Resources Negotiation for Network Virtualization in LTE-A Networks

Georgia Tseliou *, Ferran Adelantado * and Christos Verikoukis †
* Open University of Catalonia (UOC), Barcelona, Spain
† Telecommunications Technological Centre of Catalonia (CTTC), Castelldefels, Spain
{gtseliou, ferranadelantado}@uoc.edu, cveri@cttc.es

Abstract—Radio Access Network (RAN) virtualization is a promising commercial solution where multiple service providers can share underlying radio physical resources and dynamically compose heterogeneous virtual networks that coexist in isolation within the same physical infrastructure. Based on the expected future requirements, this work proposes a solution named Resources nEgotiation for NEtwork Virtualization (RENEV), which can be applied in Long Term Evolution-Advanced (LTE-A) environments, consisting of numerous small cells. This algorithm aims at achieving an efficient mapping of radio virtual network elements onto the radio resources of the existing physical network, utilizing the concept of radio resource transfer. It establishes a common virtualized control layer by handling the resources in an holistic way. The proposed solution achieves significant gains in terms of system throughput and its performance is evaluated by means of analytical model, as well as simulation results.

Index Terms—Small cell deployment, LTE-Advanced, RAN virtualization, Resources negotiation

I. INTRODUCTION

The management and provision of services of current networks, cannot match the more demanding and fast changing requirements imposed by end-user applications. Due to the existence of multiple stakeholders and the need of reducing deployment costs, network virtualization has been proposed as a promising technique to overcome the ossification of the current Internet. Coupled with an effective and efficient approach to manage virtualized resources, it is expected to be the central element of future architectures.

Today’s cellular networks have relatively limited support for virtualization. Long Term Evolution-Advanced (LTE-A) supports the isolation of different enterprise customers’ traffic into Virtual Private Networks (VPN) using traditional Border Gateway Protocol (BGP) / Multi-protocol Label Switching (MPLS) VPN technologies. However, one of the main open issues is that LTE-A does not allow different carriers to share the infrastructure to offer a complete virtual LTE-A solution to their customers. In addition, current sharing solutions have limitations in terms of separating control and data planes among operators, accommodating different requirements per operator, and adapting updated requirements. Consequently, the necessity for sharing the existing and future infrastructure among several operators and service providers in a seamless and isolated way is imminent.

Moreover, the necessity for network virtualization becomes even more important in dense architectures. The latest release of LTE-A has been especially focused on small cells, i.e. Home Evolved Universal Terrestrial Radio Access (E-UTRA) NodeBs (HeNBs) [1]. LTE-A offers the opportunity of creating very dense architectures, consisting of multiple tiers but the network sharing architecture proposed by Third Generation Partnership (3GPP) allows different core network operators to connect to a shared Radio Access Network (RAN) without exploiting this heterogeneity [2]. In the end nowadays, a single network market with operators competing at the service layer is considered a commercially viable model [3].

The motivation for this work is twofold: we want to utilize the concept of sharing resources in terms of physical Resource Blocks (RBs) in on-demand and self-service way, to achieve the principles of RAN virtualization in LTE-A, and in parallel take advantage of the newly introduced concept of small cells to offload the available data traffic. The contributions can be summarized into the following points:

• A solution based on resources transfer is presented: the Resources nEgotiation for NEtwork Virtualization (RENEV) algorithm. It is a solution of mapping virtual path requests to substrate physical topology. It is a step towards Radio Resource Management (RRM) in the context of network virtualization without altering the nodes of the existing architecture.

• We focus on how to utilize the fractional radio resources spread around on multiple physical small cells using the concept of physical resource transfer. This concept is an efficient way to redistribute the available resources and help small cells to serve seamlessly the maximum possible number of users.

The remainder of this paper is organized as follows. After presenting the related work in Section II, we describe the network deployment, the RRM procedure and RENEV algorithm for resources negotiation in Section III. Section IV provides the analytical framework for the aggregate system throughput calculation whereas Section V presents the performance evaluation of the proposed algorithm. Finally, Section VI contains the conclusions and some ideas for future work.

II. RELATED WORK

Network virtualization area in cellular networks field requires more attention. Although some results have recently been published, there is still a great need for more comprehensive ones addressing relevant issues so as to support
the emerging content-rich end-user services in a cost-effective way. Network virtualization, as a concept, can be applied in several sections of the network; also in the case of cellular networks two options for its application arise: the Evolved Packet Core (EPC) Network and the RAN. We are going to focus on the RAN side of LTE-A that makes possible the easy creation and management of virtual networks, opening up a range of new business models.

Spectrum sharing is a key technique in LTE-A RAN virtualization; it can be used at the radio interface to adapt to the traffic load variation of different virtual networks. The term eNodeB virtualization refers to the case where multiple virtual networks share the spectrum of the same physical eNodeB. In [4], a scheduling framework of the available spectrum between different eNodeBs belonging in different operators is proposed. A controlling entity called hypervisor is also included to make use of a priori knowledge in order to schedule the RBs.

A feature called Network Virtualization Substrate (NVS) has been proposed by [5] and [6], for managing and sharing the radio spectrum and eNodeB processing resources. In this work, a slice scheduler which works in conjunction with the Medium Access Control (MAC) processing monitors the amount of resources that the MAC scheduler assigns to each slice of a Macro eNodeB; so it dynamically adjusts the bearer priorities in the MAC scheduler to maintain the required resource allocation for each operator.

Dynamic resources’ slicing is another category of solutions based on the concept of RAN virtualization. The authors of [7] have proposed CellSlice; a dynamic framework to achieve active RAN sharing by remotely controlling the scheduling decisions, ensuring that each entity receives its share of the wireless resources. This idea does not require the modification of the Base Station (BS) schedulers but it constrains the BS scheduling decisions from a remote gateway.

In [8] the authors present a software defined cellular network architecture that allows controller applications to express policies based on the attributes of subscribers, rather than network addresses and locations, enables real-time, fine-grained control via a local agent on each switch, and extends switches to support features like deep packet inspection and header compression to meet the needs of cellular data services. Finally, in study [9] that completes the previous work, the same authors add to the proposed system an entity called CellSDN controller. Its design has as target to separate traffic management from the low-level mechanisms for installing rules and minimizing data-plane state.

Obviously, researchers have a tendency to focus on slicing the available spectrum instead of proposing solutions where the spectrum is delivered on-demand to the participating operators. Since LTE-A is an Orthogonal Frequency Division (OFDM) based system, the whole system bandwidth is available for an eNodeB. However, not all the subcarriers are used simultaneously in a specific set of cells, i.e. according to Inter-Cell Interference Coordination (ICIC) techniques each subcarrier is never allocated to more than one BS simultaneously. Accordingly, an efficient use of the available radio resources can be achieved if a proper coordination / negotiation of the resources is carried out among the BSs. Moreover, to the best of our knowledge, there is no previous work that takes into account the concept of resources negotiation by exploiting the dense LTE-A environment. RENEV presents a practical solution based on network virtualization to implement such resources negotiation. As the minimum resources unit defined in LTE-A is the RB (a 0.5msec time slot with 180KHz bandwidth), our work proposes the negotiation of the resources among BSs on RB basis.

III. PROPOSED SCHEME

A. Network Deployment

In principle, a wireless cellular network deployment has two main objectives. Firstly it should guarantee coverage continuity by minimizing the outage probability and interference levels and secondly it should be able to reduce the cost of the deployment itself. Although cellular network deployment has been traditionally modeled with regular hexagonal shaped cells, this is no longer valid in current and future networks. The inclusion of small cells, e.g. HeNBs, along with the irregular traffic distribution poses new challenges in the management of the radio resources. In such a context, the underlying considered network, is a residential region composed of an eNodeB and a number of HeNBs located close to each other in random positions [2]. Throughout the rest of this work, we refer with the general term BS to all the RAN nodes of the system, both eNodeBs and HeNBs.

When a user is served by a certain HeNB, this latter is called serving HeNB of the user. Here, an open access small cell network is considered and we assume that the downlink transmitted power is fixed and the same for all the HeNBs. In particular such consideration is efficient in today’s 3GPP LTE-A where the same amount of power is transmitted on all RBs and there is no or very limited power control in the downlink [10].

B. Resource Management in LTE-A

As radio resources are scarce and at the same time the number of users and their demands increase, their management becomes a crucial point in the performance of any wireless network. In LTE-A, small cells are involved in distributed control protocols in order to manage various procedures such as handoff, interference etc. They also handle admission control and radio resource allocation. Radio resource is an inherently shared characteristic among RAN nodes, so the lack of central control leads to several difficulties in optimizing the radio access related tasks [3].

Our proposal focuses on the Access Stratum (AS) of the LTE-A. The control plane of a RAN node can be logically split into two entities: the baseband and the network module. The baseband module is responsible for bearer configuration with the users via the Radio Resource Control (RRC) protocol whereas the network module connects the BS with the EPC network. RRC, is a Layer 3 AS protocol of the control plane layer that handles the User Equipment (UE) management and
controls Layer 2 and Layer 1 parameters, as well as UE - eNodeB Signalling by transferring common dedicated information. Furthermore, the latest 3GPP specification of LTE-A, supports the direct control and data information exchange between HeNBs via the definition of the point-to-point, logical X2 interface. This occurs independently of whether any of the involved HeNBs is connected to an intermediate node or not [2].

RRM is an eNodeB application level set of functions, ensuring the efficient use of available radio resources. RRM manages the assignment, re-assignment and release of radio resources, taking into account single and multi-cell aspects. The RRM, at RRC is performed by the following functions: Radio Admission Control (RAC) and Radio Bearer Control (RBC). RAC admits or rejects the establishment requests for new radio bearers in the cell, whereas RBC builds, maintains and releases the radio bearer by taking into consideration all the radio resources of the cell [11]. RBC maintains radio bearers of existing users and releases the bearers after each user ends its communication. A new bearer will be built only if the radio resource in the cell is surplus [12].

One of the main principles of network virtualization as a concept, is the division of the control and data planes of a system. The innovation inserted by RENEV, is based on the fact that the baseband part of the RAN nodes could be shared among different HeNBs and a common RRC layer for a specific group of them could be created; the target is to concentrate and orchestrate the control plane functionalities to serve a specific group of users. It creates a common control plane among a group of HeNBs where the available radio resources could be dynamically transferred in the network, according to the users’ demands in an holistic way. The control plane of LTE-A in the RAN nodes is concentrated in RRC protocol, which is terminated in the BS on the network side. Its main functionalities are the establishment of the connections with the users, configuration of the radio bearers and their corresponding attributes and control of mobility.

C. Resources Negotiation for Network Virtualization (RENEV) Algorithm

Physical resource migration among HeNBs, is necessary for covering the traffic demands of the existing users. Since a HeNB has some spare resources, it is available in order to participate to the resources negotiation process. This process is decentralized since all the existing HeNBs of a topology can participate, as soon as they have spare resources.

So in this work, we propose RENEV for resources negotiation between small cells, by the cooperation of RAC and RBC functions, belonging in RRC of different small cells. This solution is based on radio physical resource transfer in isolation and on-demand basis. Furthermore, our solution supports common RRC scheduling between different HeNBs. RENEV is described by the following steps:

Step 1: If a user can be served by the resources of the serving HeNB then it gets served [11].

Step 2: Otherwise:

- The user enables the RRC connection with the serving HeNB.
- This HeNB finds the nearest 1 and less loaded neighbour HeNB.
- When it finds it, the two RRC functions of the node are enabled; the RAC function is responsible for checking if the node has the available resources and the RBC for establishing the radio bearer.
- A control connection is created between the involved HeNBs via the logical point-to-point X2 interface.
- The serving HeNB leases the demanded resources so the user is getting served. This happens by setting up X2 interfaces and resetting the link resolving security issues for the exchange of HeNB configuration data over the link.

The target metric that this algorithm improves is the aggregate system throughput, since the resources negotiation in terms of RBs affect the data rates that are delivered to all terminals in a system.

IV. Analytical Formulation

A. System Model and Assumptions

The general topology where the RENEV is applied is a dense residential area including two tiers; a macro BS and randomly located small cells. The two tiers use different carriers so as not to have interference issues. The algorithm is applied only in the small cells tier and consequently only users connected to that tier are considered. The users of the system have specific characteristics in terms of demanded traffic. To represent the network random deployment, it is assumed that HeNBs are randomly distributed on a two-dimensional Euclidean plane $\mathbb{R}^2$. Within this model, let us denote by $x_i \in \mathbb{R}^2$ the location of an HeNB. By the above considerations and notation, the signal strength from an HeNB $i$ received at a location $y \in \mathbb{R}^2$, expressed in dB, is thus:

$$p_i(y) = P_{Tx} - L_i - \{X_i\},$$  \hspace{1cm} (1)

where $P_{Tx}$ is the constant that includes antenna gains and transmitted power, and $L_i$ is the path loss from the HeNB to $y \in \mathbb{R}^2$. Although $L_i$ depends on the location $y$, it is omitted for the sake of simplicity. In a general sense, the fading includes medium-scale variations which are due to shadowing, and short-scale fluctuations whose main effect is this on the bit level performance. In our case, only medium-scale variations are considered [13]. Slow shadowing is commonly described as a log-normal distributed random variable. Accordingly, the shadowing may be modelled by a normal variable, namely $\{X_i\}$, when expressed in logarithmic units, with 0 mean and a standard deviation $\sigma_x$ typically around 8dB.

The signal quality of HeNB $i$ expressed in terms of signal-to-interference-plus-noise ratio (SINR) received at $y$, when no interference is received, is given by:

1The term “nearest” indicates the neighbour HeNB located geographically closer to the serving HeNB. This fact restricts the effect of the algorithm geographically, in order to avoid instability issues.
\[ Q_i(y)_{dB} = p_i(y) - N_0, \]  
\[ (2) \]

where \( N_0 \) represents the noise average power. In our work, as subcarriers are not reused by neighbouring cells, we consider that interference is negligible. In the following, the aggregate system throughput is analysed, with respect to a nominated user located at the origin. Note that in case of no ambiguity, we will omit the location variable \( y \) in involving definitions for notational simplicity.

B. Problem Setup

In principle, it should be beneficial to the network throughput to associate each mobile to the HeNB from which it obtains the best signal quality. In our case, we simply assume that the number of RBs per HeNB are allocated a priori and that each mobile is always connected to the HeNB of the best signal quality. This provides the upper bound of the network throughput. Let \( Y \) be the best SINR received from the HeNBs located in an area \( B \). Following (2), it is expressed as \( Y = \max_{x_i \in B} Q_i \).

Discrete adaptive Modulation and Coding Schemes (MCSs), (i.e. quaternary phase-shift keying (QPSK), 16 quadratic-amplitude modulation (QAM), and 64-QAM) are supported in this work [14].

C. Formulas of Aggregate Throughput

Using the above definitions, we are able to formulate and derive the aggregate throughput for the downlink in the cases whether the algorithm is applied or not. In this section the final corresponding elaborated equations are presented, whereas in section IV-D the analysis follows. In a scenario where the proposed algorithm is not applied, the users connected to a particular BS must be served with only the resources allocated to the HeNB. On the contrary, when the proposed algorithm is applied, resources can be transferred from one HeNB to another, according to their subscribers’ needs. Given a total number \( N \) of users in the scenario, the throughput achieved in HeNB \( i \) when the proposed algorithm is not applied, \( T_i \), may be expressed as:

\[ T_i = \min(N \cdot P(Q_i = Y) \cdot R, T_i^{RB} \cdot B_i), \]
\[ (3) \]

where \( R \) is the mean user demand (in bps), \( P(Q_i = Y) \) defines the probability of having the maximum value of SINR, \( T_i^{RB} \) is the average throughput per RB in HeNB \( i \) and \( B_i \) is the resources allocated to HeNB \( i \) (i.e. the number of RBs). The aggregate throughput of the scenario is then,

\[ T = \sum_i T_i. \]
\[ (4) \]

On the contrary, when the resources negotiation algorithm is applied, the whole pool of resources is dynamically distributed among the HeNBs. In this context, the mean throughput of a single RB within the scenario, \( T_i^{RB} \), is denoted as:

\[ T_i^{RB} = \sum_i T_i^{RB} \cdot P(Q_i = Y), \]
\[ (5) \]

and accordingly the aggregate system throughput is:

\[ T = \min(N \cdot R, T_i^{RB} \cdot \sum_i B_i). \]
\[ (6) \]

D. Analysis

According to each user’s distance from the serving HeNB centre, it obtains a certain SINR value. This value is responsible for the corresponding MCS that will be used among the available ones (i.e. QPSK1/2, QPSK3/4, 16-QAM1/2, 16-QAM3/4, 64-QAM2/3, 64-QAM3/4). The probability of using a certain MCS in the HeNB \( i \), is expressed as \( P_i(MSC_n) \).

The average throughput per RB in HeNB \( i \) can be calculated by the following formula:

\[ T_i^{RB} = \sum_{n=0.5}^{RB^n} P_i(MSC_n), \]
\[ (7) \]

where \( RB^n \) denotes the throughput achieved with a single RB according to the corresponding \( MCS_n \). The terms \( Q_i^{min} \) and \( Q_i^{max} \), denote the minimum and the maximum SINR with which \( MCS_n \) is applied. Since the probability of achieving a certain MCS depends on the SINR, it could be expressed as:

\[ P_i(MSC_n) = P(Q_i^{min} \leq Q_i < Q_i^{max}) = P(Q_i^{min} \leq Q_i < Q_i^{max} \cap Q_i = Y), \]
\[ (8) \]

where \( Q_i = P_{Tx} - L_i - \{X_i\} - N_0 \) according to (2). The denominator of the expression (8), equals to:

\[ P(Q_i = Y) = P(\cap_{j \neq i} Q_i > Q_j) = \prod_{j \neq i} P(Q_i > Q_j), \]
\[ (9) \]

since SINR values of a particular HeNB are considered to be independent from the SINR of the rest of the HeNBs. From (9) it is necessary to calculate the probabilities of having higher SINR values in an HeNB, denoted by \( P(Q_i > Q_j) \):

\[ P(Q_i > Q_j) = P(P_{Tx} - L_i - \{X_i\} - N_0 > P_{Tx} - L_j - \{X_j\} - N_0) = P(\{X_i\} > \{X_j\} + \mu_{ij}), \]
\[ (10) \]

where \( \mu_{ij} = L_i - L_j. \)

It should be noted that \( \{X_i\} \) and \( \{X_j\} \) are both random variable following Gaussian distributions with the same mean and deviation. We denote as \( f_{x_i} \) and \( F_{x_i} \) the corresponding Probability Density Function (PDF) and Cumulative Density Function (CDF) of the shadowing, expressed in dB. Based on the analysis in [15], and after a convenient change of variables, equation (10) is equal to \( F_{X_i}(\mu_{ij}) \cdot \frac{\mu_{ij}}{\sigma \sqrt{2}} \). Furthermore, the probability of the joint occurrence of pairwise and global independent events is equal to the product of the events’ marginal probabilities. Correspondingly, the numerator of (8) can be calculated as follows:

\[ P(Q_i = Y) = \prod_{j \neq i} P(Q_i > Q_j) = \prod_{j \neq i} P(Q_i > \mu_{ij} + \{X_j\}). \]
can be expressed as follows:

\[ P(Q_n^{\text{min}} \leq Q_t < Q_n^{\text{max}} \cap Q_i = Y) = \prod_{j \neq i} P(Q_n^{\text{min}} \leq Q_t < Q_n^{\text{max}} \cap Q_i > Q_j). \] (11)

If we substitute the values \( \{X^0\} = P_{\text{Tx}} - Q_n^{\text{max}} - L_i \) and \( \{X^1\} = P_{\text{Tx}} - Q_n^{\text{min}} - L_i \), each of the components of (11) can be expressed as follows:

\[
P(\{X^0\} \leq \{X_i\} < \{X^1\} \cap \{X_j\} > \{X_i\} + \mu_j) =
\int_{\{X^0\}} f_{x_i}(x_i) dx_i - \int_{\{X^0\}} f_{x_i}(x_i) dx_i + \int_{\{X^1\}} f_{x_i}(x_i) dx_i - \int_{\{X^1\}} f_{x_i}(x_i) dx_i
\]

\[
= (F_{x_i}(\{X^1\}) - F_{x_i}(\{X^0\})) - \int_{\{X^0\}} f_{x_i}(x_i + \mu_j) f_{x_i}(x_i) dx_i
\]

\[
= (F_{x_i}(\{X^1\}) - F_{x_i}(\{X^0\})) - V(\{X^1\}, \{X^0\}).
\] (12)

Also, as noted, \( f_{x_i} \) and \( F_{x_i} \) are the PDF and the CDF of a normal variable. Expression (12) depends on the values of the random variables \( \{X^1\} \) and \( \{X^0\} \), as well as it has no closed form and it is evaluated numerically.

V. PERFORMANCE EVALUATION

We consider 3GPP HeNB settings for the setup of small cell network. The system transmission bandwidth is equal to 20MHz, corresponding to 100RBs, and the transmission mode is Single Input Single Output (SISO). A custom-made Matlab simulation tool is employed to validate the proposed scheme. Consider that there are 6 small cells not uniformly distributed in an area of 100m x 100m, belonging to one service provider and one network operator. The propagation path loss in the small cell network is given by the following path loss model [16]:

\[ L_{dB} = 37 + 30 \log_{10}(d) + 18.3 f(0.147 - 0.46), \] (13)

where \( d \) is the distance in meters from the antenna and \( f \) is the number of penetrated floors in the propagation path. For dense wireless networks that could be located generally, including outdoor urban areas where there are less penetrated walls and floors, \( f = 3 \) is considered in our work. It is assumed that the total transmit power including the antenna gain of each HeNB is 32dBm. Shadow fading is modelled as random variable with log-normal distribution of 0 mean and standard deviation 8dB. The received noise power is the one of an Additive White Gaussian Noise (AWGN) channel. In the following, we investigate small cell network performance under random topology.

In this set of experiments, we compare the system with and without the application of RENEV, to illustrate the benefits gained in terms of network’s aggregate throughput. We also compare it with NVS, another framework presented in works [5] and [6] of the state of the art, that opportunistically allocates the unused resources among the existing slices in a BS. We adapt this framework to our scenario that consists only of HeNBs, by creating distinct slices, each one accommodating a certain percentage of the overall RBs that can serve a specific number of users. All users inserted into the topology, download files using File Transfer Protocol (FTP) at an average data rate of 300Kbps in the downlink. Following common practice in commercial cellular networks, FTP requests are always admitted regardless of the system’s load conditions.

In Fig. 1 the aggregate system throughput is shown with respect to an increasing offered traffic load for the system with and without the application of RENEV as well as for the NVS framework. For low offered load, up to 9Mbps, the system’s behaviour is the same; the users’ demanded traffic is served in all the cases. However, as the load increases, the system without the application of RENEV is able to serve less traffic load, compared to the system where the algorithm is applied. When saturation is reached (i.e. when the offered load equals 27Mbps) the achieved throughput raises 45.11%. This could be explained by the fact that in the first case, the available resources are distributed among the group of the participants HeNBs in order to cover the maximum of the users’ traffic demand.

In the case where RENEV is not applied, each HeNB controls its own resources and after a while these resources are depleted. System saturation is reached in the case where more load is introduced but the existing RBs are depleted and consequently no more users can be served. NVS reaches higher system throughput than the system without the application of RENEV, due to its capability to allocate the free resources in the slices that contain users that need it. Since here one type of traffic and fixed percentage of resources among the slices are introduced, this solution restricts the number of the resources that are transferred. We could consider that RENEV adds one more dimension to the vision of NVS in order to achieve virtualization in LTE-A environments. NVS is based on the heterogeneity of services and RENEV on the idea of resources transferring in HeNBs that do not own specific percentage...
of resources to transfer. So, RENEV takes advantage of this capability adding one more degree of flexibility in the resource transferring among the existing flows that share one or more physical BSs.

Figure 2 depicts the percentage of the transferred RBs versus the offered load during the application of RENEV. When the demanded traffic reaches 27Mbps the system requires the highest number of RBs in order to satisfy the existing users; 23.15% of the total RBs belonging to the system are transferred. After this point, although the number of users that require resources is augmented, the number of transferred resources decreases because the system runs out of resources since all of them are already allocated to the existing users. HeNBs are only capable of transferring resources to other HeNBs when they have unused resources. Accordingly, when the offered traffic grows, the possibility of transferring resources to other cells falls. During the application of RENEV, as the offered load increases the HeNBs request more RBs. However, after a certain point, the successful RB transfer decreases.

![Figure 2 - Percentage of transferred Resource Blocks](image)

RENEV is a decentralized proposal for transferring resources among several HeNBs. This means that when the offered load is augmented, the total number of resources is distributed among the users according to their requirements dynamically as they come from a common pool. This leads to a peer-to-peer common RRC scheduling between the participants HeNBs and also a common control plane for the RAN nodes. With the use of RENEV, all the system’s resources are dynamically used according to the users’ needs on an isolated and on-demand basis. In this way, the majority of the users is served, as long as spare resources exist. In any other case, the users would receive lower quality of service or they could not get even served at all.

VI. CONCLUSION

In this paper, we propose RENEV, an algorithm for resources negotiation, in LTE-A cellular environments consisting of small cells. The proposed scheme takes advantage of the fact that in such environments not all the subcarriers are used simultaneously among the cells, so spectrum resources can be transferred from one HeNB to another. Due to the fact that the resources negotiation is conducted in an on-demand and isolated way, RENEV could be regarded as a RAN virtualization solution dedicated to LTE-A systems. The proposed solution achieves significant gains in terms of system aggregate throughput.

In addition, we note potential extensions of this work. A future step is to increase the small cell density and in parallel extend RENEV so as the macro BS to participate. Something that we should consider in this case is the potential interference between the two tiers. Besides, it would be interesting to see how the decision of which RB should be used has an impact on the achievable throughput. Finally, one interesting extension of this work is to investigate the system’s behaviour for emerging data traffic patterns which are different from the ones presented in this paper, for various numbers of service and network providers.

ACKNOWLEDGEMENTS

This work has been funded by the MITN Projects CROSSFIRE (PITN-GA-2012-317126) and GREENET (PITN-GA-2010-264759).

REFERENCES

[1] 3GPP. Overview of 3GPP Release 11 V0.1.4. 3GPP Std., March 2013.