Load Balance Algorithm Suitability: A New Paradigm on Self-Organized Networking

Fall Hachim[1], Ouadoudy Zytoune[2] and Yahyai Mohamed[1]

Abstract – **Spatio-temporal variation in traffic demand makes the cellular technologies suffer from load imbalance problem. The diversity of propositions handling this issue demonstrates their partial contribution to network performances. This paper presents Algorithm Suitability theory, which optimizes permanently system metrics. Based on software-defined networking and lexicographic optimality, it improves both energy and spectral efficiency.**

Keywords – **Algorithm, Cell State, Load Balance, Radio Resource Distribution, Software-Defined Networking, Suitability.**

I. Introduction

In a given wireless cellular network site, power and bandwidth budget are physically limited resources. Until the creation of 4G network technologies, the design of radio protocols was motivated by spectral efficiency (SE) due to the rising number of emerging high data rate wireless applications [1]. Meanwhile, energy efficiency (EE) has become, more and more, central concernsfor network operators in the rendezvous of effectiveness and green society. However, optimizing both SE and EE do not always coincide and may even conflict sometimes [2]. With the random behavior of mobile users, spatio-temporal variation in traffic demand causes a non-uniformly load distribution among cells and,leverages negatively the SE and EE performances. Third Generation Partnership Project (3GPP) provided load balancing (LB) operation through its self-organized network (SON) functionality [3]. As soon as the standard LB schemehas been published, it has been demonstrated that its original formulation could be optimized in term of SE and EE.In the light of scientific literature, several solutions have been proposed. Therefore, authors in [4] approach the phenomenon in the side of user Quality of Service (QoS) constraints. Differing from this study, authors of [5] introduce an EE scaling factor as a criterion for target cell selection in LB procedure. An interference-aware LB solver is studied in [6] where an optimal solution guarantees a low level of inter-cell interference (ICI), which leverages edge user throughputs. While in [6], a network state (ICI) is considered, authors in [7] advocate a cell-reselection-based LB scheme where they demonstrate an effectiveness in an environment with lot of small-size data packet services, which is a frequent scenario with the diffusion of smart phones.

[1]Fall Hachim and Yahyai Mohamed are with the department of mathematics at Ibn Tofail University, Morocco, E-mail: Hachim.fall@uit.ac.com.

[2]Ouadoudi Zytoune is with the National School of Management and Trading at Ibn Tofail University, Morocco.

By analyzing this non-exhaustive literature review, we realize that LB algorithms suffer mainly from these drawbacks: first, their diversity demonstrates their partial contribution in network performances. The consequence is a non-permanently optimized system. Second, their formulation uses combinatorial optimization approaches, which are often complex. Given that they are distributed among base stations (BS) that have limited capacity, they cause high power consumption and delay degradation. Third, the actual design principle is hardware oriented and is not in adequacy with next generation mobile cellular network requirements. Therein, scalability will be an important performance metric indicator [8].

To counter the limitations cited above, algorithm suitability (AS) is proposed as an interesting alternative. The concept tries to optimize permanently the network performance by benefiting from all advantages provided by different solvers. We define therefore what we call spectro-energy efficiency (SEE), which represents the number of bits received by a mobile per combined energy and frequency unit. A multi-objective function of EE and SE is formulated using scalarization method. By using information uploaded by BSs, a SDN (Software-Defined Networking) controller supervises in real time fashion the network state. Then, with a lexicographic optimality criterion, it maximizes the objective function by ascribing the resolution of two wireless LTE radio interface operations (LB and radio resource distribution (RRD)) to predefined optimizers.

After presenting the system model and problem formulation in Section II, the resolution through a lexicographic optimality criterion is described in Section III while Section IV discuss the obtained results before we conclude in Section V.

II. System Model and Problem Formulation

Consider a wireless cellular deployment and a set B of neighbor BSs. Let W_b be the available bandwidth atevery BS b. The access mode to LTE radio interface is based on Orthogonal Frequency Division Multiple Access (OFDMA). Every user k in the set K of mobiles turns a random number of services (VoIP, Streaming Video, Online gaming, etc…). The bandwidth W_b is shared in a set N of physical resource block (PRB). The resource allocation is submitted to relation (1), where $x_{k,n,s}$ represents an assignment parameter taking *1* when the PRB W_n is allocated to the mobile k on its service s and 0 otherwise.

$$\sum_n^N x_{k,n,s} W_n \leq W_b. \quad (1)$$

The bandwidth usage ratio is defined in Eq. (2) as:

$$\mu_b = \frac{\sum x_{k,n,s} w_n}{W_b}. \quad (2)$$

According to [9], when $70\% \leq \mu_b < 100\%$, the cell is heavily loaded, while $\mu_b \geq 100$ characterizes anoverloaded cell. Load Balance is recommendedand, a mobile user k is attached to only one BS b in the context of Eq. (3):

$$\sum_b m_{k,b} = 1 \quad (3).$$

Let K^e denotes a subset in K and represents the cell edge mobile users. At cell edge regions, the throughput of users suffer from SINR (signal to interference plus noise ratio) denoted$\alpha_{b,k^e}$and defined by Eq. (4):

$$\alpha_{b,k^e} = \frac{P_{b,k^e} H_{b,k^e}}{\sum P_{b',k^e} H_{b',k^e} + \delta}. \quad (4)$$

$P_{b,k}$ and $H_{b,k}$ denote respectively the power seen by the mobile $k$and the channel gain from BS b. δ is the Additive White Gaussian Noise (AWGN). The maximum available rate on a given PRB n for a mobile user k is given in Eq. (5) and, for a minimum rate $r_{k,s}$, on its service s, the required QoS follows relation (6):

$$R_{k,n} = W_n log_2(1 + \alpha_{b,k}) \quad (5)$$

$$\sum_n x_{k,n,s} R_{k,n} \geq r_{k,s} \quad (6)$$

For energy characterization, the power seen by a mobile k from BS b is the sum of total powers received in every PRB n:

$$\sum_k \sum_n P_{k,n} \leq P_{max} \quad (7)$$

P_{max} is the overall power budget available at the BS. The SE is defined as the number of bits received by a mobile per unit bandwidth and the global SE of a BS b is as seen in Eq. (8):

$$SE = \frac{R}{W_b} \quad (8)$$

where $R = \sum_k R_k$.

The EE represents the number of bits received by a mobile per unit energy as seen in Eq. (9):

$$EE = \frac{R}{P_{max}} \quad (9)$$

SE and EE are increasing function of bandwidth and power respectively and, their optimization may present two conflicting objectives [1]. LB Algorithms, which are based on Qos constraints [4], optimize the SE as the throughput requirement (constraint 6) relies on an efficient use of bandwidth. As far as that goes, the solvers taking into account the SINR [6], walks on the same way because a low level of ICI means a good rate while the energy-aware LB solver [5] relies on power mode of target BS. Without being a LB scheme, resource efficiency presented in [1] makes a combination of conflicting objectives as shown in Eq. (10). However, this scheme consider a perfect channel state information, i.e. without taking into account SINR phenomenon.

$$\text{Max} F = \gamma_1 SE + \gamma_2 EE \quad (10)$$

s.t. (1), (6), (7)

Eq. (10) is a summation of two parameters with different dimensions ((bit/Hz) and (bit/joule)). However, it could be interesting if we introduce the following parameters:

$$\beta_{EE} = \frac{EE}{W_b}, \quad (11)$$

$$\beta_{SE} = \frac{SE}{P_{max}}. \quad (12)$$

Interestingly Eqs. (11) and (12), measure the number of bit per unit energy and bandwidth (bit/(Hz*joule)). Thus, let SEE be a single parameter representing both SE and EE as seen in objective function represented by Eq. (13):

$$\text{Max} F_{SEE} = \gamma_1 \beta_{SE} + \gamma_2 \beta_{EE} \quad (13)$$

s.t. (1), (6), (7)

An EE maximizer only use as bandwidth as possible [1]. Then, the denominator of first term in Eq. (11), increases and decreases the first term of Eq. (13), the same reasoning can be done for the second term in Eq. (13). In the following, we present a way to counter these drawbacks.

III. SPC-based Lexicographic Optimality of Algorithm Suitability

We define the average SINR of cell edge users for a BS b as:

$$\alpha_b = \frac{1}{K^e} \sum_{k^e} \alpha_{b,k^e} \quad (14)$$

At frame (i), Eqs. (2) and (14) give the matching information in the processes of predicting the network state at frame ($i+1$). Lexicographic optimality is an optimization approach where several objectives, in competition, are classified according to a specified order of importance [10]. It can be formulated as follow:

$$(MOP_{lex,i}) = \begin{cases} \min f_i \\ s.t \\ x \in \Omega \\ f_1(x) = f_1^* \\ f_2(x) = f_2^* \\ . \\ . \\ . \\ . \\ f_{i-1}(x) = f_{i-1}^* \end{cases} \quad (15)$$

with $f_j(x_j^*) = f_j^*$ and f_j^* the better solution found by optimizing the f_j objective function. Ω is the set of feasible solutions.

Using this above mathematical theory, we propose the following LB scheme by considering these hypotheses:

- State 1 : $\mu_b < 70\%$, normal network operation
- State 2: $70\% < \mu_b < 100\%$, the cell is heavily loaded
- State 3: $\mu_b \geq 100\%$, the cell is overloaded.

For SINR phenomenon and for a user k^e, the SINR α_{b,k^e} must verify:

$$\alpha_{b,k^e} \geq \varphi, \quad (16)$$

where φ is the minimum required signal level for guaranteeing 1% BLER (bloc error rate) [11].We assume that when $\alpha_b \leq \varphi$, the ICI starts to destroy transmission, mainly for edge users governed by a BS b.

Load balancing means transferring some cell edge users from a heavily or over loaded cell to a slightly loaded neighboring one. Thus, technically speaking, all LB algorithms have same objectives [3]. However, they differ from mathematical formulations, triggering parameters, cell performance metric considerations, etc…. Consider the LB algorithm treated in [6], it worries about interference level and provide good performance by reducing the ICI at cell edge regions. Likewise, for balancing load, the energy mode of potential target cells can be considered as in [5]. Therefore, there is a network state dimension in the formulation of algorithms. Then, the first objective function (f_1) in our lexicographic order represents the network state. This first criterion is submitted as a constraint in the second, where the performances of algorithms are evaluated and represent the second objective function (f_2). Algorithms differ also by the complexity of mathematical approach(f_3). Therefore, we can resume algorithm suitability as follow:
In a given cell state, which algorithm offers more performances with less complexity (SPC).

ALGORITHM I describes the proposed solver, which is aimed at simplicity because the LB and the RRD solvers are already complex (Table I). At every TTI (time transmission interval), the BS forwards the cell state about load and ICI in line 2 (the two considered network state parameters in this paper. As the system is open, any other implementation can be done). Given that the SDN controller is a high sever capacity, it analyzes all the cell states, chooses the matching algorithms, performs the related calculation and, forwards the plane to the BS that executes instructions (line 4 to 12).

IV. Results and Discussions

The performances of LB algorithmsare evaluated through call blocking rate, load balance index and fifth percentile throughput. However, in the aim to keep faithful to the paper requirements, we assess EE and SE behaviors only of Algorithm suitability in comparison with some reference algorithms (TABLE I).

Abbreviations:

CR-LB: Cell Reselection-based Load Balancing algorithm [7]

IA-LBA: Interference-Aware Load Balancing Algorithm [6]

EE-LB: Energy Efficiency Load Balancing [5]

PSO: Particle Swarm Optimization RRD algorithm [12]

$\boldsymbol{WF^2Q}$: Fair-Weighted Fair-Queening interference based radio resource scheduling [11].

QA-EERS: Qos-Aware Energy Efficiency Resource Scheduling [13].

O: Oriented

SSPE: Small Size data Packet Environment.

ICI: Inter-Cell Interference

ESM: Energy Saving Mode

EE: Energy Efficiency

ALGORITHM I
ALGORITHM SUITABILITY LOAD BALANCING

1. **FOR** each BS $b \in B$ and at every frame i
2. **CALCULATE** μ_b and α_b using (2) and (14)
3. **END FOR**
4. **IF** 70% $< \mu_b < 100\%$
AND $\alpha_b \geq \varphi$
5. **FIND** an EE-oriented LB scheme and a SE-oriented RRD one by resolving (15) among algorithms in TABLE I
6. **END IF**
7. **IF** 70% $< \mu_b < 100\%$
AND $\alpha_b \leq \varphi$
8. **FIND** an ICI-oriented LB scheme and an EE-oriented RRD one by resolving (15) among algorithms in TABLE I
9. **END IF**
10. **IF** $\mu_b \geq 100\%$
11. **TURN** an ICI-oriented LB scheme and a Load-oriented RRD one by resolving (15) among algorithms in TABLE I

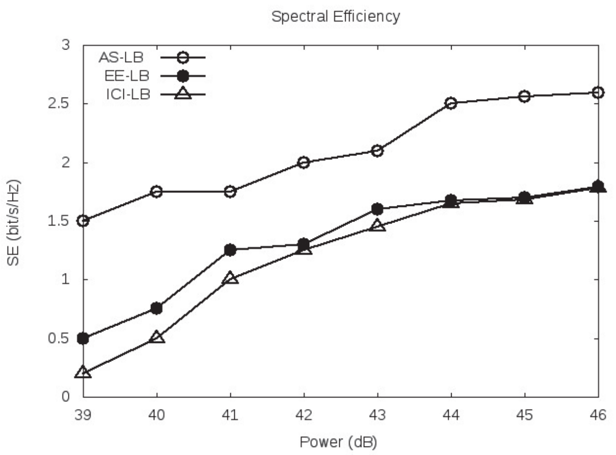

Fig. 1. Spectral Efficiency vs. Transmission Power with $\varphi = 3.8\ dB$ MSC=QPSK 2/3 [Schoenen 14]

TABLE I
RADIO RESOURCE MANAGEMENT ALGORITHMS (LB & RRD)

Algorithm	operatio n	characteristics		
		state	*performance*	*Complexity*
$CR-LB$	LB	SSPE-O	acceptable	Low
$IA-LBA$	LB	ICI-O	acceptable	high
$EE-LB$	LB	ESM-O	acceptable	Low
PSO	RRD	Load-O	acceptable	high
WF^2Q	RRD	ICI-O	acceptable	average
$QA-EERS$	RRD	EE-O	acceptable	high

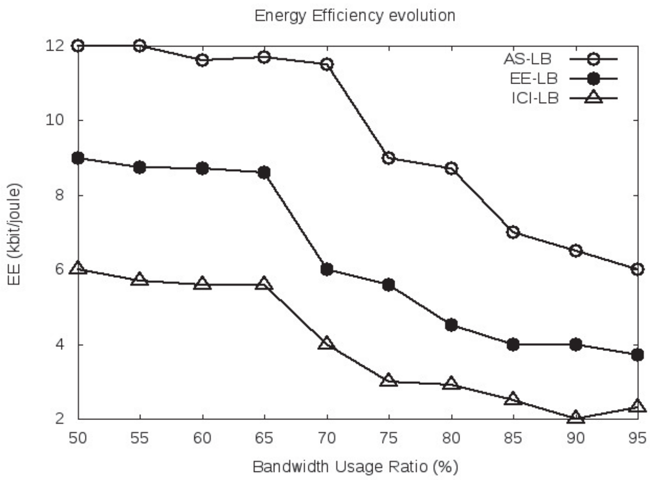

Fig. 2. Energy Performance vs. Bandwidth Usage Ratio

Figs. (1) and (2) describe the evolution of SE and EE respectively in function of energy and bandwidth. AS-LB outperforms other algorithms (EE-LB and ICI-LB) because when LB is engaged, it handles the required algorithm, which offers the performances responding better to the experienced state. The presented theory introduces also a second level of optimization: RRD. When a spectral efficiency LB solver is chosen, an energy efficiency RRD one is performed in such that the terms in objective function in Eq. (13) are maximized.

V. CONCLUSION

In this paper, there was talk about the load balancing issue. By realizing that the solver performances (EE and SE) vary following the network conditions, it has been proposed Algorithm Suitability as alternative solution. We have seen through simulations that differing to one algorithm implementation; the proposed scheme optimizes permanently the system. Based on SDN theory, AS-LB makes the system to be scalable and energy efficient which is actually an important network performance metric indicator. In addition, the openness of SDN paradigm enables a rapid implementation ofnew radio protocols when ongoing traffic pattern requirements happen.

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