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Planning and Profit Sharing in Overlay WiFi and LTE Systems toward 5G Networks

Danielle Saliba[1], Rodrigue Imad[2], Sebastien Houcke[3] and Bachar El Hassan[4]

Abstract

Nowadays, with the increasing demand for data traffic and with the massive foreseen deployment of the Internet of Things (IOT), higher data rates and capacity are required in mobile networks. While Heterogenous Networks (HetNets) are under study toward 5G technology, Wireless Fidelity (WiFi) Access Points (APs) are considered a potential layer within those multiple Radio Access Technologies (RATs). For this purpose, we propose in this paper a novel WiFi dimensioning method, to offload data traffic from Long Term Evolution (LTE) to WiFi, to ensure a balanced traffic between both networks. This dimensioning method, calculates the remaining available capacity of the WiFi network based on the estimated load of each WiFi physical layer channel, by considering the channels overlapping characteristic, thus calculating the minimum needed number of WiFi APs that ensure same or better throughput for the transferred LTE heavy users. Having the minimum needed WiFi APs that will support LTE, we estimate then the profit sharing between LTE and WiFi by considering data bundles subscription revenues and the infrastructure capital and operational costs. We calculate for each network the profit share using a coalition game theory Shapley value that pinpoints the benefit of the cooperation using the proposed dimensioning method.

Index Terms— LTE WiFi offload and coexistence, 5G, Heterogeneous Networks, Shapley Value profit sharing

Introduction

With the increasing demand for wireless communication technologies and data traffic, the main limitation in mobile networks is the lack of available licensed spectrum. Operators have limited and expensive spectrum, so they need to plan the effective utilization of their radio resources. This can be done by offloading mobile data between licensed and unlicensed spectrum. To avoid the channel access conflicts, current LTE Unlicensed (LTE-U) technology introduces the duty cycle of LTE, while License-Assisted Access (LAA) technology introduces Listen-Before-Talk (LBT) mechanism [1].

Furthermore, most of the current macro-cellular traffic comes from indoor locations or mobile users with fixed positions [2]; therefore, multi Radio Access Technologies (RATs) solutions as the integration between Long Term Evolution (LTE) and Wireless Fidelity (WiFi) is an alleviating solution which aims to distribute the connected users efficiently between the Heterogenous Networks (HetNets) and ensure throughput stability for the best Quality of Service (QoS) and capacity limitations management.

Many offloading methods have been proposed for shifting traffic from cellular networks, which use licensed spectrum resources, to 802.11x WiFi networks, which use un-licensed spectrum resources. In contrast with the licensed spectrum used in cellular networks, unlicensed spectrum is less expensive, where 802.11x WiFi network may have better throughput and consume less power than the cellular network [3]. In addition, WiFi Access Points (APs) are easily and quickly deployed in many residential areas and indoor environments, with affordable cost of investment and without any restrictions in hardware size or needed physical or practical customization.

[1] Signal and Communication, Mines Telecom Atlantique, Brest, France (e-mail: danielle.saliba@imt-atlantique.fr).
[2] Mechatronics, University of Balamand, Al Kurah, Lebanon (e-mail: rodrigue.imad@balamand.edu.lb)
[3] Signal and Communication, Mines Telecom Atlantique, Brest, France (e-mail: sebastien.houcke@imt-atlantique.fr)
[4] Telecommunication and Networking, Lebanese University, Tripoli, Lebanon (e-mail: bachar_elhassan@ul.edu.lb)

Moreover, most of the smart devices are equipped with WiFi capabilities, and based on different studies, more than 80% of mobile traffic came from indoor environment. Thus, WiFi could have an advantage of establishing a communication infrastructure over other wireless communication networks [2]. However, most of current WiFi networks consist of randomly deployed WiFi cells since there is no limitations or policies on WiFi AP deployment [4]. The unplanned installation of APs may cause the WiFi networks to be implemented inefficiently.

There have been several studies on WiFi cell deployment problems. In [4], the minimum required number of WiFi APs was investigated based on the active users' density, the coverage of the WiFi AP and the transmission probability of a user, without taking into consideration the WiFi network available capacity. In [5], the authors propose WiFi deployment algorithms based on realistic mobility characteristics of users to deploy WiFi APs for continuous service for mobile users, based on maximum continuous coverage where WiFi network capacity was not considered. In [6], the number of APs required for WiFi offloading with different quality of service for data delivery was quantified, however, authors just provided a feasibility study on such offloading solution through real mobility traces and did not perform any mathematical analysis for this problem.

In addition, many studies have analyzed the cooperation and offload between LTE and WiFi based on different criteria and assumptions. In [1], authors proposed a Low Amplitude Stream Injection (LASI) method to enable the simultaneous transmissions of WiFi and LTE frames in the same channel and recover the data from the conflicts. In [2], the offload to WiFi was analyzed based on the Remaining Throughput Scheme (RTS) for Wi-Fi selection. In [3], the offload to WiFi networks was proposed based on Software Defined Network (SDN) architecture to ensure WiFi Device-to-Device (D2D) link. In [7], it was proposed to transfer WiFi users to the LTE system according to the availability of Channel State Information (CSI): the random transfer, the distance-based transfer, and the CSI-based transfer. In [8], the offload was analyzed based on the energy cost incurred to the cellular base stations and according to a routing policy within the overlay network.

It is obvious that cellular traffic can be partially offloaded if we use both LTE and WiFi together. However, the key issue is to define the minimum number of WiFi APs needed to support a proper number of users while guaranteeing an adequate user experience level. Obviously, when extra APs are installed, a WiFi network will achieve higher throughput through additional available capacity. Nevertheless, increasing the number of APs and consequently the related capital and operational expenditure (CAPEX/OPEX) without any constraint, is not a good solution. Therefore, it is important to investigate the minimum required number of the APs that achieves a certain level of performance.

This paper proposes a novel method of planning the offload from LTE to WiFi in addition to the dimensioning of the WiFi network to support the offloaded traffic. This method calculates the minimum needed number of WiFi APs based on the estimated average available capacity of the WiFi overlapped physical channels thus the available capacity of the WiFi network. The existing WiFi network constituted of minimum one AP, will be handling the LTE offloaded traffic on top of its initial traffic, and then any needed extra capacity will be reflected by incrementing the number of WiFi APs. The proposed solution will alleviate the LTE cell energy consumption for certain calculated and defined heavy users, and thus instead of increasing the capacity and number of Base Stations (BSs) in the LTE network, we are proposing to increase the number of WiFi APs. This architecture can provide a low-cost solution compared to other solutions such as increasing the number of LTE BSs or small cells that necessitate additional cost of investment. In this case the investment in hardware, implementation and maintenance cost CAPEX and OPEX will be reduced; to note that the profit sharing for both networks is measured at the end of the paper by applying the gaming theory of Shapley value, to pinpoint the benefit of the coexistence and cooperation between both systems.

This paper is organized as follows: in section 2, the overlay network model is described. In section 3, the problem formulation along with users transfer schemes are described. The available capacity of the WiFi network and dimensioning of the needed number of WiFi APs are calculated in section 4. Section 5 describes the profit for each network based on the gaming theory Shapley value. Section 6 shows the simulation results and the performance of the proposed solution, and section 7 concludes the paper.

Overlay LTE/WiFi Network Model

We consider in this paper a network where an LTE Advanced (LTE-A) cell that operates in the licensed spectrum, also known as eNB, is covered by K WiFi APs (K unknown variable to be calculated) that operates in the unlicensed spectrum and that will support the transfer of heavy users from LTE-A to a WiFi with a sufficient capacity and proper available coverage.

The proposed architecture of the overlay network is depicted in Fig. 1 where the eNB serves a set of Mobile Users (MUs) (or User Equipments (UEs)) that also have WiFi interfaces. We consider that the MUs are in range with at least one or more WiFi APs. The amount of data to be downloaded or uploaded from/to the internet differ between different users, as well as for their channel conditions with the BS.

In our paper, the selection of the LTE transferred users is not random. Instead, it is based on the users with heavy data consumption depending on the requested throughput and transmitted power, so the minimum needed number of WiFi APs is calculated to cope with the traffic of those transferred users as previously described. In addition, the offloading decision is not random or based on the probability of WiFi channels occupation or on the Channel State Information (CSI) either. Instead, it is based on the exact information sent by the WiFi network informing the LTE eNB about its remaining average capacity.

This remaining average capacity depends on the estimated channels load of the physical layer of the WiFi network [9]. In this paper, we consider the average of the channels load or occupation value of the channels that has been calculated in [9], however this value has been averaged for several days during the peak hour traffic of the WiFi network. Based on this averaged value, we have a global estimation calculated through the multiple APs to be collected on a higher control node of the network to estimate the remaining available capacity and to facilitate the measurements collection and processing time.

Therefore, our framework is divided into two phases to transfer cellular data traffic from LTE BS to WiFi:

- The first phase is to determine the heavy users who will transmit the higher power and thus should be offloaded from the LTE system.
- The second phase is WiFi APs dimensioning. This is considered through WiFi APs remaining capacity calculation, and it is based on the remaining throughput of each WiFi AP based on the average occupation or load value of the physical channels.

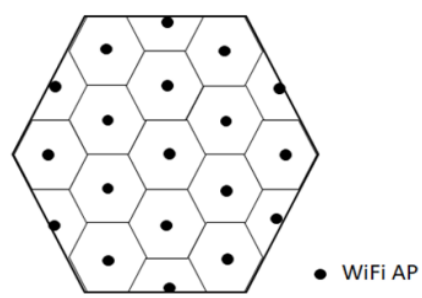

Fig. 1. An overlay network with ‘K’ WiFi APs deployment covering a regular hexagonal LTE-A cell.

Problem Formulation

The WiFi network should assure a minimum acceptable and predefined average per user throughput for an efficient LTE offloading. Based on this average per user throughput, we will calculate the minimum required number of WiFi APs in the overlay network.

As illustrated in Fig. 1, we consider a scenario with one LTE BS and K WiFi APs operating separately in licensed and unlicensed spectrum, respectively.

In our scenario, we assume a coverage area of 802.11n WiFi APs with no interference, each transmitting on an orthogonal channel in the 2.5 GHz unlicensed spectrum, selected based on the minimal calculated load value of the channels referring to the algorithm in [9]. This model has also been adopted in other literatures, such as [4] and [7]. Following the same principle, the analysis of 5 GHz spectrum and 802.11ac could be applied [9].

The coexistence of WiFi and LTE could be facilitated by assuming that an inter-system coordinator exists, which performs the WiFi user transfer and resource allocation, as in [7]. To note that our proposed system is very useful for the case where LTE-A and WiFi are deployed by the same network operator. In this case, the inter-system coordinator can be implemented by the cellular network operator itself. Otherwise, it can be implemented by a third-party vendor that provides service enhancement for both WiFi and LTE.

In our paper, the basics of the problem formulation for the LTE eNB is an energy minimization problem and not a throughput maximization problem. The energy minimization solution consists identifying the users who consume the highest energy and require high throughput rates which is considered in our simulation greater or equal to 20 Mbps [11]. This decision affects the capacity of the WiFi network, as the offloaded users should be in range with an AP having an adequate capacity. In order to determine the heaviest users in LTE that should be offloaded to WiFi network, the operator needs to determine the resource allocation policy, in terms of Resource Blocks (RBs) assignment and transmission power [8].

We consider the downlink operation of one LTE-A macro cellular BS for a time period of T subframes, possibly expanding over multiple frames. There exists a set of N_c users within the cell. The BS has a set of M available RBs that can be allocated to users in each subframe $(t = 1,2,\ldots,T)$. The value of M depends on the available spectrum. Hence, there are in total $(M * T)$ RBs. The system is considered quasi-static, i.e., users do not join or leave the cell during the current time period, and channels do not change significantly (flat fading). Note that, even if channels change rapidly, the eNB will not be aware of this fact, as users transmit their Channel Quality feedback Information (CQI) parameters only once during this time period.

In the beginning of the period, the eNB devises the RB assignment and power allocation policy for serving his users.

Let $x_{nm}(t) \in \{0,1\}$ denote whether RB $m \in M$ is allocated to user $n \in N_c$ during subframe t.

Let $P_{nm}(t)$ denote the respective transmission power. For each RB, the BS can determine a different transmission power. However, the total power consumption should not exceed a maximum level of aggregated transmission power P_{max} (Watt).

Assuming orthogonal allocation of RBs, and ignoring inter-cell interference, i.e., we assume that proper Enhanced Inter-Cell Interference Coordination (eICIC) techniques are applied, the instant rate for each user n is calculated by [8]:

$$r_n(t) = \sum_{m=1}^{M} x_{nm}(t).W_b.log\left(1 + \frac{h_{nm}.x_{nm}(t).P_{nm}(t)}{\sigma^2}\right) \quad (1)$$

Where $W_b$is the symbol rate per RB, h_{nm} the channel gain of user n in RB m during the current time period, σ^2 is a parameter considering the variance of the noise [12]. These parameters are estimated through the CQI feedback that is provided by the users, once every period T. Based on this policy, the operator determines which users consume the highest power and hence are most costly and should be transferred to WiFi.

WiFi Dimensioning Method

In this section, the proposed dimensioning method for the minimum needed number of WiFiAPs K is presented.

4.1 Available WiFi Capacity

To calculate the WiFi network remaining capacity, we need to measure the network load or occupation level.

The channels occupation in WiFi systems may be measured through the standard physical carrier sense mechanism Clear Channel Assessment (CCA), which listens to the received energy on the radio interface. CCA is defined in the IEEE 802.11-2007 standards as part of the Physical Medium Dependent (PMD) and Physical Layer Convergence Protocol (PLCP) layer.

Carrier sense refers the ability of an AP receiver to detect and decode an incoming WiFi signal preamble. CCA must be reported as BUSY when another WiFi signal preamble is detected, and must be held as BUSY for the length of the received frame as indicated in the frame's PLCP Length field. Typically, any incoming WiFi frame whose PLCP header can be decoded will cause CCA to report the medium as busy for the time required for the frame transmission to complete [13]. However instead of adopting the instant CCA info on each WiFi AP on the network to reflect the network occupation, we rely in this paper on the channel load estimation method previously analysed in [9], which enables to scan and measure the occupation of all WiFi overlapped physical channels simultaneously, collected on a higher control node, instead of the local measurement on each AP. This load estimation method facilitates the occupation measurements aggregation and processing time.

In addition, since initially this value is an instant occupation measure, we consider in this paper the average value of channels occupation during peak hours for several days within the LTE-WiFiHetNet, so the dimensioning calculations will be based on an averaged occupation value for several days to reflect more accurately the load of the WiFi network.

Let α_i denotes the average load or occupation value of channel i; $(1 - \alpha_i)$ is therefore the available idle capacity of this WiFi channel. In addition, since WiFi APs operate on the different 12 channels of the 802.11n system based on the minimum load value of the channel [9], different APs might be operating simultaneously on a specific channel i, taking into consideration that they are not neighbor APs to avoid the inter-channel interference. Therefore, the total available capacity of this channel i will be divided between at least two APs. If we consider t_i as the number of APs operating simultaneously under the different frequencies of the WiFi channels $(1 < t_i < 12)$, we can deduce the below equation [10]:

$$K = \sum_{i=1}^{12} t_i \quad (2)$$

$K \geq 1$ is the number of WiFi APs to be calculated.

Consequently, we can define the available capacity in terms of bit rate for a WiFi AP L $(L = 1,\dots,K)$, operating on a frequency of channel i, and for the whole WiFi network, denoted as R_L and R_{tot} respectively, as follows [10]:

$$R_L = R_{w_{max}} \cdot \frac{(1-\alpha_i)}{t_i} \quad (3)$$

$$R_{tot} = \sum_{L=1}^{K} R_L \quad (4)$$

where $R_{w_{max}}$ is the maximum throughput of the WiFi APs (considered as same releases and specs),i is WiFi channel number $(i = 1,\dots,12)$, R_{tot} is the total remaining capacity or throughput of the WiFi network and RL is the remaining capacity or throughput of the WiFi AP L $(L = 1,\dots,K)$.

From equation 4, we can estimate the total available capacity of the WiFi network, and thus dimension the minimum needed number of WiFi APs that will handle the transferred LTE users according to certain throughput criteria that will be analysed in the next section.

4.2 Dimensioning of the WiFi Network

To ensure the same user experience, the average per-user throughput offered by the WiFi network should be at least equal to or higher than the cellular network throughput.

Based on this constraint, we set the target average per-user WiFi throughput as follows [4]:

$$S_W^{user} \geq S_C^{user} \quad (5)$$

Where S_W^{user} and S_C^{user} represent the average per-user WiFi throughput and the average per-user cellular throughput respectively.

We define a maximum throughput threshold within the LTE network, considered in the simulations as 20 Mbps as average [11], where each user exceeding this threshold is considered as heavy user and should be transferred from LTE to WiFi. From equation 4 we can conclude the below equation:

$$Avg(S_W^{user}) = \frac{R_{tot}}{N_w} \quad (6)$$

Where N_w is the number of the heavy users to be transferred from LTE to WiFi as previously described.

While setting the maximum throughput threshold within the LTE as the minimum needed throughput per user to be ensured by the WiFi network, we calculate the minimum required number of WiFi APs K that achieves the target average per user WiFi throughput.

We can express the mathematical expression of K by:

$$K = \mathrm{argmin}_K \, S_W^{user} \quad (7)$$

Where $Avg(S_W^{user}) \geq r_n(t)$, $r_n(t)$is calculated in equation 1.

Profit Estimation

LTE and WiFi operators seek a monetary profit in case of cooperation while heavy users are transferred from LTE to WiFi. Each player WiFi or LTE tries to adopt a network configuration that decreases its own costs in order to maximize its profits. Thus, we evaluate in this section the Shapley Value that proved to be very effective in profit sharing in a multiplayer context, where several types of relationships are involved [14]. The idea is that eachplayer will have a profit share proportional to its contribution in the network setting and the added value it brings to the overall value chain.

5.1 The Shapley Value: definition and properties

The Shapley value is the share gained by a player i when he is in coalition S. This value$\varphi_i(S,V)$ as defined by Shapley in [14] and [15] is given by:

$$\varphi_i(S,V) = \frac{1}{N!}\sum_{\pi\in\Pi} \Delta_i\big(V, S(\pi,i)\big)\ \forall i \in N \tag{8}$$

where N is the set of players and S a given coalition formed by a subset of these players, $V(S)$ is the worth function that denotes the weight or payoff of coalition S, Π is the set of all $N!$ players permutations, $S(\pi,i)$is the coalition formed by players from rank 1 till i in a given permutation. $\pi \in \Pi$ and $\Delta_i\big(V,S(\pi,i)\big) = V(S) - V(S\backslash\{i\})$ is the marginal contribution of player i in coalition S defined as the difference between the worth functions of (S) and $(S\backslash\{i\})$ and representing the benefits or losses that player i could bring if he entered coalition $(S\backslash\{i\})$.

Note that the Shapley value has the following additivity property: if the worth function V(S) can be divided into two components $V(S) = V_1(S) + V_2(S)$, then the Shapley value is equal to:

$$\varphi_i(S,V) = \varphi_i(S,V_1) + \varphi_i(S,V_2) \tag{9}$$

5.2 Profit Sharing Using Shapley Value

In our model, there are two players only, LTE and WiFi, considered managed by the same operator in scenario 1, and by different operators in scenario 2.

The profit is the difference between the total revenue and costs, and is to be shared among the different players in the system. Using the above defined Shapley additivity property, the worth function of any coalition S, i.e., its payoff $V(S)$, is simply the difference of the revenue worth function $V_r(S)$ and $V_c(S)$. This yield the profit share of each player i as follows [14]:

$$\varphi_i(S,V) = \varphi_i^r(S,V_r) - \varphi_i^c(S,V_c) \tag{10}$$

where r and c are the revenue and cost components respectively.

We now derive closed-form expressions for the Shapley value so as to ease its numerical computation and overcome the exhaustive summation in equation 8.

5.2.1 Revenue Sharing:

5.2.2 Revenue depends on the pricing of data traffic offered to mobile users, and the volume of this traffic. In general, operators offer various data bundles with a flat rate for each one. Therefore, by having the total number of mobile subscribers within the LTE network, N_L, , and the number of users transferred to the WiFi network, N_W, along with their related average Mbps volume per month, the operator can estimate the related revenues.

Let $\gamma_L$andγ_w be the total average volume in Mbps per month per user connected on LTE and per user transferred to WiFi respectively. This volume is calculated based on an average value per month calculated from equation 1. λ is the price per Mbps per user in LTE network as presented in table 1.

The revenues of the network in presence of LTE only, and in presence of LTE and WiFi are calculated as per the below equations respectively:

Case where WiFi supports LTE:

$$\mathrm{G_L} = (\mathrm{N_L} - \mathrm{N_W}) * \gamma_L * \lambda \tag{11}$$

$$G_{L,W} = (N_L - N_w) * \gamma_L * \lambda + N_w * \gamma_w * \lambda \tag{12}$$

Case where WiFi does not support LTE:

$$G_L = (N_L * \gamma_L * \lambda) - (N_W * \gamma_W * \lambda) \tag{13}$$

$$G_{L,W} = N_L * \gamma_L * \lambda \tag{14}$$

Revenues in presence of WiFi network only are not applicable, since this case is not considered, thus $G_w = 0$.

By applying the Shapley value of equation 8, we calculate the share of both LTE and WiFi in the revenues, assuming the different permutation of the two players as per the below equations:

$$\varphi_L^r = \frac{1}{2}.(G_L + G_{L,W}) \tag{15}$$

$$\varphi_W^r = \frac{1}{2}.(G_{L,W} - G_L) \tag{16}$$

φ_L^r and φ_W^r are the shares in revenues of LTE and WiFi respectively.

5.2.3 Cost Sharing:

5.2.4 The cost of equipment and related operations expenditure for the LTE BS and WiFi AP areC_{LBS} and C_{WAP}respectively presented in table 1.

In addition, based on equation 8, the cost shares of the network in presence of LTE only, and in presence of LTE and WiFi are calculated as per the below equations:

$$C_L = L \,.\, C_{LBS} \tag{17}$$

$$C_{L,W} = (K.C_{WAP}) + (L.C_{LBS}) \tag{18}$$

K is the number of WiFi APs calculated in equation 7, and L is the number of LTE BSs that will assure an average throughput per user greater than 20 Mbps for around 100 simultaneous active users [11] (minimum values for L are considered as follow: $L = 1$ in case of WiFi support, $L = 2$ in case WiFi does not support LTE).

Similarily, the cost in presence of WiFi network only is not applicable since this case is not considered, thus$C_W = 0$.

Same method based on Shapley value is applied for the cost shares of LTE and WiFi to get the below equations:

$$\varphi_L^c = \frac{1}{2}.(C_L + C_{L,W}) \tag{19}$$

$$\varphi_W^c = \frac{1}{2}.(C_{L,W} - C_L) \tag{20}$$

5.2.5 Profit Sharing:

5.2.6 The profit distribution of each player is simply the difference between its revenue and cost share as per equation 10.

We consider as previously described two scenarios:

- Scenario 1: the case of a single, joint LTE/WiFi operator.
- Scenario 2: the case where the LTE and WiFi operators are separate.

For both scenarios, we calculate the profit in case WiFi APs supports LTE for its heavy users and in case there is no WiFi support.

In scenario 1, we consider the total cost share, revenue share and profit share as per the below equations:

$$\varphi^c = \varphi_L^c + \varphi_W^c \tag{21}$$

$$\varphi^r = \varphi_L^r + \varphi_W^r \tag{22}$$

$$\varphi = \varphi^r - \varphi^c$$

(23)

Whereas in scenario 2, the profit share is calculated separately for LTE and WiFi as per the below equations:

$$\varphi_L = \varphi_L^r - \varphi_L^c \tag{24}$$

$$\varphi_W = \varphi_W^r - \varphi_W^c \tag{25}$$

Due to its fairness, the profit distribution under Shapley value is appealing in cooperative games. Each player is rewarded a profit proportional to its contribution in the overall profit. This is demonstrated in the simulation results section, where the profit started to be positive or beneficiary, in case of WiFi support, earlier than the case of without WiFi support. This is due to the fact that the cost of investment in WiFi is much less than the additional cost of investment for the LTE BSs, with same subscribers' revenues and offered throughput per user.

Simulation results and performance evaluation

We consider in our simulations, an LTE FDD system for one eNB cell operating in 1800 MHz with an available bandwidth of 10 MHz [8] [16]. The WiFi network is based on 802.11n system that operates in 2.5 GHz bandwidth with 12 overlapped channels on the physical layer [9].Every Transmission Time Interval (TTI), the eNB makes a scheduling decision to dynamically assign the available time-frequency RBs to the UEs. The eNB scheduler aims at power minimization while also at satisfying UEs demands.

Table 1 summarizes the basic system model configuration, while considering a total number N_c of LTE users operating in the heterogeneous network varying from 10 to 100 users per eNB making simultaneously data sessions.

TABLE 1
SYSTEM CONFIGURATION

Parameters	Values
Bandwidth	10 MHz
Duration	10 ms
RBs per Time Slot	50
RBs per TTI	100
Subcarriers per RB	12
Max eNB TX Power	43 dBm
Max UE TX Power	23 dBm
Symbols per RB	7
Number of subframes(T)	20
Block Error Rate	0.1
Channel Gain	6 dB
Max WiFi AP	600 Mbps
Cost of LTE BS	45,000 USD
Cost of WiFi AP	500 USD
Cost of 1Mbps data traffic	0.001 USD

Based on the configured setup, we present in this section, numerical results by using MATLAB to analyze the minimum required number of WiFi APs versus LTE and WiFi throughput. By varying the number of simultaneous active users in the LTE cell from 10 to 100 active users, Fig.2 represents the number of users considered as heavy users and that need to be offloaded to WiFi network.

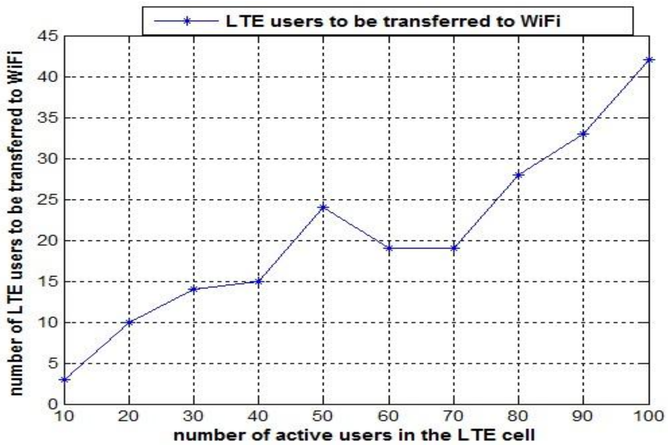

Fig. 2. Number of users to be offloaded to WiFiwith respect to the total number of active users in the LTE cell.

Taking into consideration that the LTE users will be offloaded when their demands exceed the 20 Mbps, considered as the average per user throughput in LTE-A network [11], the minimum needed number of WiFi APs, and the acquired throughput in the WiFi network are shown in Fig. 3 and Fig. 4 respectively, noting that there is no restriction in this case on the maximum offered throughput per user in the WiFi network.

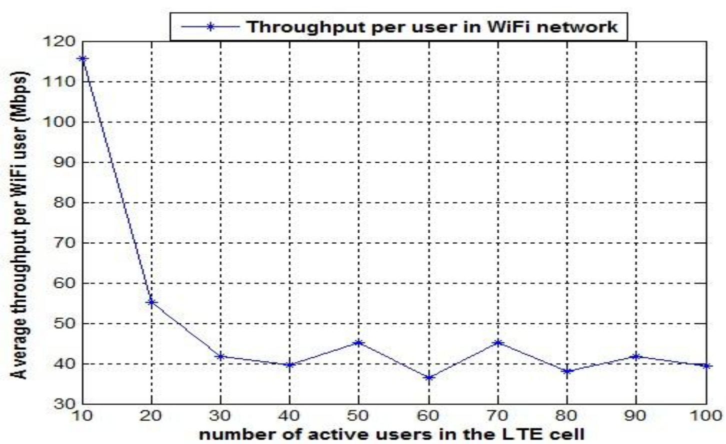

Fig. 4. Average per user WiFi throughput (Mbps)

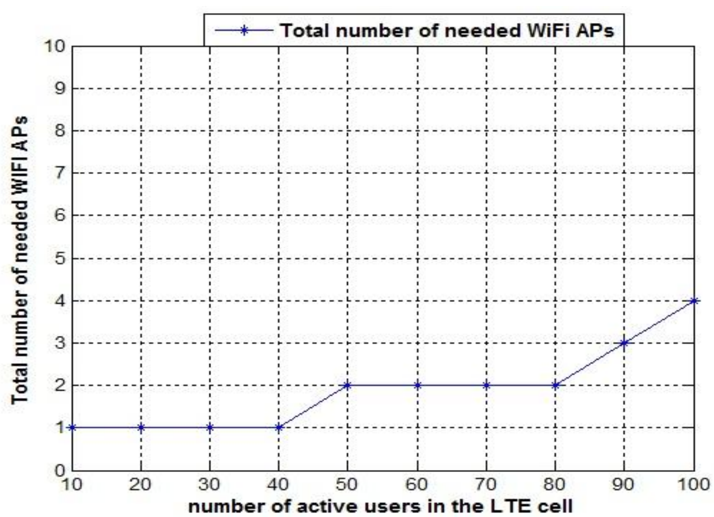

Fig. 3. Total number of needed WiFi APs with no limitation on average per user WiFi throughput.

As we can observe, with few LTE users to be offloaded, the WiFi network with only one AP can provide up to around 120 Mbps as theoretical value on top of its existing users. The WiFi throughput per user decreases with the additional number of offloaded simultaneous active users, with an average of 40 Mbps, thus greater than the maximum defined threshold in the LTE network (20 Mbps). By adopting this method, in addition to the saved cost when increasing the WiFi APs in indoors environment, to a maximum of 4 APs as shown in Fig. 3, instead of increasing the number of eNBs; the user experience will be enhanced instead of suffering from any possible congestion or throughput deterioration with limited number of LTE eNBs.

If we take the scenario of a restricted threshold of throughput offered to the offloaded users in the WiFi network (e.g. a max of 20 Mbps), the needed number of WiFi APs will be reduced to 3 APs as presented in Fig. 5.

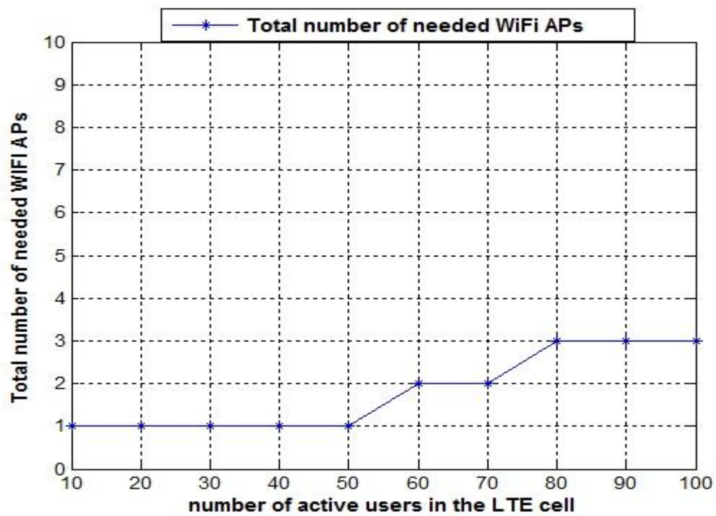

Fig. 5. Total number of needed WiFi APs with average per user WiFi throughput set to 20 Mbps maximum.

To pinpoint the saving in LTE when applying our proposed dimensioning method, we have measured the average power consumption saving related to the transmitted power after being transferred to WiFi. Fig. 6 and Fig. 7 represent the average saved power consumption in the eNB in Watts, and the percentage of power saving in respect to the total consumed power, respectively.As we can observe, there is on average 40% saving of the total consumed power in the eNB.This saving is expected to grow obviously when the number of offloaded users increase.

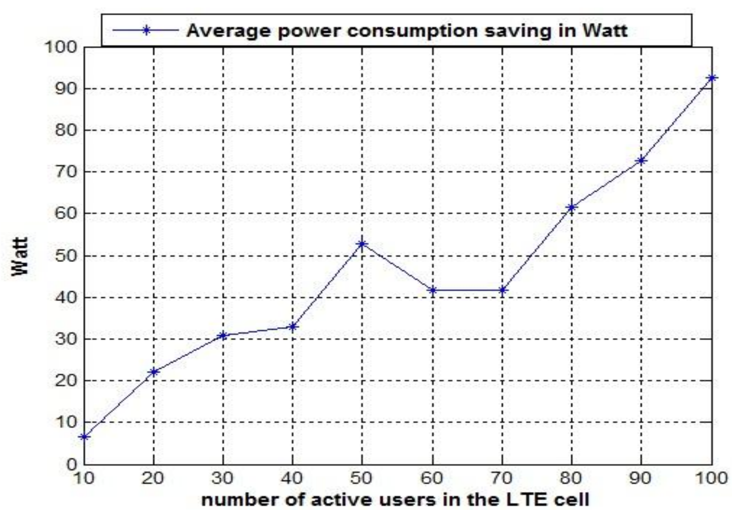

Fig. 6. Average Power Consumption saving in Watt.

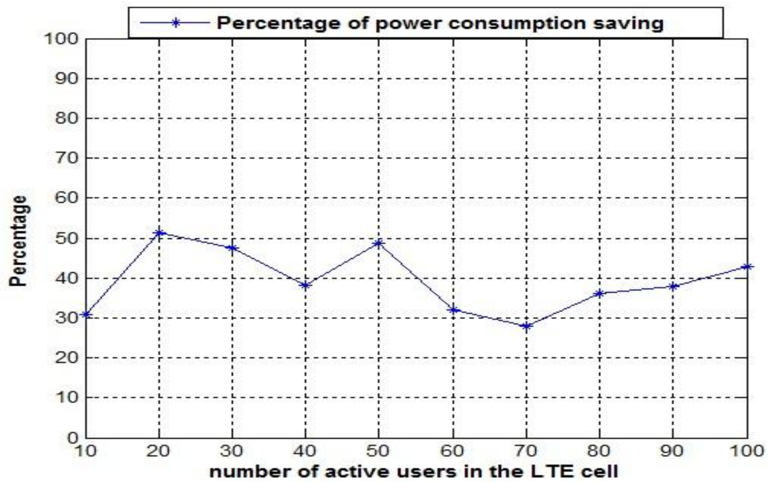

Fig. 7. Percentage of Power Consumption saving.

Finally, the results of the profit calculations based on Shapley value are presented in Fig. 8 and Fig. 9 for the scenario 1 (joint operator) and scenario 2 (separate operators), respectively.

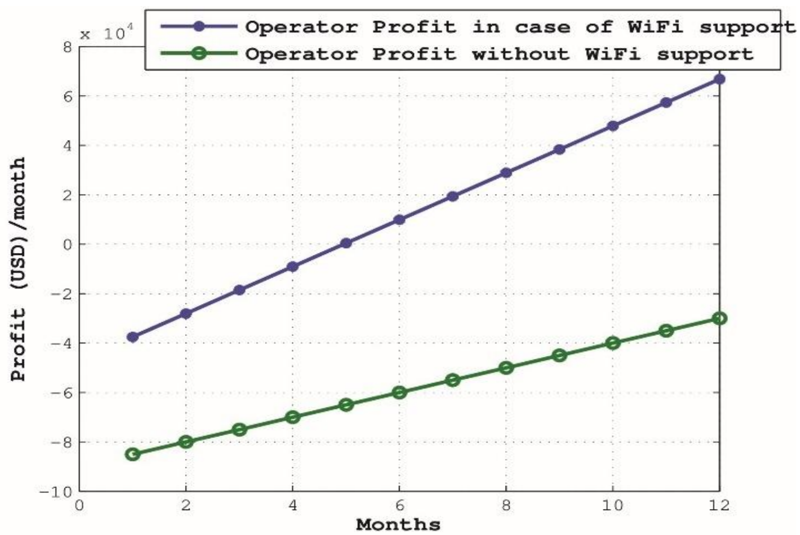

Fig. 8. Profit in case of Joint WiFi/LTE operator

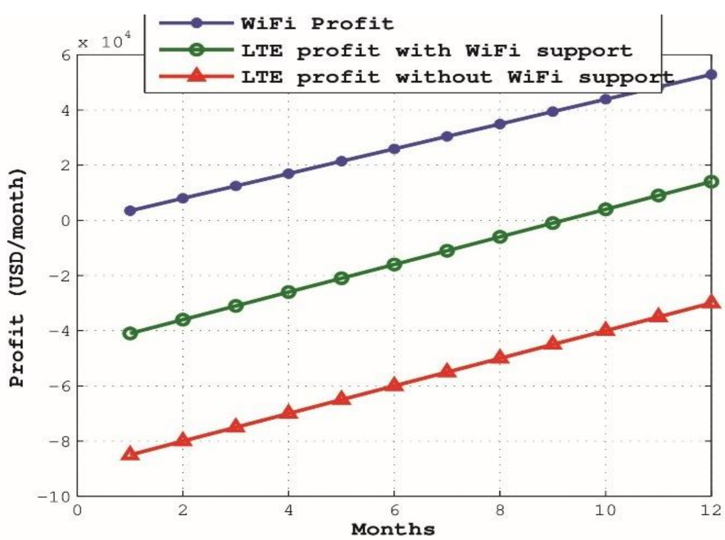

Fig. 9. Profit in case of separate WiFi and LTE operators

The study is spread over 12 months where we only consider that the subscribers' number is constant during this period without additional growth on LTE network (data traffic and network expansion). In this case we consider that a minimum of 1 BS is needed for 100 simultaneous active users with WiFi network support, and 2 BSs are needed in case of no WiFi support. After one year, the growth of subscribers and consequently the growth of revenues will affect both LTE and WiFi dimensioning, which will be considered as a further study not found in this paper. In case of joint operator in Fig. 8, we can observe that the breakeven point for profit is found almost starting the 5th month where the revenues share become higher than the investment cost in case WiFi supports LTE. However, this gain is much more delayed for almost several additional months in case there is no WiFi support.

In the case of separate operators in Fig. 9, the positive profit is noticeable starting the 9th month whereas staying less than the profit in case of WiFi support for joint operator. Thus, we can conclude that the Return on Investment (ROI) is maximum in the scenario where the operator owns both WiFi and LTE networks and while WiFi is providing support to LTE. Finally, we can as well observe that the profit of the WiFi is always positive in case of separate operators as shown in Fig. 9, since the traffic transferred to WiFi is directly covering the investment expenses or cost.

Conclusion

In this paper, we have proposed a mathematical approach to find the minimum required number of WiFi APs to support the heavy users' traffic transferred from LTE to WiFi network, based on the remaining available capacity of the WiFi network. This capacity was estimated considering the overlapping characteristics of the physical channels of the WiFi technology, where we can estimate the average percentage of busy time and idle time of the channels during peak hours traffic and for several days to estimate the global occupation and thus capacity of the WiFi network.

The benefit of the proposed WiFi dimensioning method, which cooperates with LTE to handle the heavy users' traffic, is presented through the profit calculations by applying the gaming theory Shapley Value. The estimated profit using Shapley value is maximal when the same operator owns both WiFi and LTE networks and while WiFi is supporting LTE. Furthermore, through the mathematical approach proposed in our paper, we can ensure an efficient coexistence between LTE-A and WiFiHetNets, while providing a high level of bit rate to the end users, and with minimum required hardware and investment cost.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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