CelEc Framework for Reconfigurable Small Cells as Part of 5G Ultra-Dense Networks

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***Abstract*— This paper proposes the Cella Ecosystem (CelEc) concept for emerging 5G ultra dense Networks, to evolve and supplement the Mobile Radio Network by using the crowd's User Equipments (UEs), densely distributed in our physical world and environment, as an integral part of the Infrastructure. Towards this end, CelEc establishes a decentralized ecosystem (the CelEc Tier) of numerous, unbound and ubiquitous networking and computing elements offering their networking functionalities and computing and storage resources to bridge coverage gaps, supplement capacity, increase data rates, and boost computing, whenever the Network is stressed. This is in the same spirit as the introduction of smaller sized cells throughout the evolution of mobile telephony, to maximize spectrum resource efficiency. Specifically CelEc, by enhancing the UEs with eNodeB's functionalities and additional networking operation functions, realises the smallest, portable, and reconfigurable cells (i.e., the Cella cells) allowing for dynamic massive deployment, and enables the efficient flows of data, whenever and wherever needed. As such CelEc provides for a dynamic reconfiguration of the Mobile Network infrastructure, in an effortless, costless (in terms of CAPEX) and flexible manner, hence removing the restrains of existing Small Cells beyond their static positioning. A preliminary evaluation of some of the ideas discussed in this paper for CelEc, showed among others, scalable massive mobile support, and significant improvements on the overall capacity, data rates, energy and spectral efficiency, as envisioned for 5G.**

Keywords—5G; Small Cell; HetNets; Mobile Cellular Networks; Ultra-Dense Networks.

I. Introduction

According to [1], by 2020 the amount of mobile broadband connections is foreseen to reach almost 70% of the global base, demanding mobile traffic to be increased at least ten-fold [2]. The current generation of Mobile Networks, are not sufficient to address the rapidly increasing number of connected mobile devices and the associated huge increase in data traffic and the higher data rate demands [3], pushing a rethink of the current generation of Mobile Cellular Communications and migration to 5G. To meet these demands, Small Cells play a pivotal role [3]-[5][15][16], and will become, according to Dell'Oro group, the primary driver of growth in the overall 5G RAN market.

Following in the same spirit of Small Cells, this paper proposes the Cella Ecosystem (CelEc) concept for emerging 5G ultra dense Networks, to evolve and supplement the Mobile Radio Network by using the numerous Mobile and Portable User Equipments (UEs), densely distributed in our physical world and environment, as an integral part of the Mobile Network Infrastructure. Toward this end, CelEc exploits the power of the crowd involvement, by recruiting part of the masses under a "leasing service contract" as Network Operation "Facilitators", and utilizes their UEs to assist in a more effective Network operation and meet the key challenges and technical objectives of emerging 5G Networks [3].

With CelEc the UEs of the recruited Facilitators are enhanced and embedded as an integral part of the Network Operators' (NetOps) Network Infrastructure, establishing a decentralized ecosystem of numerous, unbound and ubiquitous networking and computing elements (i.e., the **CelDes**), forming the **CelEc Tier** as the bottom layer of the 5G Mobile Network Architecture (see Fig. 1). The CelDes embedded in the CelEc Tier will offer their networking functionalities and computing and storage resources to bridge coverage gaps, supplement capacity, increase data rates, boost Network's storage and processing power and assist in the efficient data flow, whenever the Network is stressed.

Specifically, CelEc enhances the UEs with: **i)** eNodeB's functionalities, introducing the new small and unbound Cella cell in the Small Cells' family; and **ii)** additional networking operation functions and computing and storage services, such as establishment of Data Tunnels, transportation, storage and processing of data. These services will be available wherever and whenever demands for more efficient data flows are requested. It is worth noting that the new Cella cell realises the smallest, portable and reconfigurable cell for tiny coverage areas, thus removing the restrains of current Small Cells (i.e., Pico, Femto, Metro cells) beyond their static positioning (see Chapter II), by allowing for their dynamic massive deployment whenever and wherever needed. Hence, it allows the dynamic and real time reconfiguration of the NetOps' Infrastructure, in an effortless, costless and flexible manner. This enhanced UE will be referred to as CelEc Device (CelDe; see section IV.A).

A preliminary evaluation of some of the ideas discussed in this paper showed, among others, scalable massive mobile

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device support, and significant technical improvements on the uplink and downlink network capacity, data rates, throughput, spectral efficiency and energy efficiency, thus showing its potential in addressing many key challenges and becoming an enabler for emerging 5G Networks.

The aim of this paper is to motivate the CelEc concept in 5G Networks, propose a framework for CelEc, describe the main elements forming it and their networking operation functions and promote the CelEc concept as a potential enabler towards the emerging 5G vision. The technical details and potential concerns related to the crowd recruitment, CelDes' security, privacy, battery drain, availability, deployment ease and financial gains, etc., will be investigated in future work. Thus, the paper is organized as follows: Chapter II motivates the CelEc concept in emerging 5G Networks. Chapter III discusses relevant research work. Chapter IV describes the CelEc Framework and its main elements. The main network operation functions and services provided by the CelDes embedded in CelEc Tier are elaborated in Chapter V. Chapters VI and VII provide a preliminary evaluation of CelEc concept, concluding remarks and future directions.

II. Motivating CelEc Concept in Emerging 5G Networks

To meet the key technical features of 5G (i.e., 10 – 100x in the number of connected devices, 1000x higher mobile data volume per area, etc.; [3]) a massive amount of Small Cells are needed everywhere (indoors, outdoors, at homes, offices, hospitals, stadiums, shopping malls, etc.). These should be deployed in all of their form (e.g., Micro, Pico, Femto, etc.) and supporting all known "flavors" of networks (LTE, 3G, WiFi, etc.). Furthermore, the rapid shifting of population to cities creates more and more hotspots in urban areas, making mobile data traffic more dynamic and asymmetrically distributed restraining the current NetOps' Macro and Small Cells deployment to handle these mobile traffic dynamics.

The aforesaid, raises a major technical concern for 5G Networks in dealing with mobile traffic dynamics, currently not efficiently addressed in current Macro and Small Cells due to the restraint abilities of their static positioning. Thus, the Network either underutilizes the radio resources, providing reduced revenue for the NetOps, or over utilizes them causing congestions and call drops. This is related to the fact that mobile traffic is not always uniformly distributed in both spatial and time domains due to the dynamic activity and mobility of the human factor. Also, the location preferences of the masses change through time (e.g., due to changing people behaviors or the creation of new hotspots). In this case the only solution will be either to invest in new BSs Equipments or move the old ones to the new (ultra-dense) hot spot areas on demand. Either way, this would be an expensive exercise.

The CelEc concept, with the introduction of the new tiny Cella cell in the Small Cells' family, allows for massive dynamic Small Cell deployments at any time and at any locations the "Facilitator" might be found. It provides for an effortless, flexible and dynamic reconfiguration of the NetOps infrastructure, driven always by the current location preferences of the masses, thus removing any restrains related to mobile traffic dynamics. All the hot spot areas (old and new) will be effectively supported by the "Facilitators" that, as a part of the mass, will always follow the masses location trends. Thus, with CelEc, the major issues related to the shifting mobile traffic dynamics can be efficiently addressed; extending capacity in a scalable manner and achieving higher revenues for the NetOps.

Furthermore, NetOps have already invested heavily over the past years, and foresee their CAPEX to increase much further, estimated to reach a total of 1.4 Trillion USD by 2020 [1], to support further deployments of Small Cells and meet the forthcoming demands of 5G Networks. This scale of CAPEX investment is a limiting factor that stresses major considerations affecting NetOps' business sustainability and thus restraining their potentials for migrating towards 5G Networks [1]. To convince NetOps to make the next step towards 5G, either: **i)** new and sustainable business models that will not only achieve full depreciation of their investment but also provide "satisfactory" profits must be developed; and/or **ii)** new cost-effective Small Cell solutions that will relax risks affecting NetOps business sustainability and achieve migration to 5G Network in a flexible and effortless manner must be proposed. CelEc achieves the second; it provides the means to meet the previously mentioned demands, addressing many of the key technical features of 5G, with trivial NetOps' CAPEX. It addresses NetOps' major considerations related to:

1) The potential of Small Cells deployment, restrained by the great CAPEX that the NetOp will have to invest: Related to the price of purchasing the huge amount of small BSs Equipments needed for effectively addressing the rapidly increasing number of connected UEs, the huge data traffic and higher data rate demands of 5G Networks; The CelEc concept provides the means to NetOps to exploit the Facilitators' CelDes (also functioning as mini eNodeBs; Section V.A), and use their networking functionalities to deploy as many Cella cells as required, for effectively adressing all the aforesaid technical demands of 5G Networks, with trivial CAPEX.

2) The potential of small cells deployment, restrained by the time and economic costs, related to their installation: the negotiation process with individual site owners or local authorities to mount a huge amount of BSs Equipments on walls or street furniture; the fees that will have to be paid for being allowed to deploy them in the respective locations; as well as their expensive installation costs. With the CelEc concept the BSs Equipments (i.e., the CelDes) deploying the Cella cells are always "mounted" on the "Facilitators". Thus, there is no need for negotiations, fees or expensive installations on walls or street furniture. Deployment of Cella cells is realised, in an effortless, costless, timeless and flexible manner, at any time and location (indoor, outdoor and mainly everywhere), that "Facilitators" are or can be located. Thus, the time and economic cost related to their installation and operation is vastly eliminated. Hence, the NetOps' OPEX can be signifigantly reduced as well.

III. Background and Related Work

The challenges that need to be addressed to make the 5G vision a reality are not trivial. Many industries and organizations are working towards the definition of the standards that will realize the 5G Networks; however standards are yet to be evolved, as several challenges need to be handled first. Surveys on new architectures, methodologies and technologies proposed for 5G Networks, are provided in a plethora of articles, like [3]-[5]. Here we refer only to those approaches that are most relevant to the CelEc concept.

The adoption of: **i)** Multi-tier architectures, having Macro BSs on the top-tier and Small BSs in the lower-tier working under the control of the Macro BSs [6]; **ii)** Network densification and Small Cell deployment [3]-[5]; **iii)** Mobile Femto cells [7]; **iv)** Ultra-Dense Networking (UDN) [8]; as well as **v)** the Heterogeneous Networks (HetNets) [9], for indoor and outdoor deployment of Small Cells, are considered mandatory for 5G Networks by several articles in the open literature, serving a significant role in enhancing the overall system performance to meet 5G demands. Also, as referred above, a pivotal role in meeting the 5G key technical features is played by the deployment of Small Cells (e.g., Pico, Femto, Metro, etc.) [3]-[5][15][16]. Note that cost-effective Small Cell solutions are already a focal issue of the industry (i.e., Small Cell Forum, Huawei, AT&T, Ericson, Artemis, etc.).

Small Cells deployment is flexible (as they offer the possibility of deployment in a wide range of locations, both indoor and outdoor) and they can be deployed in a more targeted manner to relief traffic in hot spot areas. Small Cells reduce the physical separation between the UEs and the BS, which leads to: **i)** higher data rates and throughput; **ii)** increased spectral efficiency and higher capacity; **iii)** reduced energy consumption (both from the UEs and the BSs by allowing UEs to communicate at a shorter range with low signaling overhead); **iv)** keep interference at an adequate level; and **v)** enable the minimization of the power emitted by both the UEs and the BSs and the total Electromagnetic Field exposure. Also the manual plug and play utility of some types of Small Cells can further boost the on-demand capacity.

Proposed Personal Cells (PCs) include Femtocells, a term documented around 2005 for a standalone, self-configuring home BS, with Motorola engineers in Swindon claiming to have built the first complete 3G home BS in 2002. This kind of Personal cell was seen as an alternative way to deliver the benefits of fixed mobile convergence for indoor deployment however providing benefits only to their owners (residence and business use). Their main limitation was their static deployment, making them inflexible to cover dynamic needs, plus for outdoor use they face deployment difficulties, as described above. The scope of Femto cells was then extended outdoors, with the term Metro cell becoming used by some vendors, to include outdoor urban/rural/remote areas. This increased scope led to an evolution into the term Small Cell.

Another noteworthy example of a Personal Cell proposing a similar approach (i.e., using UEs with e-NB functionality), albeit limited to direct Device to Device (D2D) [11]-[12] communication within a cell is provided in the patent [17]. The patent claims is: "a User Equipment (UE) is enabled to operate or function temporarily as a personal Femto cell base station so that it can communicate with another UE that is within its nearby physical neighborhood. The result creates a "Personal Cell" (PC) that enables UEs to communicate directly with each other without the need to establish a communication path through an evolved base station ("eNodeB")".

Artemis' pCell technology [18], exploited in a C-RAN architecture, uses a different approach, requiring customized infrastructure, to deploy a personal cell.

For addressing the upcoming exponential traffic growth and facilitate evolution toward HetNets, a holistic Small Cell strategy is vital. However, the challenges to Small Cells technology still remain [16]: **i)** Lack of suitable backhaul availability; **ii)** Small Cell sites acquisition and operation; and **iii)** Small Cell technology integration and monetization. With the additional complexity of installing and maintaining massive amount of Small Cell sites, NetOps have to address both technical and commercial challenges, ensuring ease and flexibility to deployment and profitability. This is especially challenging in Ultra Dense 5G deployments.

IV. The Cella Ecosystem (CelEc) Framework

Following the same spirit of Small Cells described above, but especially targeted toward outdoor, dynamic, ultra-dense deployments, this section proposes the CelEc Framework. The main idea of CelEc is to evolve and supplement the Mobile Radio Network by using the numerous Mobile and Portable UEs as an integral part of the NetOps' Mobile Network Infrastructure. Towards this end, NetOps recruits part of the masses, under a "leasing service contract" as Network Operation "Facilitators", and embeds them, through the use of a **CelDe** (section IV.A), as the smallest building blocks and fundamental units of their Mobile Network Infrastructure. These CelDes, densely distributed in our physical world and environment, will form the **CelEc Tier** at the bottom layer of their 5G Network Architecture (see Fig. 1) and offer their networking functionalities and processing and storage resources, to supplement and support the Overlay Tiers by carrying out all sorts of network processes and functions (section IV.B and Chapter V), wherever and whenever needed.

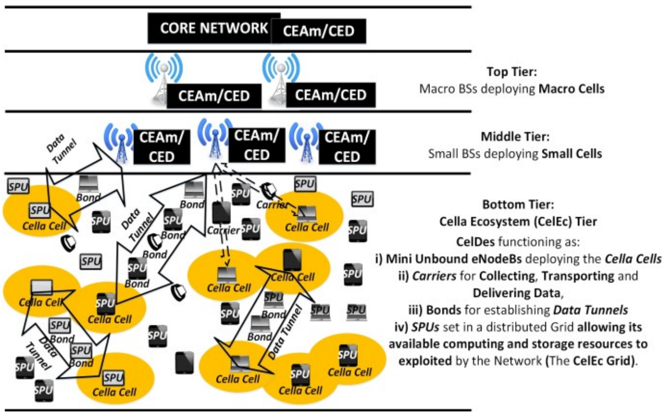


Fig. 1. The CelEc Tier at the Bottom Tier of 5G Network Architecture

The **CelEc Tier,** formed by a numerous, unbound and ubiquitous networking and computing elements (i.e., the CelDes), provides networking and computing operation functions and services, aiming to assist in a more effective Network operation and meet the key challenges and technical objectives of emerging 5G Networks [3]. The CelEc Tier is administrated by the **CelEc "Administration" module** (**CEAm**), running both on the Overlay Tiers and the Core Network, and integrating all the intelligence needed for the effective and efficient supervision and management of all the CelDes embedded. Yet, for any administrative decision made by CEAm, another important element, the **CelEc Database** (**CED**; section IV.C) holding the context info of all CelDes comprising the CelEc Tier, is proposed.

A. The CelEc Device (CelDe)

A CelDe can be any programmable Mobile/Portable UE already in the Market (e.g., Smartphones, Laptops, Tablets), preferably with minimum capabilities of Class 5 UEs. These should: **i)** include advanced hardware (i.e., strong and high life lasting battery, powerful processor, significant memory capabilities, strong MIMO antennas, etc.); **ii)** support multiple radio interfaces (e.g., LTE, 3G, WiFi, etc.); and **iii)** Integrate 5G technologies (e.g., CR, D2D, MIMO, etc.) for supporting all needed functionalities expected to be provided by the CelEc Tier (Chapter V) in a reliable, effective and efficient manner.

A crucial aspect for CelDe, is the Software that needs to be installed by the NetOps allowing it to be embedded and become an integral building block compatible with their existing Mobile Network Infrastructure. This Software will guarantee strong Security of the Device as well as the Privacy and integrity of any data communicated through or installed on it. Also it will allow the Device, additionally with its build in functionalities (i.e., functioning as a Smartphone, Tablet, etc.) to: **i)** operate as a mini eNodeB, compatible with the Overlay Tiers, able to deploy and manage the Cella cells (section V.A); and **ii)** in a tight cooperative and collaborative manner with all the other CelDes of the established CelEc Tier, allow for the ubiquitous and efficient flow, processing and storage of the data (section V.B – V.D). Here SDN concepts may be adopted.

B. The CelDe's Modes and Functions

Once the CelDes are embedded in the CelEc Tier, they become an integral part of the NetOps' Mobile Network Infrastructure. This allows CEAm to have full access to them and exploit their networking functionalities and computing and storage resources, whenever the Network is stressed. Thus, based on the Network demands, the CelDes' mode will be set dynamically by CEAm, according to the respective functionalities that the CelDes are expected to provide (e.g., bridge coverage gaps, supplement Network's capacity, storage and processing power, decongest the Overlay Tiers, etc.).

We propose the following six modes and respective functionalities, which will be subject to standardization: **i) Active:** Function as a mini eNodeB deploying a Cella cell, supporting a number of Client users located in its proximity (section V.A); **ii) Bond:** Function as a relay station, embraced as a "bond" in the setting of a Data Tunnel (section V.B); **iii) Carrier:** Function as a transporter of delay-tolerant data within the CelEc Tier (section V.C); **iv) SPU:** The CelDe is set in a distributed Grid, forming a virtual powerful Processor and massive Data Store integrated in the NetOps' Infrastructure, allowing its available computing and storage resources to be exploited by CEAm, (section V.D; the CelEc Grid); **v) Available:** The CelDe is "on call" and ready to be exploited, by the CEAm, whenever and however needed (see above); **vi) Withdrawn:** The CelDe is not available for use.

Setting CelDes to "Active", "Bond", or "Carrier" will not be performed in an arbitrary manner, but it will follow a request/accept process administered by the CEAm. The idea rests in the philosophy that the Facilitators are in control of their own CelDes at all times. This will be assisted by an App installed on the CelDe, facilitating communication between the Facilitators and the CEAm. Specifically, we envision to include: **i)** buttons allowing Facilitators to indicate their willingness (i.e., Available or Withdrawn) to provide services or temporarily withdrawn from CelEc; aims to allow a more harmonized operation of the CelEc Tier and avoid any QoS and QoE degradation from occurring; and **ii)** a Notification Panel allowing CEAm to request any assistance services from the Facilitators; e.g., CEAm can request Facilitators, in close proximity, to attend an area and supplement for extra capacity.

C. The CelEc Database (CED)

The role of CelEc Database (CED) is to hold the current context of all CelDes embedded in the CelEc Tier and provide CEAm full awareness and all the needed input that will facilitate in their effective and efficient administration, whenever the network is stressed and demands for more efficient data flows are requested.

CED will hold one record for each CelDe, including among others: **i)** Type of CelDe (i.e., Smartphone, Tablet, Laptop, etc.); **ii)** Geographical location and exact time of presence; **iii)** RSSI measured from proximate Overlay BSs; **iv)** RSSI measured from proximate CelDes (i.e., indicate strength of potential bonds); **v)** Remaining resources (e.g., battery level, computing, memory, etc.); and in case the CelDe is deploying a Cella cell **vi)** the IP Address of each Client user that it supports. It is worth highlighting that since a Cella cell is not expected to span more than ~10 meters in range, indirectly this will aid in determining a `precise` location of the Client users; this info can be exploited by NetOps for commercial use (e.g., Location-based Mobile advertising, Proximity-based Marketing, etc.).

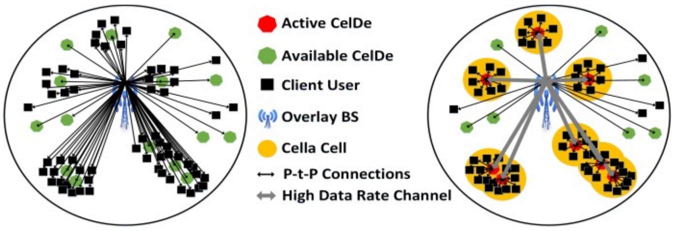
The above context information will have to be reported by the CelDes, through time, either periodically or after a request from CEAm. It can be kept in CED for additional or historical analysis, for inferring other valuable information like, for example, predicting trajectories, modelling the Facilitators' individual daily mobility patterns, etc. This info can be used for a more efficient and effective administration of the CelEc Tier's CelDes (e.g., for selecting the Active, Carriers and Bonds). The context reporting and storing will have some memory, processing and signaling overheads, though trivial, as the context information reported is in the range of a few bytes.

V. THE CELDE'S MODES AND ROLES IN THE CELEC TIER

A. Active Mode: Cella Cells Deployment

A CelDe is set to "Active" mode, when it is selected by the CEAm to deploy a Cella cell and support a number of Client users located in its proximity. While set to "Active", the CelDe functions as an integral part of the NetOps Radio Infrastructure mini eNodeB, that collects and fuses all data streams of the

Client users (including its own; note the Facilitator is also a Client user) into one higher data rate stream, which will be then handled as a single, more reliable and higher data rate cellular licensed radio channel with the Overlay BS (Fig. 2). Note that the aim of a Cella cell is not to support a huge number of users neither to reside in fixed locations for long periods of time; this is the job of the Overlay Tiers (Fig. 1). Thus, the supported coverage of the Cella cells does not have to be large (expected to be less than ~10 meters radius). Moreover, the Cella cell's coverage radius could be dynamically adjusted either intelligently by the CelDe or manually, for example based on the environment or the current distribution of the Client users in the area; especially where the demand is dynamic and even at times unpredictable. Also it does not necessarily have to span the whole designated area (e.g., support the whole area of a cafeteria) as there is always a great possibility to have more than one Facilitators located in the area willing to support; thus having more than one, even overlapping, Cella cells deployed.



a) Current Small Cell concept: All Connections are handled by the Overlay BS

b) CelEc concept: Major amount of direct connections are handled by the Active CelDes (i.e., the Cella cells)

Fig. 2. The "Active" CelDe: Deployment of Cella cells

Moreover, to further improve the spectral efficiency and capacity, we also suggest that the CelDe implements intelligent algorithms, exploiting and further extending concepts from the Cognitive Radio (CR) paradigm [10]. That is, whilst the CelDe is going "Active", it will scan, select in an intelligent manner and adopt (after consulting with the CEAm) a Radio Access Technology (RAT) as well as a licensed or unlicensed frequency band that will interfere the least with the other surrounding Cella cells or Overlay BSs.

B. Bond Mode: Establishment of Data Tunnels

A CelDe is set to "Bond" mode, when it is selected by the CEAm to function as a relay station, embraced as an intermediate bond in a communication path setting a Data Tunnel for flow of data (Fig. 3). Depending on the type of network traffic imposed, Data Tunnels can be established between a Cella cell (i.e., an Active CelDe) and an Overlay BS, or between two proximate Cella cells for direct communication. Note that in case there is a plethora of "Available" CelDes distributed in the designated area, multiple communication paths can be exploited in the setting of a Data Tunnel; achieving in this way higher data rates, for both Uplink and Downlink. However, for robustness, it is recommended the different communication paths setting up the Data Tunnel are independent from each other; that is avoid embracing the same CelDe as a "Bond" in two or more communication paths.

The establishment of the Data Tunnel will be administrated by the CEAm by consulting the records (comprised in CED) that includes the context information related to the CelDes (i.e., geographical location, mobility status, remaining battery lifetime and resources, RSSI between proximate CelDes, etc.) located in the designated area. The target is to establish a Data Tunnel that will guarantee: **i)** a reliable, robust and secure connection during the whole data flow; **ii)** maximize spectral efficiency, data rates and throughput; and **iii)** minimum delays during the data flow between the two ends. To achieve this, intelligent algorithms exploiting and further extending concepts from both CR [10] and D2D communication paradigms [11] will be implement in the CelDes and complement the CEAm's decision. Once the Data Tunnel is identified, each CelDe involved will be provided by CEAm all needed info (e.g., the CelDes that will "bond" with, the type of RAT and frequency band that will be used for each bond, etc.) for establishing the communication path(s) setting up the Data Tunnel. It is worth noting that the established Data Tunnel is as strong as its weakest "Bond".

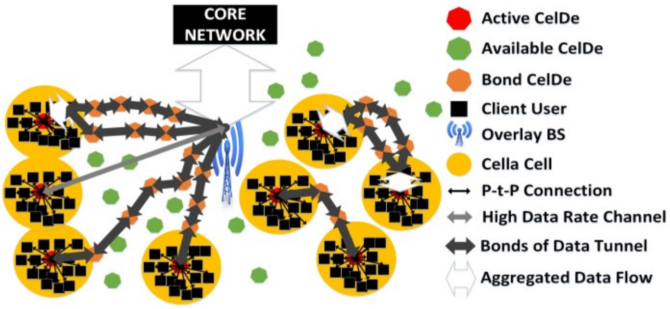


Fig. 3. The "Bond" Mode: Establishement of Data Tunnels

C. Carrier Mode: Delivery of Delay Tolerant Data

The "Carrier" mode exploits and further extends concepts from Delay Tolerant Network (DTN) [14] and is mainly used for complementing delivery of delay tolerant data, in case a Data Tunnel cannot be established. The aim of the Carrier mode is to "save" the available spectrum by collecting (form the Transmitting end), transporting and conveying data (to the Receiving end) as soon as it finds itself in a place that is conducive to a more efficient data transmission, instead of having them directly transmitted; this can potentially overcome the issue of spectrum scarcity and the cost-ineffective transmission of mobile traffic over the expensive licensed bands which is expected to become more obvious in future 5G Networks. The need for a Carrier can be indicated by any Active CelDe deploying a Cella cell. This will be done automatically by sending a request to the CEAm.

The role of the Carrier will be primarily undertaken by "Available" CelDes located in proximity. However, here things become more complex as trajectory prediction techniques will need to be developed. For this, smart algorithms, exploiting the accumulated historical data registered in CED for modelling the individual daily mobility patterns assisting in the Facilitators trajectory prediction, have to be designed; the technical details will be reported in future articles.

To address any risks due to: **i)** deviations from predicted trajectories or **ii)** the risk of one Carrier not being able to collect all the accumulated data from the Pick-up point (due to the limited time the two nodes will have in their disposal to communicate), CEAm identifies more than one potential Carriers to execute the transportation. It is worth noting that this mode is seamless to the Facilitators; i.e., they will not be requested to change their route or trajectory. All the identified potential Carriers will then be provided with the ID and location of the Pick-up point (e.g., the "Active" CelDe requested for them). The Carriers will then collect the data to be delivered once located in close proximity with the Pick-Up point and communication between them is established. The data will then be transported and conveyed as soon as the Carriers find themselves in a location very close to the specified Destination Point. In case no Carrier is identified, the data will be then either directly transmitted to the proximate Overlay BS or stays stored in the "Pick-up" point and by itself executes the role of the Carrier.

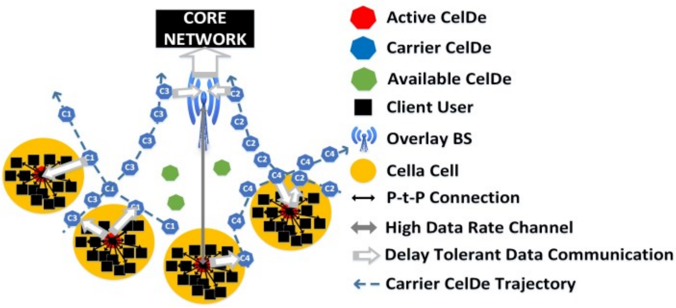


Fig. 4. The "Carrier" Mode: Delivery of Delay Tollerant Data

D. *SPU Mode: The CelEc Grid concept*

The CelEc Tier (Fig. 1) is formed by a distributed ecosystem of numerous and powerful computing elements (i.e., the CelDes), normally not fully exploiting their full potential (i.e., storage space and computing power). With the SPU mode, we attempt to exploit these underutilized resources for the NetOps benefit. To achieve this we introduce the CelEc Grid concept that builds and further extends concepts from the Fog Computing paradigm [13], by migrating computing and storage services in the CelEc Tier's CelDes.

By setting a CelDe to the "SPU" mode, automatically is embedded in a distributed grid (i.e., the CelEc Grid) of autonomous computing elements forming in aggregate a powerful Virtual Processing Unit and a massive Data Store, on which CEAm is allowed direct access and full control. This CelEc Grid can be exploited for example for storing the Client users' data (i.e., documents, photos, etc.) and furthermore for undertaking the execution of any other processing requests received from the Overlay Tiers, thus releasing the Network from significant computational loading and storage stretch. It is worth noting that, since the CelDes in SPU mode will store users' data, this mode should be agreed between the Facilitator and the NetOp, during their contract, and will be always on, independent of the other modes that the CelDe can be in.

VI. Preliminary Performance Evaluation

For a preliminary evaluation of some of the ideas discussed in this paper, aspects of the CelEc concept have been implemented and simulated on OPNET Modeler v18.5 using a simple one LTE Micro cell scenario (similarly to Fig. 2) assuming a 2Km radius, 10 MHz bandwidth, an urban environment with static or very low mobility users. The majority of the users are concentrated in an area with 8 newly created hot spot areas currently not supported by other Small Cells (e.g., Pico, Femto, etc.). The scenario was simulated for about 9 minutes and started with 80 users; 60 receiving and 20 transmitting a 128Kbits/sec video. Every 10 seconds, 40 users, 30 of them receiving and 10 transmitting a 128Kbits/sec video, were set to be admitted. A number of 70 Facilitators were randomly distributed in the area of these 8 newly created hotspots, and set to "Active" only when demands for supplementing capacity were detected. For the deployment of the Cella cells, WiFi radio interface was used to serve the Client users. Two instances of the same scenario have been simulated, the one exploiting the CelEc concept allowing for the dynamic deployment of the Cella cells, and the other using current Small Cell deployment approach. The results from this particular example are presented and compared in TABLE I showing great potential gains when CelEc is exploited.

TABLE I. Preliminary Evaluation Results

		Current Approach	With CelEc Exploited	CelEc Gain
Peak Date Rate in LTE Cell (Mbps)	DL	46.08	226.56	491% Increase
	UP	11.24	75.52	672% Increase
Peak Throughput in LTE Cell (Mbps)	DL	39.16	201.63	515% Increase
	UP	8.68	64.94	748% Increase
Max Capacity Achieved (Users)	DL	362	1770	488% Increase
	UP	82	590	719% Increase
Average Terminal Battery Consumption (Watts)		1.23	0.078	15.77 times less battery consumed
Average LTE BS Transmission power		34.673 watts (45.4 dBm)	4.168 watts (36.2 dBm)	8.32 times less energy consumed

Beyond the potential improvements shown in TABLE I, there is considerable spectral efficiency when the CelEc Tier was used. Specifically, we compared the LTE allocated radio resources when CelEc was used at the point in time that the Micro cell became congested; i.e., when 362 users were supported in the Downlink and 82 users in the Uplink. In this particular example when CelEc was exploited, the same QoS was shown to be provided however in a more scalable manner and with less radio resources allocated; only the 13.54% of the total Uplink and only 20.31% of the total Downlink LTE radio resources were allocated when the CelEc concept was used. Moreover, the amount of direct links with the Micro cell was significantly reduced thus releasing it from substantial processing load and reduced signaling overhead. That is, from the 444 total direct connections that needed to be established with the Micro cell, only a total of 72 (that is only 16.21%) were established when the CelEc concept was used; among them 27 connections with the CelDes that were activated at that time into Cella cells supporting a total of 399 users located in the hot spot areas, and another 45 connections with the rest of the users located out of the proximity of the hot spot areas.

It is worth noting that the objective of this preliminary evaluation was not to provide a full proof of concept but rather to highlight the potential technical gains of CelEc. The results collected from this particular example showed substantial gains on the uplink and downlink network capacity, data rates and throughput, spectral efficiency, energy efficiency and scalable massive mobile device support. More comprehensive evaluations are necessary to assess the full potential of CelEc.

VII. Conclusions and Future directions

This paper proposes the CelEc concept for emerging Ultra-Dense 5G, to evolve and supplement the Mobile Network, by exploiting the crowd's UEs, densely distributed in our physical world and environment, as an integral part of the Infrastructure. Towards this end, we formulate a framework which embeds the masses, through the use a CelDe, as the smallest building blocks and fundamental units in forming the CelEc Tier at the bottom layer of the 5G Mobile Network. These CelDes will then offer their networking functionalities and computing and storage resources, aiming to assist in a more effective Network operation and meet the key challenges and technical objectives of emerging 5G Networks. Specifically, CelEc introduces new ideas allowing for a more efficient flow of data and further extends the Small Cell's family with the new Cella cell. The Cella cell realises the smallest, portable and reconfigurable cell, for tiny coverage areas. Due to its unbound nature and its convenient "location" (i.e., with the Facilitators), allows for the dynamic massive deployment of Small Cells at any time and at any locations (i.e., indoor, outdoor and mainly everywhere that "Facilitators" are or can be located), adapted to the Network stresses. Hence it provides for a dynamic and real time reconfiguration of the Mobile Network infrastructure, in an effortless, costless and flexible manner, hence removing the restrains of existing Small Cells beyond their static positioning.

A preliminary evaluation of the CelEc concept showed, among others, scalable massive mobile device support, and great potential gains on the overall network capacity, data rates and throughput, energy efficiency and spectral efficiency, highlighting its usefulness and high potential in becoming an enabler of emerging 5G Networks. Furthermore, CelEc concept does not only promise benefits on the technical perspectives, but also: **i)** positive economic impacts to the NetOps as they are provided the chance to migrate to 5G Networks and significantly increase their revenue with considerably less CAPEX and OPEX investment; and **ii)** positive economic impact and chances for socio-economic maturity for the poverty stricken regions and population (i.e., the consumers), by offering them the business proposition of becoming a "Facilitator" and thus have a small piece of the revenue "pie".

Future work will address challenges and solve issues that need to be attended before realizing the full potential of CelEc concept in emerging 5G Networks. Specifically, future work will further investigate and address, but not limited to, the following open issues: **i)** Expand the simulation model of CelEc Framework and perform a more thorough evaluation, that will complement this paper, demonstrating its full potentials in 5G Networks; **ii)** The random and dynamic mobility of the CelDes as well as the untrustworthy nature of portable hardware (i.e., can be stolen, destroyed, malfunction, etc.), in the overall network's scalability, robustness and reliability; **iii)** The dynamic selection and deployment of Cella cells, establishment of Data Tunnels, selection of the Carriers, and management of CelEc Grid; **iv)** The Mobility as well as inter- and intra- cell interference challenges introduced due to massive deployment of Cella; **v)** The issues related to the memory, signaling overheads, and CelDes' battery drain caused due to the context information reporting to CED; **vi)** Security and privacy concerns, guaranteeing strong security of the CelDe as well as the privacy and integrity of any data communicated through or installed on it; and **vii)** The Crowd recruitment strategies, guaranteeing a uniform distribution of the "Facilitators" in the whole geographical area the NetOps are operating, effectively covering all type of high-density areas occupied based on people demographics and interest.

References

[1] Groupe Spéciale Mobile Association (GSMA),"The Mobile Economy 2015", London EC4N 8AF, United Kingdom, 2016.

[2] P. Cerwall, P. Jonsson, S. Carson, P. Jonsson, et al., Ericsson Mobility Report: On the Pulse of the Networked Society", Stockholm, Sweden, November 2015.

[3] N. Panwar, S. Sharma, A. Singh, "A Survey on 5G:The Next Generation of Mobile Communication" Elsevier, Physical Communication, Special Issue on Radio Access Network Architectures and Resource Management for 5G, Vol: 18, Part: 2, pp: 64 – 84, March 2016.

[4] I. F. Akyildiz, S. Nie, S. Lin, M. Chandrasekaran, "5G Roadmap: 10 Key Enabling Technologies", COMNET, Vol: 106, pp: 17 – 48, June 2016.

[5] L. Gavrilovska, V. Rakovic, V. Atanasovski, "Visions Towards 5G: Technical Requirements and Potential Enablers", Wireless Personal Communications, Vol: 87, Issue: 3, pp: 731 – 757, April 2016.

[6] C. Wang, F. Haider, X. Gao, X. You, Y. Yang, D. Yuan, H.M. Aggoune, et al., "Cellular Architecture and Key Technologies for 5G Wireless Communication Networks", IEEE Communication Magazine, Vol: 52, Issue: 2, pp: 122 – 130, February 2014.

[7] R. Raheem, A. Lasebae, M. Aiash, J. Loo, "From Fixed to Mobile Femtocells in LTE systems: Issues and Challenges", FGCT 2013, pp: 207 – 212, November 2013.

[8] A. Gotsis, S. Stefanatos, A. Alexiou, "Ultra Dense Networks: The New Wireless Frontier for Enabling 5G Access", IEEE Vehicular Technology Magazine, Vol: 11, Issue: 2, pp: 71 – 78, April 2016.

[9] A. Ghosh, N. Mangalvedhe, R. Ratasuk, B. Mondal, M. Cudak, E. Visotsky, T. Thomas, J. Andrews, P. Xia, H. Jo, H. Dhillon, T. Novlan, "Heterogeneous Cellular Networks: From Theory to Practice", IEEE Communication Magazine, Vol: 50, Issue: 6, pp: 54 – 64, June 2012.

[10] Z. Chkirbene, N. Hamdi, "A Survey on Spectrum Management in Cognitive Radio Networks", International Journal of Wireless and Mobile Computing, Vol: 8, Issue: 2, pp: 153 – 165, January 2015.

[11] P. Gandotra, R. K. Jha, "Device-to-Device Communication in Cellular Networks: A Survey", Elsevier, Journal of Network and Computer Applications, Vol: 71, pp: 99 – 117, June 2016.

[12] M. N. Tehrani, M. Uysal, H. Yanikomeroglu, "Device-to-Device Communication in 5G Cellular Networks: Challenges, Solutions, and Future Directions", IEEE Communication Magazine, Vol: 52, Issue: 5, pp: 86 – 92, May 2014.

[13] S. Yi, C. Li, Q. Li, "A Survey of Fog Computing: Concepts, Applications and Issues", Proceedings of the 2015 Workshop on Mobile Big Data (Mobidata '15), pp: 37 – 42, June 2015.

[14] K. Massri, A. Vitaletti, A. Vernata, I. Chatzigiannakis, "Routing Protocols for Delay Tolerant Networks: A Reference Architecture and a Thorough Quantitative Evaluation", Journal of Sensor and Actuator Networks (JSAN), Vol: 5 Issue: 2:6, March 2016.

[15] Huawei Technologies Co., LTD, "Five Trends to Small Cell 2020", 22-25 February, MWC 2016, Barcelona.

[16] Y. Q. Bian, D. Rao, "Small Cells Big Opportunities", Huawei White Paper, Business & Networking Consulting, February 2014.

[17] Y. H. Kwon, FutureWei Technologies Inc, "System and Method for Device-to-Device Communication Overlaid on a Cellular Network", U.S. Patent: 20130170414Al, issue data July 4, 2013.

[18] S. Perlman, A. Forenza, "An Introduction to pCell", Artemis Networks LLC, White Paper, February 2015.