P5G: A Bio-inspired Algorithm for the Superfluid Management of 5G Networks

Mohammad Shojafar,[1] Luca Chiaraviglio,[1,2] Nicola Blefari-Melazzi,[1,2] Stefano Salsano[1,2]
1) CNIT, University of Rome Tor Vergata, Rome, Italy
email {name.surname}@cnit.it
2) Department of Electronic Engineering, University of Rome Tor Vergata, Rome, Italy
email {name.surname}@uniroma2.it

***Abstract*—5G is expected to become the dominant technology in the forthcoming years. In this work, we consider a 5G Superfluid network, as an outcome of the H2020 project SUPERFLUIDITY. The project exploits the concept of Reusable Functional Block (RFB), a virtual resource that can be deployed on top of 5G physical nodes. In this work, we target the management of the RFBs in a Superfluid network to deliver a high definition video to the users. Specifically, we design an efficient algorithm, called P5G, which is based on Particle Swarm Optimization (PSO). Our solution targets different Key Performance Indicators (KPIs), including the maximization of user throughput, or the minimization of the number of used 5G nodes. Results, obtained over a representative scenario, show that P5G is able to wisely manage the RFBs, while always guaranteeing a large throughput to the users.**

I. Introduction

According to different studies (see e.g. [1]), both the number of subscribers in cellular networks and the amount of traffic will constantly increase in the forthcoming years. This trend will be also coupled with an ever increasing mobility of users. Examples of services that will be exploited by users include high definition video streaming and tactile Internet applications. In this context, mobile networks are shifting towards the 5G paradigm, which is expected to tackle all the aforementioned challenges. 5G exploits a variety of new paradigms, including: the adoption of Multi User Multiple Input Multiple Output (MU-MIMO) in a massive way [2], an increased use of softwarized elements [3], and the exploitation of commodity Hardware (HW) to host virtualized network functions [4].

In this context, different projects are currently investigating the deployment of 5G networks (see e.g., [5], [6]). Among them, the SUPERFLUIDITY EU project, aims to propose a flexible, portable, agile and high performance 5G network. The core of the project is the definition of virtual elements, called Reusable Functional Blocks (RFBs), which are used to implement the network and computing functionalities, from the basic building blocks in the radio access, such as Base Band Units (BBUs) and Remote Radio Heads (RRHs) to advanced services like Mobile Edge Computing (MEC). More in detail, RFBs can be chained in order to implement even more complex functionalities, which include the provisioning of the service to users. In addition, thanks to the fact that RFBs are completely virtualized, they can be efficiently moved across the operator network to better satisfy different Key Performance Indicators (KPIs). Moreover, RFBs can be deployed on a variety of HW 5G physical nodes, which are not tailored to a specific vendor. In summary, RFBs allows to achieve a "Superfluid" state, in which the different elements of the network are globally managed through virtual resources, which are completely transparent to users.

In this context, several questions are arising, such as: Is it possible to practically manage a 5G Superfluid network? How do we deploy an efficient algorithm guaranteeing a large throughput to users and an efficient management of the network? The goal of this paper is to shed light on these issues. Specifically, we propose a new algorithm, called P5G, to tackle the efficient management of the Superfluid network. P5G is based on Particle Swarm Optimization (PSO), which is one of the most powerful and broadly applicable stochastic search and optimization techniques which has achieved great advancements in the related research fields, such as network optimization, combinatorial optimization, and multi-objective optimization [7]. Our results, obtained over a representative case-study, prove the efficiency and the efficacy of P5G in the management of the RFBs.

Our original contribution can be summarized as follows:

- We detail the P5G algorithm, which is able to manage the RFBs in a 5G Superfluid network under different KPIs, such as the maximization of the users throughput, and/or the minimization of the number of physical 5G nodes used;
- We compare our solution against the optimal formulation of [8], showing that P5G always performs close to the optimal problem, while being able to reduce the computation time impressively in some cases to some seconds.
- We consider a complete load variation in the network, in accordance to a typical day-night trend. Our results show that P5G is always able to guarantee a large throughput to users, while being able to wisely manage the network and computing resources in terms of: i) RFBs functionalities, ii) CPU and memory occupation on the physical 5G nodes.

We believe that this work can be the first step towards the deployment of algorithms tailored to the management of RFBs in a 5G network. More in detail, in this work we have considered a Superfluid network composed of macro building blocks (RFBs), namely RRH, BBU and MEC. The decomposition of these RFBs into smaller ones, which is in line with the current trend of softwarization [9], and the study of their mutual interactions, will be two interesting research activities that we plan to perform in the future.

The remainder of the paper is structured as follows. We review the related work in Sec. II. The 5G Superfluid network model and the problem formulation are reported in Sec. III. Sec. IV details the P5G algorithm description. The performance evaluation of the proposed solution is reported in Sec. V. Finally, Sec. VI concludes our work.

II. Related work

The RFB concept exploited in this work a generalization of the Virtual Network Function (VNF) concept proposed by ETSI [10]. However, the RFBs present unique features compared to VNFs. First, RFBs can be arbitrarily decomposed in other RFBs, while VNFs can not be decomposed in other VNFs. Second, RFBs can be mapped into different Software (SW) and HW execution environments [11], while the mapping of VNFs into virtual machines of traditional cloud infrastructures is targeted by the ETSI model.

Several works (see e.g., [12], [13], [14]) face the explosive growth in traffic volumes, the drastic increase in connected wireless devices, and the wide range of Quality of Service requirements in 5G. In this context, 5G networks will provide a much greater spectrum thanks to the exploitation of mmWave frequency spectrum bands [15], highly directional massive beamforming antennae for mobile and stand-alone devices [2], longer battery life sustained by energy harvesting techniques [16], full-duplexing communications (FDCs) [17], and higher aggregate capacity [18]. As opposed to them, our work considers also the impact of introducing at the operator level the MEC functionality.

In addition, the MEC concept is used in different theoretical and practical methods (see e.g., [19], [20], [21]). Similarly to these works, we also exploit MEC to provide the service to users.

One of the key issues in 5G is the management of HW and SW components. In fact, the network-aware combination of SDN and NFV results in HW boxes and SW that have to be managed across network segments. The main goal in this context is the release of SW that can be exploited in a 5G network. Specifically, softwarized solutions need to run advanced configuration and customization of the network functions. Recently, the authors in [9] tackled this problem by developing a self-healing framework for a SDN-based 5G network. Their framework manages the availability of the services, network functions, and engaging resources over SDN-based networks. Moreover, in [22] authors consider dynamic SW module placements in cloud-supported 5G network. Although this approach is an efficient and CAPEX-aware solution, it lacks integrity and reuseability of different network functions such as VNFs.

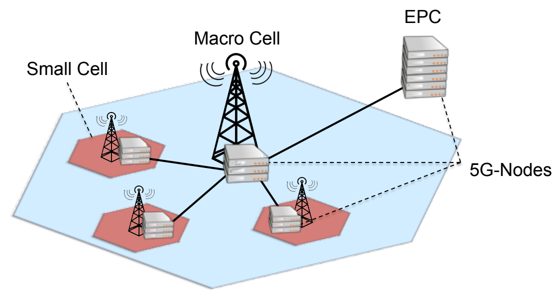


Fig. 1. Example of a network composed of different 5G Nodes.

The CAPEX/OPEX issues in 5G networks are investigated in [23], [24], [25]. Similarly to them, this work is also tailored to an efficient use of the network. In contrast to them, we consider an MU-MIMO cell architecture, which allows a more flexible network management.

Finally, different international projects (see e.g., [5], [26], [6]) aim to define comprehensive architectures to manage network components and connectivity in dense networks. Among them, the SELFNET project [6] defines a new management framework for 5G networks, which is built upon the software-defined and virtualized network paradigms [27]. Differently to this work, our solution aims to control also the user traffic and the resources across the network elements. In addition, our work is focused also on BBU and MEC functionalities to further increase the flexibility of the system.

III. Superfluid 5G Model and Formulations

We report here a brief overview of the considered Superfluid 5G network model. We refer the reader to [8] for a more detailed explanation. In brief, we consider a 5G network composed of a set of physical 5G nodes, a set of links, and a set of users. The physical 5G nodes are used to host different RFBs in order to deploy either Small Cells (SCs), Macro Cells (MCs), or to realize the core network elements of the so called Evolved Packet Core (EPC). Each physical 5G node is connected to the rest of the network by means of a path of physical links. Each user is connected to the network by means of a cell (either a MC or a SC). For the sake of simplicity, we consider a single EPC node.

Fig. 1 reports an example of the modeled physical architecture. The figure reports three 5G nodes hosting SCs, one 5G node hosting one MC, and one 5G node implementing an EPC node. The coverage area of each cell is assumed to be hexagonal in this example for the sake of simplicity. The service area, i.e., the area where the users are located, is overlapped with the MC coverage area.

Each 5G node is able to host different RFBs. An RFB performs specific tasks in the network architecture, such as processing the video to users, or performing networking and physical layer tasks. In addition, each RFB consumes an

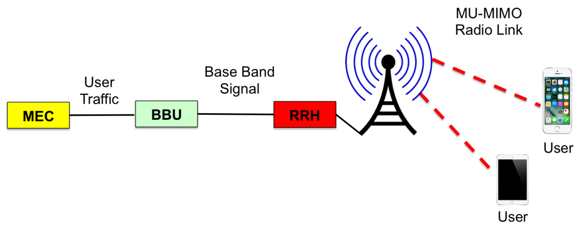


Fig. 2. A logical chain of RFBs serving a set of users.

amount of physical resources on the 5G node hosting it. In this work, we consider as physical resources the *processing capacity* and the *memory occupation*, which we denote as *capacity* and *memory*, respectively. More in detail, each 5G nodes is composed of Commodity HW (CHW), and Dedicated HW (DHW) parts to host the RFB functionalities. We assume that the RFB physical occupation on the CHW is measured in terms of capacity (i.e., typically in [Gbps]), while the RFB occupation on the DHW is measured in terms of capacity and memory (which are expressed in generic units).

A. RFB Features

In this work, we consider the following RFBs: i) MEC RFB, ii) BBU RFB, iii) RRH RFB. We then briefly describe each RFB in more detail. More in depth, the MEC RFB module provides the resources for a HD video distribution service to users. For example, a MEC RFB may act as a cache for storing the videos. In general, the MEC RFB serves an amount of traffic to a subset of users spread over the service area. The maximum amount of server traffic by the MEC RFB depends on the constraints set on the physical resources on the 5G node. Focusing then on the BBU RFB, this module acts as an interface between the MEC RFB and the RRH one. Practically speaking, the BBU RFB exchanges an amount of IP traffic with a MEC RFB, and a baseband signal with a RRH RFB. Clearly, also in this case the performance of the BBU RFB module depends on the amount of physical resources available on the hosting 5G node. Finally, the RRH RFB is devoted to physical layer operations. More in detail, the RRH RFB has to handle a set of Radio Frequency (RF) channels with users and the corresponding baseband channels with the BBU RFB. In this case, the RRH RFB performance depends on the type of deployed cells (either a SC or a MC) and the amount of available resources on the hosting 5G node.

Focusing then on the connections between the modules, we assume that the RFBs are grouped in logical chains. More in detail, a MEC RFB is logically connected to a BBU RFB. In addition, a BBU RFB is in turn connected to a RRH RFB. In order to serve a subset of users, a logical chain of one MEC RFB, one BBU RFB and one RRH RFB needs to be deployed in the network. Fig. 2 reports an example of RFBs chain and the exchanged information between the modules and the users. In addition, the different RFBs can be physically hosted in the same node, or being located in different nodes. Clearly, the RFBs are also subject to node placement constraints. Specifically, the RRH RFBs may be placed only in the DHW part of a 5G node, if the considered node is equipped with the antennas. In addition, the BBU RFBs require both CHW and DHW resources of the node. Differently from the RRH RFBs, a BBU RFB can be placed in each node of the network (i.e., not only the ones equipped with antennas). Moreover, the MEC RFBs are deployed in the CHW part of the 5G node. In this case, every node in the network can potentially host a MEC RFB.

B. Optimal Formulations

We then briefly review the optimal formulation of [8] under the considered KPIs. In brief, thanks to the fact that the RFBs are virtual elements, they can be dynamically moved across the nodes to meet different KPIs. In our context, we pursue the following KPIs: i) maximization of the user throughput ii) minimization of the number of user nodes. More in detail, while the first objective aims to maximize the user performance, the second one can be effective in reducing the Operation Expenditures (OPEX) of the operator. In addition, we assume that each RFB module belongs to a given type, which is characterized by a given amount of requested resources on the underlying.

The optimal formulation for the maximization of user throughput is the following one:

$$\max \sum_{i,j} t_{ij} \tag{1}$$

subject to: equations (16)-(43) in [8]; with control variables: u_{ij}, t_{ij}, r_{ki}, b_{kpi}, m_{kpi}. More in detail, t_{ij} is the total amount of throughput achieved by user j, connected to the RRH RFB located at node i; u_{ij} a binary variable that is 1 if the user j is served by node i, 0 otherwise; r_{ki} a binary variable that is 1 if the RRH RFB of type k is installed at node i, 0 otherwise; b_{kip} a binary variable that is 1 if one BBU RFB of type k placed at node p is used to serve the RRH RFB at node i, 0 otherwise; m_{kip} is a binary variable equal to 1 if one MEC RFB of type k placed at node p is used to serve the users connected to the RRH RFB at node i, 0 otherwise.

Similarly, the optimal formulation for the minimization of the number of used nodes is the following one:

$$\min \sum_{i} y_i \tag{2}$$

subject to: equations (16)-(43) in [8]; with control variables: u_{ij}, t_{ij}, y_i, r_{ki}, b_{kpi}, m_{kpi}. Mode in detail, y_i takes value 1 if node i is powered on, 0 otherwise. All the other variables are the same as in the previous formulation.

IV. P5G Algorithm Description

Since the aforementioned formulations are both NP-Hard, and are difficult to be solved in a realistic scenario, we have relied on a heuristic approach. Our solution, called P5G, is based on a *divide et impera* approach. Specifically, the initial problem is split in two subproblems, namely: i) allocation of users and RRH RFBs to the 5G nodes (P1), and ii) allocation of MEC RFBs and BBU RFBs to the nodes (P2). The two steps are sequentially solved in order to obtain a feasible solution.

Algorithm 1 P1: Users Allocation and RRH RFBs Placement

1: $ordered\_data$= δ_{ijk} (in decreasing order);
2: $u_{ij} = 0 \quad \forall i \in \mathcal{N}, j \in \mathcal{U}$
3: $r_{ki} = 0 \quad \forall i \in \mathcal{N}, k \in \mathcal{K}$
4: $y_i = 0 \quad \forall i \in \mathcal{N}$
5: **for** $c \leq length(ordered\_data)$ **do**
6:   extract i, j and k from $ordered\_data[c]$
7:   **if** $\sum_i u_{ij} == 0$ **then**
8:     **if** ($\sum_j u_{ij} < U_k^{max}$) & ($Cov_{ijk} == 1$) **then**
9:       **if** $y_i == 0$ **then**
10:         **if** $\sum_i y_i < N_c^{max}$ & ($\sum_i r_{ki} < N_k^{RRH}$) **then**
11:           $y_i = 1$;
12:           $u_{ij} = 1$;
13:           $r_{ki} = 1$;
14:         **end if**
15:       **else**
16:         k'=extract_RRH_type(r_{ki})
17:         **if** $k \neq k'$ **then**
18:           **if** ($\sum_j u_{ij} \geq r_{k'i} U_{k'}^{max}$) & ($\sum_i r_{ki} < N_k^{RRH}$) **then**
19:             **if** check_cov(k',u_{ij},Cov_{ijk})==true **then**
20:               $r_{k'i} = 0$;
21:               $u_{ij} = 1$;
22:               $r_{ki} = 1$;
23:             **end if**
24:           **end if**
25:         **else**
26:           $u_{ij} = 1$;
27:         **end if**
28:       **end if**
29:     **end if**
30:   **end if**
31: **end for**

Algorithm 2 P3: BBU RFBs and RRH RFBs Placement

Initialize the particles using (1) or (2) subject to equations (16)-(43) in [8];
Initialize $func[p]$, $\forall p$;
repeat
  for particle p, $\forall p$ **do**
    //update the particle's best position ($p\_best[p]$)
    if $fval(func[p]) < fval(p\_best[p])$ **then**
      $p\_best[p] = func[p]$;
    end if
    //update the global best position (g_best)
    if $fval(p\_best[p]) < fval(g\_best)$ **then**
      $g\_best = p\_best[p]$;
    end if
  end for
  //update particle velocity and position
  for particle p, $\forall p$ **do**
    for dimension d, $\forall D$ **do**
      $velocity[p,d] = velocity[p,d] + C_1 \times \text{rand} \times (p\_best[p,d] - func[p,d]) + C_2 \times \text{rand} \times (g\_best[d] - func[p,d])$;
      $func[p,d] = func[p,d] + velocity[p,d]$;
    end for
  end for
  $iteration{+}{+}$
until $iteration > Max\_iteration$

We then describe in more detail each part of the P5G of the algorithm.

A. P1: Users Allocation and RRH RFBs Placement

P1 takes as input the radio link capacity between each user, each RFB type, and each node, which is denoted with δ_{ikj} (where i is the node index, k is the RFB type index, and j is the user index). This step requires the coverage Cov_{ikj} for each node i, each RFB type k and each user j. Finally, the number of powered on nodes, denoted with N_c^{max}, and the numeber of available RRH RFBs, denoted with N_k^{RRH}, are also requested. The algorithm then provides as an output the power state of each node y_i, the allocation of each user to a 5G node u_{ij}, and the placement of each RRH type to each node r_{ki}.

Alg. 1 reports the description of the P1 part of the algorithm. Initially, the δ_{ikj} values are sorted in decreasing order in an array (line 1). The algorithm then sequentially checks the entry in the array, by extracting the current user and the current node (line 6). If the user has not been served yet (line 7), it needs to be connected to a 5G node. More in detail, if the current number of served users by the node is lower than the maximum one supported by the RRH RFB of type k U_k^{max} and the user is in the coverage area of the cell (line 8), the current user is served by the cell (lines 9-14). Clearly, if the current 5G node y_i is powered off, i.e., $y_i == 0$ (line 9), the number of powered 5G nodes is lower than N_c^{max} (line 10), and the number of used RRH RFB of type k is lower than N_k^{RRH}, y_i is powered on (line 11), the user is connected to the node (line 12) and the RRH RFB is installed (line 13). Otherwise, if the node is already powered on, the current type RRH RFB k' installed at the node is extracted (line 16). If k' is different from the type k of the ordered data, a check on the number of served users and on the number of available RRH RFBs is performed (line 18). Specifically, if the current number of served users is equal to the maximum one $U_{k'}^{max}$ and the number of installed RRH RFBs of type k is lower than N_k^{RRH}, the RRH RFB previously installed is replaced with a new one (serving a larger number of users). However, this step is performed only if the new RRH RFB guarantees coverage to the users served by the previously installed RRH RFB. If the users are covered, the current user is associated to the node, and the RRH RFB is replaced (lines 20-22). Eventually, if $k == k'$ (line 25), the current user is added to the node. When the optimization of the user throughput is performed, the number of powered on nodes N_c^{max} is set equal to the number of nodes installed in the network. Otherwise, when the minimization of the number of used nodes is pursued, P1 is sequentially repeated for increasing values of N_c^{max} (starting from 1 to the number of deployed nodes in the network), until all the users are served.

B. P2: BBU RFBs and MEC RFBs Placement

The second part takes as input parameters the allocation to users u_{ij}, the power states of the nodes y_i, and the allocation of RRH RFBs r_{ki} in order to find the allocation of BBU RFBs and MEC RFBs. The procedure then produces as an output the allocation of MEC RFBs m_{kip} and the allocation of BBU RFBs b_{kip}. In addition, the traffic from each node i to each

TABLE I
RFBS PARAMETERS

RFB	Parameter	Value	
		RFB Type $k=1$	RFB Type $k=2$
RRH	Maximum Number of Users (U_k^{max})	126	42
	Maximum Handled Capacity	29.96 [Gbps]	9.45 [Gbps]
	Number of RRH RFBs (N_k^{RRH})	1	4
BBU	Number of antennas generating traffic	126	42
	BBU capacity consumed on DHW	156 [Gbps]	52 [Gbps]
	Number of BBU RFBs (N_k^{BBU})	1	4
MEC	Maximum Capacity	29.96 [Gbps]	

user j is also retrieved. This step can be formalized with the following problem:

$$\textbf{P2:} \quad \text{Eqs. (1) or (2),} \tag{3.1}$$
$$\text{subject to: Eqs. (16)-(43) in [8].}$$

with control variables m_{kip}, b_{kip}, and t_{ij} Differently to [8], u_{ij}, y_i, r_{ki} are input parameters and not variables.

However, since this subproblem is NP-Hard (the proof is omitted due to the lack of space), we have adopted a bio-inspired metaheuristic solution based on PSO. Specifically, each particle is initialized to (1) or (2) (depending on the objective) subject to equations (16)-(43) in [8]. More in detail, each particle which is one dimension (the objective reported in (2)) or two dimensions (the objective reported in (1)) comprises possible throughput of the engaged cells or j-th user on the i-th cell, respectively. Then, we adopt a classical PSO approach, which is reported in Alg. 2, in order to obtain the new generations of the particle (lines 4-22). P5G is initialized with a group of random particles (possible solutions) and then searches for optima by updating generations. In every iteration, each particle (i.e., p) is updated by following two "best" values. The first one is the best solution (fitness) which has achieved so far that is called $p\_best[p]$ per p-th particle (6-8 lines). Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the population. This best value is a global best and called g_best. After finding the two best values, the particle p updates its velocity and positions (17-18 lines), where rand is a random number between (0,1) and C_1, C_2 are learning factors. Clearly, a maximum number of iterations is enforced (line 22) as a stopping rule.

V. PERFORMANCE EVALUATION

We first describe the scenario under investigation and then the obtained results.

A. Scenario Description

We consider a set of 5G nodes composed of one MC, four SC and one EPC. We refer the reader to [8] for the detailed scenario description. In brief, the MC is placed in the center of the service area, while each SC is located at a distance of 120 [m] far from the MC. The MC may interfere with a set of neighboring MCs, placed at the corners of a square centered by the considered MC, with an edge equal to 1000 [m]. A set of 260 users is then placed over the service area. Specifically, 70% of users are spread over the whole service area, while 30% of users are placed inside a circle with radius equal to 50 [m] centered in each SC.

TABLE II
5G NODES CAPACITY AND MEMORY

Parameter	Value		
	Small Cell	Macro Cell	EPC
DHW Cap.	122.91 [Gbps]	787.91 [Gbps]	727.99 [Gbps]
CHW (Cap./Mem.)	2 [units]	4 [units]	4 [units]

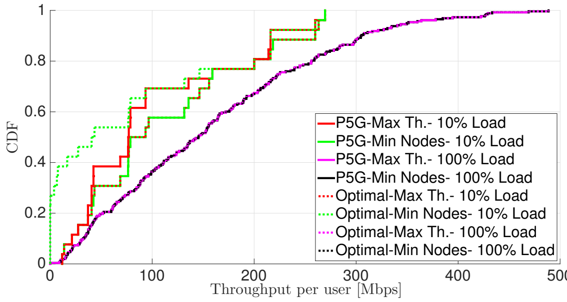
We assume a total of 5 RRH RFBs, 5 BBU RFBs, and 5 MEC RFBs available. We then consider two types of RRH RFBs, two types of BBU RFBs, and one type of MEC RFB. The intuition of having two types of RRH RFBs and BBU RFBs relies on the fact that the traffic handled by the macro cell node is in general higher than the one of the small cell one. Therefore, the resource requirements of the associated RFBs may be different, resulting in two different RFB types.

Focusing then on the RFBs and 5G features, Tab. I and Tab. II reports the main parameters. We refer the reader to [8] for a detailed explanation of the system parameters. In brief, we adopt the MIMO channel model of [28] and the BBU parameters of [29], while the MEC capacity is designed to handle the users requests.

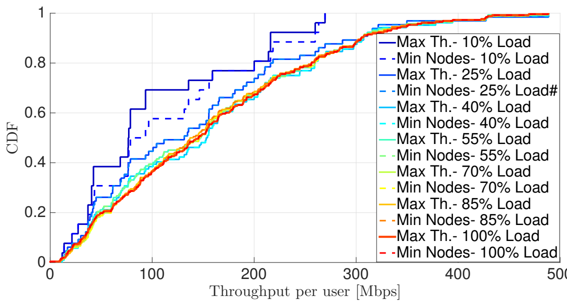
Tab. II reports then the setting of the 5G nodes in terms of deployed capacity and memory. We recall that the DHW capacity is expressed in terms of [Gbps], while the CHW capacity and memory are expressed in terms of generic [units]. These values are dimensioned to allow the pooling of the BBU RFBs and/or of the MEC RFBs in the MC node and the EPC one. Finally, focusing on the P5G algorithm parameter, we set $C_1 = C_2 = 2$ and we use 10 particles in P3.

B. Simulation Results

Given the scenario and the input parameters, we then run the P5G algorithm. More in detail, in the first set of experiments, we compare the performance of P5G against the optimal formulation of [8]. Fig. 3 reports the Cumulative Distribution Function (CDF) of the traffic for each user. We consider the load 100% case, i.e., all the users in the scenario are requesting the 5G service and the 10% one, i.e., a percentage of 10% of users requesting the service. In addition, we consider two different objectives as KPIs: i) maximization of user throughput and ii) minimization of the number of used nodes. Focusing on the 100% case, we can note that the P5G algorithm achieves an optimal throughput per user, i.e., more than 150 [Mbps] on average. In this case, both P5G and the optimal solution always keep the MC and all the SCs powered on, even when the minimization of the number of powered on nodes is pursued. Focusing instead on the 10% case, the average throughput is close to the optimal one when the maximization of the throughput is pursued. Eventually, the average throughput is even larger than the one of the optimal



(a) Optimal-vs.-P5G



(b) Min nodes/Max Throughput-vs.-various loads

Fig. 3. CDF comparisons for the two test scenarios.

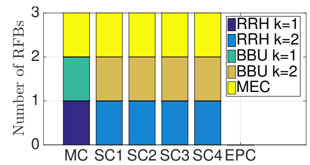
solution when the minimization of the number of nodes is pursued. By further investigating this issue, we have found that in this case P5G keeps powered the MC and one SC, while the optimal solution exploits only the MC. Therefore, the additional cell powered on by P5G allows to serve better the users falling in its coverage area.

We then extend the evaluation of P5G vs. different values of load, as reported in Fig. 3(b). Interestingly, the average throughput per user is always very close considering the two KPIs. However, we can note that the throughput tends to decrease when the load is decreased. To better understand this aspect, Tab. III reports the average throughput for the different values of load with the two KPIs. Interestingly, when the load is equal to 10%, the throughput is lower compared to the other values. By manually investigating this issue, we have found that in this case there are different users located at the MC edges, which can not achieve a high throughput due to relatively bad channel conditions. Such users will be likely served by the neighboring MCs in a realistic scenario. In addition, we can note that in this case the average throughput is higher considering as KPI the minimization in the number of used nodes. In this case, in fact, few nodes are powered on (i.e., typically only the MC), thus decreasing the overall interference between the cells and consequently alleviating the channel conditions for different users.

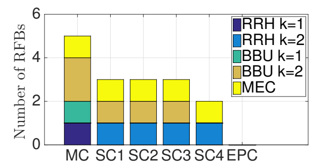
In the following, we investigate the RFBs placement over the nodes performed by our solution. Fig.4 reports the RFB placement across the nodes for different values of load when the maximization of user throughput is pursued. Interestingly, by increasing the load the P5G algorithm tends to place more MEC and BBU RFBs over the MC in order to increase the

TABLE III
AVERAGE THROUGHPUT VS LOAD.

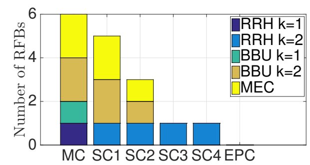
P5G Strategy	Load						
	10%	25%	40%	55%	70%	85%	100%
Min. Nodes	113.86	142.30	158.67	155.35	157.91	158.17	158.35
Max. Th.	101.05	142.17	158.67	155.35	157.91	158.17	158.35



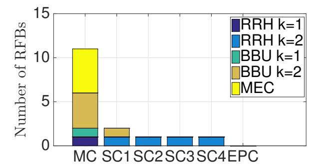
(a) 10% load



(b) 25% load



(c) 70% load



(d) 100% load

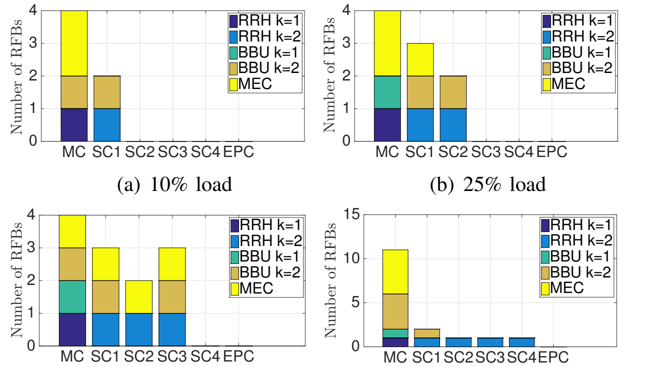
Fig. 4. RFBs placement for 10%, 25%, 70% and 100% load traffic in the maximum throughput scenario in P5G. SC:=small cell, MC:=macro cell.

throughput and performance of the users (by exploiting the resource pooling); and, (ii) all nodes (except the EPC one) are used in this scenario. Correspondingly, Fig.5 presents the RFBs placement over the nodes for various load values for the minimization of 5G nodes in the network architecture. An examination of the results of this figure leads to two main conclusions. First, by increasing the load rates the number of running cell increases in order to serve more users. Second, P5G algorithm tries to adopt less RFBs while fewer number of cells are utilized.

Finally, Tab. IV reports the computation time of P5G vs. different values of load. The simulations are carried out by exploiting the numerical software of the MATLAB platform over dual-core MacBook pro system which are equipped with 2.7 GHz Intel core i5 CPU and 8GB of RAM. Interestingly, we can note that the execution time is always less than 30 [s]. In addition, the total time is decreased when the load, and consequently the considered number of users, is decreased (as expected).

VI. Conclusions and Future Directions

We have targeted the management of the RFBs in a Superfluid 5G network in order to deliver a HD video service to user. More in depth, we have designed the P5G algorithm, a 2-steps solution able to: i) associate the users to the nodes, ii) allocate the RRH RFBs and iii) allocate the BBU and MEC RFBs. We have then run P5G on a representative scenario composed of MC, SC, and EPC nodes. Our results show that: i) P5G performs close to the optimal solution, ii) the throughput per user is typically larger than 100 [Mbps], iii) the RFB placement depends on the considered strategy, iv) the computation time of P5G is always pretty low.



(a) 10% load (b) 25% load

(c) 70% load (d) 100% load

Fig. 5. RFBs placement for 10%, 25%, 70% and 100% load traffic in the minimum node scenario in P5G. SC:=small cell, MC:=macro cell.

TABLE IV
TOTAL EXECUTION TIME OF P5G.

Load	10%	25%	40%	55%	70%	85%	100%
Execution Time [s]	3	23.7	36.5	30.1	32.8	38.1	27.9

As the future, we plan to solve P5G in a metropolitan scenario, composed of a large number of 5G nodes. In addition, we plan to consider more complex management of RFBs, including the composition of the logical chains jointly together (e.g. one MEC RFB serving more than one BBU RFB and more than one RRH RFB), as well as a more detailed decomposition of RFB functions.

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