network should be chosen to serve the call. If new calls are blocked because of limited capacity, there is a possible overflow system to the other network service.

There are two classes of network access service: voice and data, these are formed by new calls and handover. These requests arrive in accordance with Poisson processes and system parameters (parameters λv_n and λd_n, for voice and data respectively; where n indicates if the request is to connect to macrocell ($n = m$) or femtocell ($n = f$) or if it is a request where it has to be decided to which cell it should connect ($n = u$). The times of voice calls and packet data service follow exponential distributions with parameters $1/\mu v_n$ and $1/\mu d_n$, respectively.

It should be made clear that the system is modeled so that it can be observed by the user. Thus, when the user needs to connect to make a voice call or data, the mobile station must decide which network connect to, by means of information regarding the number of connections, parameters of quality of service and the level of signal strength of each network. The last of these can be obtained directly, but other variables have to be investigated for the system.

4.2 Simulation Parameters

In order to validate and analyze the performance of the Markov model described, the simulator NS (network simulator)-2 was used in Version 2.29 [13]. Based on the specifications of the proposed scenarios in Ref. [10], four scenarios were created. In all the proposed architecture in Section 4.1, all scenarios were specified by a distance between the mobile user and femtocell with 20 m and between mobile user and macrocell with 480 m. Therefore the user is in the coverage area of both cells. The first scenario (called macro) which the users transmit only in this network. In second (called femto), only the femtocell network can be used as output, in third scenario (called macro/femto), the both networks are used and finally the fourth scenario (called policy) in which the both networks can be used, but the choice is made by the Makov policy.

To evaluate the energy consumption of mobile nodes, among the battery models available in the literature, it was chosen as the RV (rakhmatov-vrudhula) battery model, which is a non-linear model and considered as the most realistic regarding the batteries currently user, because considering different consumption values for different states, the mobile node can be find [14]. The initial value of the battery charge in the simulation was 1,000 J [15].

The mobile nodes start the simulation connected to macrocell and during the same the move to the femtocell coverage. Fifteen users were included in scenario, the simulation lasts 70 s and was repeated 30 times, with a confidence interval of 95%. The parameters used to define the macrocell and femtocell are described in Table 1 [15].

The femtocell technology is similar to ADSL2+ modem for cellular network and macrocell is like to LTE/3G access point with 1 Mbit/s data rate.

To evaluate the model three types of applications it was considered: data, voice and video, which are described in Tables 2 and 3.

The Evalvid [16] tool was used in the simulations, allowing real videos to be inserted in the simulation and evaluated by MSU, Video Quality Measurement Tool [17]. The video was used is “Akiyo” which has the 300 frames in YUV color format with resolution 352×288, which was encoded with MPEG-4 video codec at a rate of 30 frame/s [18].

4.3 Developed Policy

The policy developed aims to meet the voice and data optimally. Owing to the characteristics of the exchange arrivals, the user voice and data network features (macrocell and femtocell), which were described in Ref. [10] obtain the policy aims to route the femtocell network calls until it runs out of capacity. After the capacity of this network has been exhausted, calls are routed to the macrocell network. Once both

Table 1 Femtocell and macrocell parameters [10].

Parameters	Macrocell	Femtocell
Power	25 dBm	13 dBm
Antenna gain	1,0 dBi	1,0 dBi
Frequency	2,5 Ghz	2,412 Ghz
Bandwidth	75 Mbps	54 Mbps
Coverage radius	1 km	50 m
Data rate	1 Mbit/s	5 Mbit/s
Packet loss	0.5%	2%

Table 2 Voice and data parameters [9].

Parameters	Voice	Data
Packet size	244 bits	1,024 bits
Data rate	12,2 Kbps	144 Kbps
Protocol	UDP	UDP

Table 3 Video parameters [15, 16].

Video	Resolution: 352 × 288 ; frame rate: 30 frame/s; color mode: YUV
Queue	DropTail (40 msdelay)
Packet size	1,052 bytes
Maximum packet Fragmentation	1,024 bytes

networks have been exhausted, the calls are blocked. Every call termination opens a vacancy in the network that must be filled with a new call and the femtocell network is prioritized (Fig. 3). Due to space limitations, only the decision flow for voice calls is displayed but the same process is applied to data calls (video are included in this category).

4.4 MIH Module

The MIH enables vertical handover, between different technologies, through a set of services and triggers signaling events, that can be combined with any technology [19]. The MIH is a cross-layer entity that mainly covers the unification of obtains network information, events and control mechanisms of the lower layers of different technologies liaison (Fig. 4). Thus by abstracting the technology used for the upper layers, no matter what technology is being accessed at the time, the available functions remain the same for the upper layers.

Among the many goals of the MIH, there are three which should be highlighted: (1) to assist decision making in the mobility control mechanism by providing access to information about the link state and seeking the execution of handovers with minimal delay, even when the networks have access to various technologies; (2) to define semantic methods to allow the acquisition of information in heterogeneous environments; (3) to allow continued connectivity throughout these environments, (both homogeneous and heterogeneous), through the control of seamless mobility.

Thus, mobility is obtained independent of the network address and wireless communication technology. However, the decision making of the MIH handover is only performed if the signal strength (RSS (received signal strength)) of an AP/BS, proves to be insufficient to ensure the QoS of the applications [20].

Thus, we adopted the existing MIH module in NS-2 to assist in the handover decision, which applied the political class in the handover tracer Handover2.cc which is located within the MIH module simulator NS–2 network directory. This class uses three main methods as follows:

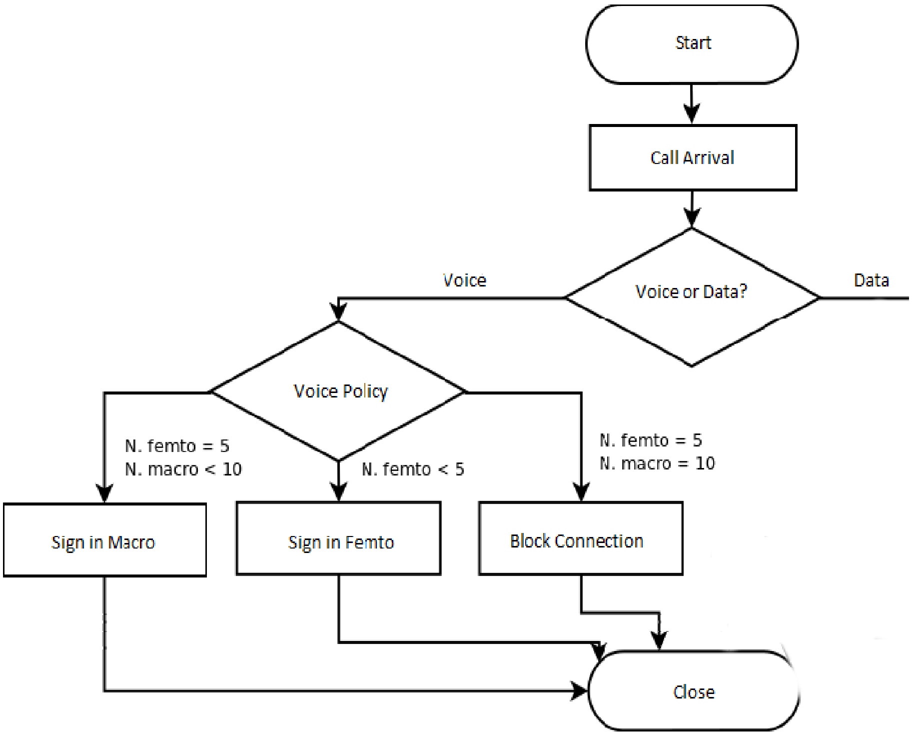

Fig. 3 Flowchart policy

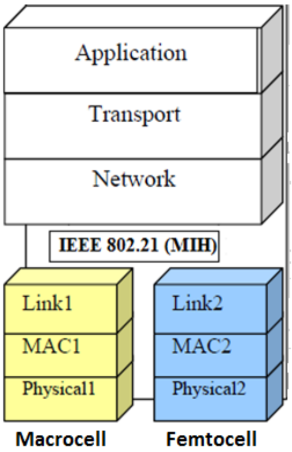

Fig. 4 Architecture MIH module.

- Link up: a method that connects the MS to a network;
- Link down: a method that disconnects the MS from a network;
- Link detected: the method that detects a new network signal.

Through these three methods, the handover class receives information of a given network which allows it to decide to connect to a new network. Join this class to the algorithm proposed for decision making (Fig. 3). Thus, attempts were made to connect the user to the network and provide the best QoS level with reduced power consumption for the mobile device.

5. Results

When analyzing the network behavior in terms of energy efficiency, the model proposed in Ref. [10] can be observed as an effective, the battery discharge to the policy scenario was approximately 1.2%, in femto scenario was approximately 1% and in macro scenario was approximately 1.5%. The value with policy is a value closer of femto scenario.

The values obtained for the model are consistent with expectations, since it provided for a percentage of consumption that falls between the other two tested technologies (macrocell and femtocell), meaning that the model is directing calls to the most appropriate network, reaching levels of efficiency energy in relation to the macrocell network, where a reduction in the consumption of 4% is observed.

The objective of the allocation model proposed is to achieve the best possible solutions for energy consumption and ensure quality of service to the users; thus the QoS parameters for these applications (Table 4) that were analyzed were as follows: delay, jitter and packet loss. The blocked calls also serve as a parameter for this study, as a way of finding out which network served calls most effectively (Table 4).

It is worth mentioning that the allocation policy for the user obtains improvements in performance measures. On average, there was a 66% decrease in delay in relation to the macrocell obtained is 32% compared to the femtocell network. To measure jitter performance, was obtained a reduction of approximately 66% related to the macrocell network and 44% over the femtocell network. Also policy received a 0.4% reduction in blocking calls against femtocell network and an increase of approximately 0.2% related to the macrocell network (Table. 4). It is

Table 4 QoS performance measurements.

Scenario	Delay (ms)	Jitter (ms)	P. loss (%)	Blocked calls
Macro	2,400	17.2	0.0	495
Femto	1,180	10.3	0.0	498
Policy	800	5.7	0.0	496

Table 5 QoE performance measurements.

Simulation	PSNR (dB)	SSIM	VQM
Macro/femto	20	0.9	3
Policy	45	0.98	0.4

also observed that the macrocell networks, femtocell and politics had no lost packet in simulation result. Thus, because the model used to characterize a network with low load.

In order to evaluate the performance of the video application, it was used PSNR (peak signal-to-noise ratio) [21], SSIM (structural similarity) [21] and VQM (video quality metric) [21] metrics.

The PSNR checks the difference of frames received from the original, 30 dB is considered the minimum for the transmission has been carried out with minimum quality [21]. It can be seen from Table 5 that with the use of policy, the difference in quality was 56%, of a lower quality value 20 dB (macro/femto) can be raised to 45 dB (policy).

Although the PSNR is a measure of satisfactory performance, it does not consider aspects such as color similarity, luminosity and structure of the video. Thus, the SSIM metric was used. It analyzes the three aspects described above, this metric is efficient to extract visual information from videos/images [22]. The value is a decimal from 0 to 1, and the closer to 1, the better quality of video. Again the policy was effective in search of quality, enabling an improvement of 8%, as shown in Table 5.

The VQM measures the perceptual effects of video impairments including blurring, jerky/unnatural motion, global noise, block distortion and color distortion, and combines them into a single metric [23]. The closer to 0, the better the quality. Here can see the effectiveness of the proposed model, yielding an increase in quality of 87%, as indicated in Table 5.

In view of this, we can observe that the policy was successful in reducing energy consumption, and call blocking, as well as providing better performance in QoS and QoE measures for the macrocell and femtocell networks.

6. Conclusion

Future mobile communication systems will require much higher data rates, which may consume more energy than is that of the case with existing 3G and 4G systems. These restrictions raise state-of-the-art questions about energy efficiency and green networks, both for planning purposes and for the management and operation of networks. Thus, the domain for solving these issues is very important for the design of future communication systems. In this context, the smart use of user connection between macrocell and femtocell always creates a demand for QoS, QoE and low energy consumption. Furthermore, the reduction of energy consumption of BSs and MSs can directly assist in reducing CO_2 emissions.

This work has established strategies that lead to more efficient planning of networks that adhere to the concepts of green networks. The strategy combines the potential use of Markov models and analytical solutions of discrete simulation, which are aimed at reducing the battery consumption of the users, without affecting the quality of service of applications for the allocation of macrocell and femtocell users in networks.

From the results obtained in the simulation, the model proposed policy achieved significant savings in energy consumption, improved the quality of service and quality of experience with regard to macrocell and femtocell networks, by proving to be efficient in the way they significantly changed the QoS and QoE metrics.

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