Flexible Network Deployment in 5G: Performance of Vehicular Nomadic Nodes

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***Abstract*—The Fifth Generation (5G) of mobile and wireless networks is expected to fulfill the requirements of high variety of new use cases. One of the key challenges will be the varying capacity and coverage demands, non-uniformly distributed over space and time. In the current wireless networks, small cells are deployed at fixed locations via network planning, and, hence, lack the flexibility of reacting to spatially varying service requirements. Dynamic radio topology is an emerging concept towards 5G to address the real-time provisioning of services by means of flexible network deployment. In this regard, one promising system element of flexible network deployment to complement the existing heterogeneous networks (HetNets) is Vehicular Nomadic Nodes (VNNs). A VNN is a low-power access node which has a flexible backhaul, is movable, and activated temporarily to provide additional system capacity and/or coverage on demand. VNNs can be integrated into vehicles especially in urban areas, such as those of car sharing fleets or taxicab services. In this work, system-level performance of VNNs considering several flexible deployment scenarios is evaluated. Experiments are carried out separately in uplink (UL) and downlink (DL), where the performance of VNNs in terms of the user throughputs is compared with that of stationary picocells in a fixed HetNet, taking the macrocell-only deployment as the reference. The results show that flexible network deployment via VNNs is a promising enhancement to the current HetNets.**

Keywords—5G; Flexible Network Deployment; Dynamic Radio Topology; Vehicular Nomadic Node; RAN Design

I. Introduction

In the next decade, mobile and wireless networks will be challenged to meet diverse requirements of wide range of services that are becoming available. To overcome the huge growth of mobile traffic demand, deployment of low-power base stations (BSs) arose as one of the solutions within 4G Long Term Evolution Advanced (LTE-A) [1]. Low-power BSs such as microcells or picocells are deployed with an intention to help offloading the macro BSs by means of providing capacity and coverage enhancements to the network.

Towards the Fifth Generation (5G) systems, the concept of moving networks has emerged where both devices and cells are in constant or temporary motion. The requirements of the new use cases are expected to be satisfied, considering the inhomogeneous distribution of traffic over time and space [2]. Namely, the network to be deployed has to react quickly and dynamically to fulfill the increased service requirements in a certain time period and at a target region. In this sense, fixed small cells lack the flexibility of such networks in addition to their not-always-needed availability, which brings excess energy consumption and cost.

In this scope, one of the emerging components to enable dynamic radio topology is vehicular nomadic node (VNN) which provides a complementary approach to fixed low-power BSs, besides sharing their aforementioned advantages. VNNs are non-operator-deployed access nodes with relay-like capabilities, distributed with an uncertain availability in the network (called as “moving” or “nomadic” network). A typical example can be given as electric cars equipped with on-board cellular infrastructure and advanced backhaul antennas, parked on the street. While the locations of operator-deployed small cells or relays are optimized via network planning, the locations of VNNs are not controlled by the network operator, and, hence considered as being random. VNNs are assumed to be stationary during their operation, however, their availability changes with respect to time and space according to their battery state or change of location, hence the term “nomadic”. VNNs are expected to operate in a self-organized way that they are activated or deactivated based on capacity, coverage, load balancing, and energy efficiency requirements of the network. These features make VNNs a reasonable supplement to current cellular nodes concerning the flexibility and the dynamism required by the future wireless networks [1].

In this work, a thorough system-level performance evaluation of VNNs in a cellular wireless network is presented. For this purpose, a system-level modeling of VNNs is conducted within a MATLAB simulation platform. Specific flexible deployment scenarios are evaluated separately on uplink (UL) and downlink (DL), using different network configurations. Results are compared with that of picocell deployments which are assumed to be a part of a fixed heterogeneous network (HetNet), taking the macrocell-only deployment as the reference. The simulation results show VNNs as a promising enhancement to HetNets via flexible network deployment.

The rest of the paper is organized as follows. Section II gives an overview of dynamic radio topology and VNNs. In Section III, our deployment scenario, system model assumptions, and simulation setup are provided. Next, results of the simulations are given and evaluated in Section IV. Finally, Section V concludes the paper.

II. VEHICULAR NOMADIC NODES IN HETEROGENEOUS NETWORKS

A. Dynamic Radio Topology

According to the expected variety of use cases and business models, 5G is required to support a high degree of flexibility, besides being reliable and secure. Network resources have to be provided and allocated dynamically to the users depending on the demand and the context over time. Under the principle of dynamic radio topology design, moving networks are seen as essential elements of the 5G system [2].

The term "moving" or "nomadic" network describes a group of mobile nodes such as moving cells, relays and hubs, or mobile terminals, e.g. vehicles integrated with communication capabilities, forming a "moving network" which enables the communication between those nodes [2]. It is important to call attention to that the communication is not limited within the vehicle (e.g. links provided to the passengers in a high-speed train) but is also extended to the networks between (e.g. vehicle-to-vehicle communications) and outside the vehicles as in the case of VNNs.

VNNs are considered as movable or nomadic with regards to their availability over time and space, i.e., they can shut down their service, change location and serve at another place. It is expected that, VNNs are densely distributed in urban areas. Potentially, VNNs can be mounted on any widely-available public vehicle such as those of car rental or car sharing ventures, taxi fleets or emergency services (e.g. ambulances, fire engines and police cars). Furthermore, privately-owned vehicles could also be available for this purpose.

By means of flexible deployment, VNNs will become the part of the existing cellular infrastructure to provide additional capacity and coverage on demand. For instance, in a street festival, high capacity demand of a user crowd can be met by the activation of VNNs that are parked around, e.g., belonging to a car sharing company, or in the event of a road accident, the coverage and capacity demand of the involved users can be satisfied with the police car as a VNN, arrived in the scene.

B. Benefits and Challenges of Vehicular Nomadic Nodes

The concept of VNN has been introduced in 5G research project METIS as a component to enable flexible network deployment, considered for future wireless communication systems [3]. From the METIS contributors and the industry side, several works have been published regarding VNNs. In [1], an analysis on the operation of VNNs considering the aspects of dynamic VNN selection schemes and energy optimization of the networks is conducted. Various relaying modes for VNN deployment are assessed in [4], some of which are shown to improve the network performance in terms of coverage and capacity.

In [5], [6], and [7], VNNs are shown to reduce the energy consumption of the network via several optimization methods regarding their selection. In studies [1], [8], and [9], clear gains in terms of the backhaul link signal-to-interference-plus-noise ratio (SINR) and the mean end-to-end rate are shown by coarse VNN selection methods (considering the impact of shadowing on the backhaul link) compared to random selection. Furthermore, in [10] and [11], substantial performance gains of VNN operation are presented in a real urban environment with the help of ray-tracing propagation modelling.

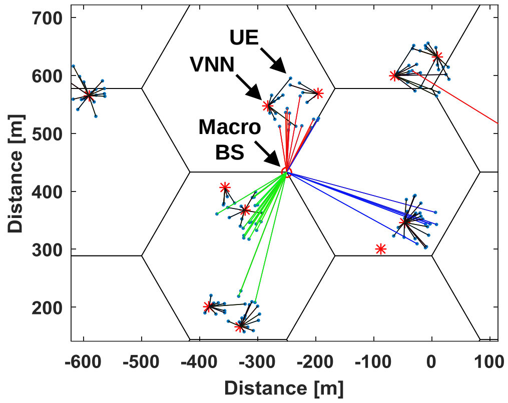

Fig. 1. A section of the network showing the links between the UEs (blue dots) and the VNNs (red asterisks) as black lines, and the links between the UEs and the macro BSs (red circles at the center of each site) as colored lines

Regarding the usability of VNNs, one main advantage is that they are favorable to conventional small cells in terms of the reduced operational costs (VNNs are utilized only for the needed time, and there is no site cost when they are not active). VNNs can be mounted on vehicle fleets such as that of car rentals or car sharing companies. Car sharing market is expected to grow between 30% and 35% until 2020 which seems to be a promising implementation domain for VNNs [12]. Sufficient space on vehicles allows more advanced implementation of cellular infrastructure on-board [1].

On the other hand, such a dynamic network of VNNs brings a number of challenges, e.g., management of battery time, interference mitigation, and service continuity when an active VNN leaves the target service region. Furthermore, agreements between the car manufacturers, mobile network operators and the private initiatives should take care that all parties benefit as a part of the business [1].

III. SYSTEM MODEL

A. Deployment Scenario and Assumptions

In this study, we consider a baseline cellular network, consisting of macro BSs deployed on a hexagonal grid with an inter-site distance of 500 m.

In the considered scenario, mobile user equipments (UEs) are distributed in the network as random hotspots (1 per macrocell, in average). Constituting each hotspot, UEs are randomly distributed within an annulus region bounded by the radii of 10 and 50 m, centered at a random point in the macrocell. The number of UEs per hotspot are 25 and 50 in the UL and DL experiments, respectively.

In the assumed scenario, there are 20 randomly located and inactive VNNs, present at each macrocell, in average. VNNs are assumed to be parked during their operation, without considering any mobility. A specific number (varied as a parameter in the experiments) of the closest VNNs to the center

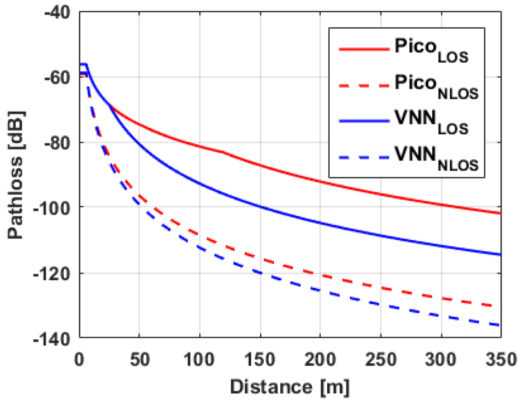

Fig. 2. A comparison of the picocell (Pico) and vehicular nomadic node (VNN) access link channel models. Pathloss in decibels (dB) with respect to distance in meters (m) for line-of-sight (LOS) and non-line-of-sight (NLOS) conditions are shown.

of each hotspot are activated by the network. UEs are not forced to connect to the activated VNNs but they still attach to the node with the largest reference symbol received power (RSRP) value, as the conventional cell selection scheme. A section from the simulated network is given in Fig. 1, showing the links that UEs are connected to. With this service-aware activation of VNNs, the network aims at providing the hotspots with the opportunity to benefit from a larger capacity and coverage.

To evaluate the effect on the network performance, the number of activated VNNs for each hotspot is varied as 1, 2 and 4. For the last two cases, the minimum distance between the activated VNNs is kept at 50 m which is the decorrelation distance of the shadowing process in the network. Keeping such a distance is introduced to mitigate the interference among the closely activated VNNs, and increase spatial diversity. To observe the potential gain of the flexible network deployments, the performance of VNNs is compared with fixed HetNet deployments, consisting of 1, 2 and 4 picocells per macrocell.

Considering the height of the vehicles to be placed on, the height of the VNN antenna is determined as 1.5 m above the ground, same as the UE antenna height. On the other hand, pico and macro BSs are assumed to have antenna heights of 5 m and 32 m, respectively. The transmit power and the antenna gain of VNNs are assumed to be the same as that of pico BSs, which are 30 dBm and 5 dBi, respectively.

B. Channel Model

The outdoor-to-indoor channel model provided in the Annex A.2.1.2 of the 3GPP standard TR 36.843 [13] is considered both for the VNN-UE and pico BS-UE access links, to allow a fair assessment. This model is adopted by 3GPP from the WINNER+ B1 urban microcell scenario (UMi) channel model [14]. Distance-dependent path loss of pico BS and VNN access links in LOS and NLOS conditions are compared in Fig. 2. It can be seen that for short distances (< 25 m) VNN has a similar access link with picocell both in LOS and NLOS conditions. For larger distances, picocell has better LOS and NLOS links. As maintained by the used model, the difference between the links is mainly due to different antenna

TABLE I. SIMULATION PARAMETERS

Feature	Implementation
Network Topology	Wrapped-around hexagonal grid of 19x3=57 macrocells; randomly placed picocells and VNNs, the latter being 20 per macrocell in average
UE Layout and Load	Randomly dropped hotspots, 1 per macrocell in average, containing 25 and 50 UEs in UL and DL, respectively; all indoor UEs (20 dB penetration loss)
Inter-Site Distance	500 m
System Bandwidth	20 MHz and 10 MHz in UL and DL, respectively; centered at 2.6 GHz; FDD
Frequency Reuse	1
eICIC Parameters	CRE offset of 12 dB; ABS ratio of 25% and 50% in UL and DL, respectively
Traffic Type	FTP
Scheduler	Proportional fair
Shadowing	Log-normal shadowing fading with standard deviations 8 dB macro BS to UE, 10 dB pico BS to UE, and 7 dB VNN to UE Shadowing decorrelation distance of 50 m
Noise Power	-174 dBm/Hz + 10xlog10(15 kHz) + $NF_{UE/BS}$
Tx Powers	Macro BS: 46 dBm Pico BS: 30 dBm VNN: 30 dBm UE: max 23, min -40 dBm, with UL power control
Antennae	Gains: macro BS 14 dBi, pico BS 5 dBi, VNN 5 dBi, and UE 0 dBi Noise figures: macro BS, pico BS and VNN 5 dB (NF_{BS}), and UE 9 dB (NF_{UE}) Heights: macro BS 32 m, pico BS 5 m, VNN 1.5 m, and UE 1.5 m
Receiver	1x2 Maximal-ratio combiner
Modulation	QPSK, 16QAM and 64QAM

heights, where pico BSs benefit from larger antenna height relative to VNNs.

According to the utilized model, shadowing standard deviation for the VNN access link is taken as 7 dB [13], whereas a typical value of 10 dB is assumed for the pico BS-UE link [15]. In the network, the backhaul links of pico BS and VNN are assumed to be ideal (e.g., out-band mmWave).

C. Simulation Setup

To evaluate the performance of the VNN deployment scenarios, a dynamic system-level HetNet simulator is employed. The simulator is implemented in MATLAB according to the 3GPP standards TR 36.814 [15] and TR 36.839 [16], and calibrated in line with the 3GPP scenarios.

The simulator generates a time-driven data traffic with a transmission time interval (TTI)-level clock of 1 ms, by the use of the following protocols: Transmission Control Protocol (TCP) New Reno with slow start, congestion avoidance, fast retransmit and fast recovery; Packet Data Convergence Protocol (PDCP) with data transfer and discard and procedures; Radio Link Control (RLC) protocol with Acknowledged Mode (AM) data transfer, Automatic repeat request (ARQ) and Unacknowledged Mode (UM) data transfer procedures, and Medium Access Control (MAC) protocol with all essential functionalities.

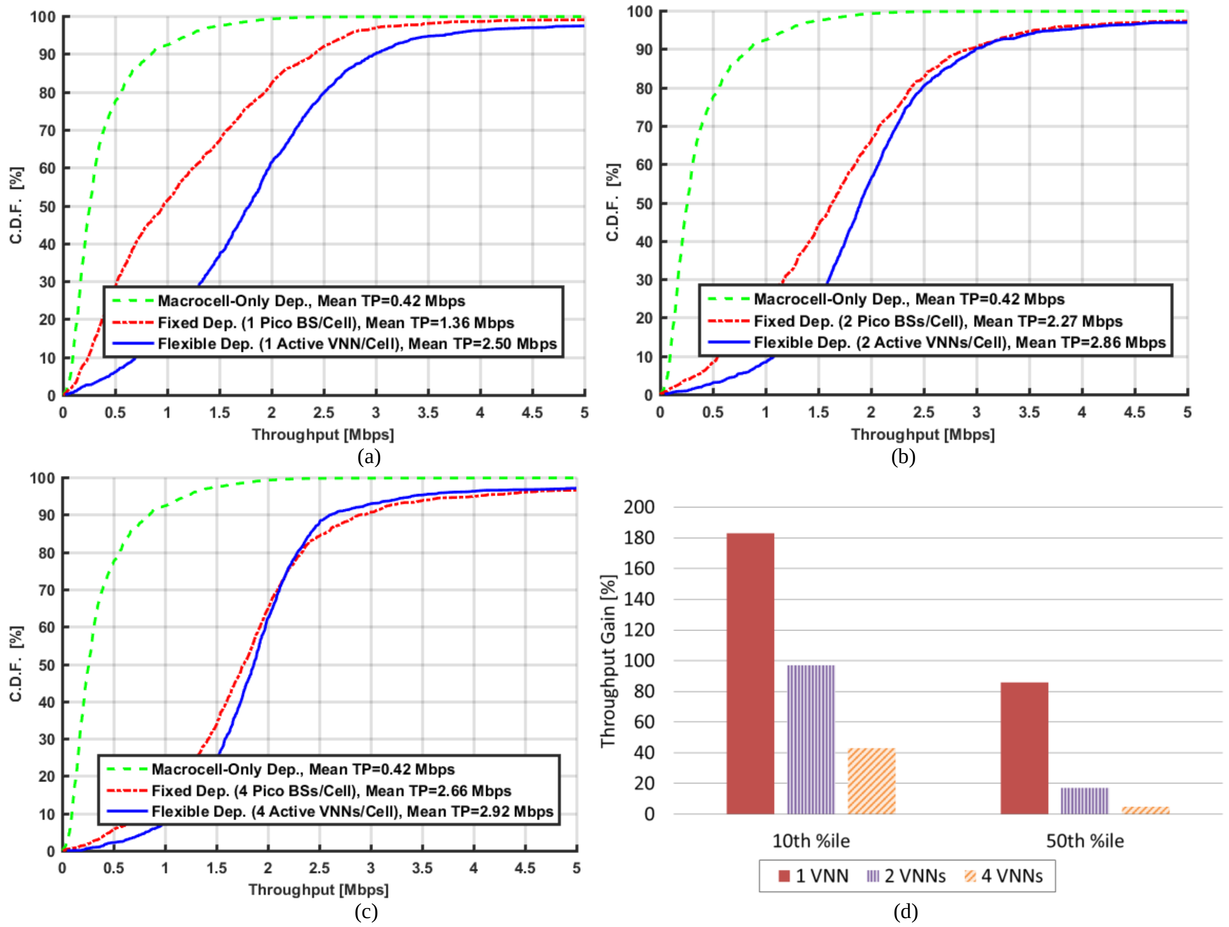

Fig. 3. CDFs of user packet call throughputs in UL with different deployment scenarios (a), (b), and (c), together with the throughput gain of the VNN deployments compared to picocell deployments in the 10th and the 50th percentiles of the CDFs as a column chart (d). Mean user throughputs (Mean TP) are provided in the legends.

Information of channel quality per subcarrier is used to generate transmission quality for the current TTI by Exponential Effective SIR Mapping. Block error probability of the transmission is looked up from the effective SIR value for different physical resource block (PRB) sizes. Then a random check determines whether the MAC protocol data unit (PDU) is correctly received or not. This way, link-level information is mapped to system level.

Picocells and VNNs are deployed on top of a wrapped-around hexagonal grid consisting of 19 tri-sectored macro BSs.

The simulator also features the enhanced inter-cell interference coordination (eICIC) introduced by 3GPP. This coordination involves two controllable parameters which are the almost blank subframes (ABS) ratio of the macro BSs and the cell range extension (CRE) bias of the pico BSs or the VNNs. ABS ratio is the percentage of muted subframes at the macro BS to reduce the interference on DL and CRE allows the deployed small nodes to extend their coverage by increasing the offset value which increases the attachment probability of the UEs in order to offload macro BSs [17]. The optimum values for the CRE bias and the ABS ratio used in the experiments were determined according to the initial simulation tests [18], and same values are used both for the VNN and picocell deployments.

The simulations are conducted independently in UL and DL, using different configurations in line with 3GPP [15]. 16 s of network operation is simulated where a random number UEs are activated at each TTI to generate packet calls. Hence, a total number of 16,000 realizations of random UE locations are generated during the simulations. The selected parameters for the experiments are provided in Table I.

IV. Results and Evaluation

The system-level performance of the flexible deployment of VNNs is evaluated in terms of the user throughput as the key performance indicator. In Figures 3 and 4, cumulative distribution functions (CDFs) of the user packet call throughputs for the considered deployment scenarios are given for the UL and DL experiments, respectively. Three cases are considered as the flexible deployment scenarios, whose results are provided in the parts (a), (b), and (c) of Figures 3 and 4. In each case, among the 20 randomly distributed VNNs per macrocell, the closest 1, 2 and 4 VNNs to each randomly distributed hotspot in the macrocells are activated, respectively. Performance of the VNNs is compared to that of the fixed HetNet deployments consisting of randomly placed 1, 2 and 4 picocells (equal to the number of the activated VNNs in each case) respectively, and taking the macrocell-only deployment as reference.

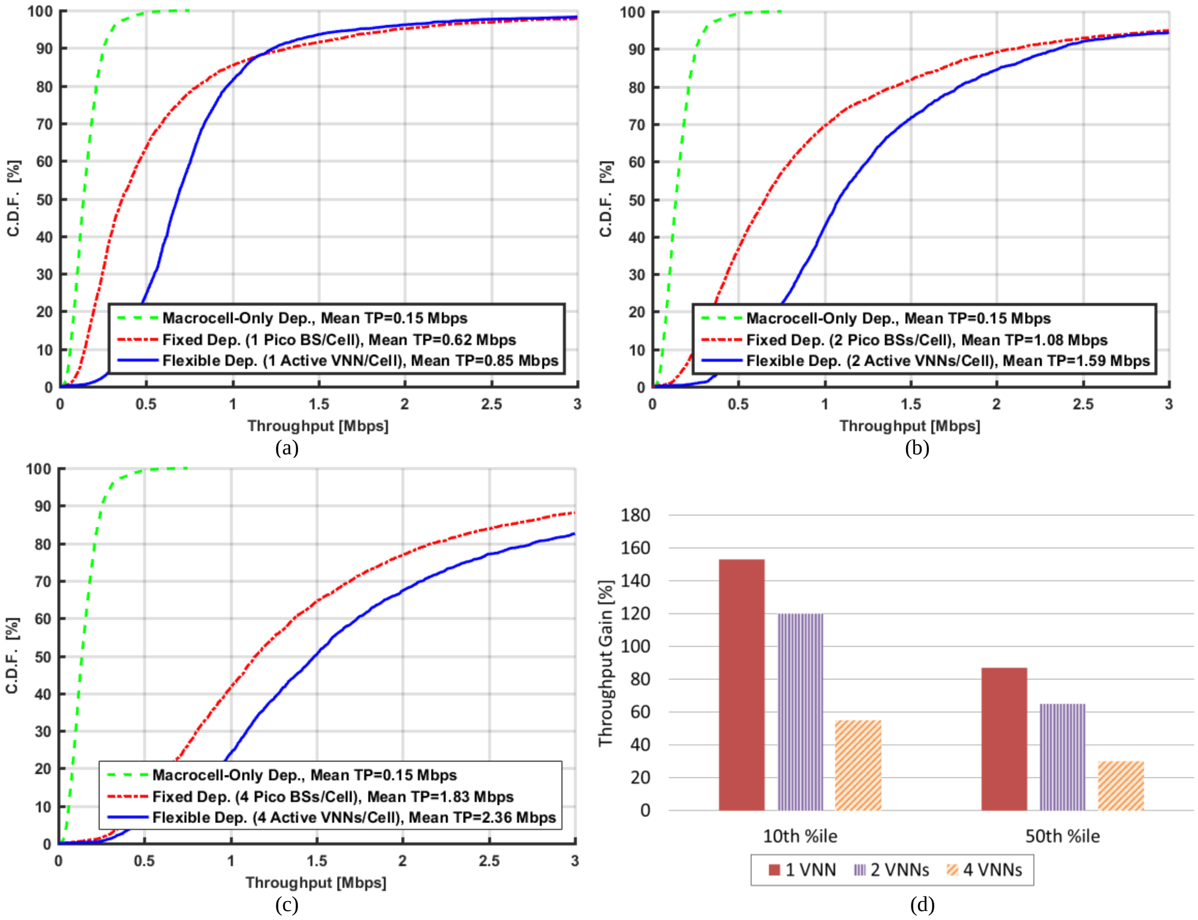

Fig. 4. CDFs of user packet call throughputs in DL with different deployment scenarios (a), (b), and (c), together with the throughput gain of the VNN deployments compared to picocell deployments in the 10th and the 50th percentiles of the CDFs as a column chart (d). Mean user throughputs (Mean TP) are provided in the legends.

Throughput gains of the VNN deployments with respect to picocell deployments for the lower (10th) and the median (50th) percentiles of the CDFs are also presented as column charts in Figures 3d and 4d.

In UL, in the first case as shown in Fig. 3a, activation of a single VNN closest to each hotspot achieves a gain of 84% in mean user throughput compared to a single randomly placed picocell deployment and a gain of 492% compared to the macrocell-only deployment. As can be seen in Fig. 3d, by activating the VNNs, it is possible to provide a high capacity gain of 183% at the lower (10th) percentile of the user throughput CDFs, compared to the picocell deployment. In the following cases where the closest 2 and 4 VNNs to each hotspot are activated, respective performance improvements in the mean throughputs are 26% and 10% compared to the picocell deployments, as Fig. 3b and 3c show, respectively. The decrease in the gains can be explained by the power control mechanism utilized by the users in UL, where the UEs compensate any channel losses.

By comparing Fig. 3a, 3b and 3c, it can be also observed that the user throughputs are not linearly proportional to the number of access nodes, which can be explained by the increased interference experienced by the nodes, especially among the VNNs very close to each other. However, the hotspot users are still provided with a larger throughput than the picocell deployment even with the increased number of VNNs.

In DL, activating the closest VNN to each hotspot is able to provide 36% higher mean throughput than that of the picocell deployment and 456% than that of the macrocell-only deployment, as observed in Fig 4a. The cases of activating the closest 2 and 4 VNNs to the hotspots have the throughput gains of 48% and 29% when compared to deployments of 2 and 4 fixed picocells per each macrocell, as can be observed from Fig. 4b and Fig. 4c, respectively. By comparing Fig 3d and 4d, it can be seen that in the absence of power control in DL, relative gains of the VNNs compared to the picocells are still significant even for larger number of active nodes.

Note that UL and DL simulations were conducted separately by using different network configurations, e.g. the number of UEs per hotspot is doubled and the system bandwidth is reduced to half in DL, compared to UL. Therefore, given the same deployment scenarios, mean user DL throughputs are lower than that of UL, when Fig. 3 and 4 are compared, as expected.

From the results, it can be concluded that the flexible deployment of VNNs provides significantly better performance in terms of the capacity, when compared to fixed deployment of picocells as well as the macrocell-only deployment, both in UL and DL. This demonstrates that flexible network deployment is a promising complementary enhancement to HetNets for the next generation of wireless and mobile networks.

V. Conclusions

In this paper, system-level performance of VNNs within the framework of dynamic radio topology is evaluated considering various deployment scenarios. The experiments conducted in UL and DL showed that the flexible deployment of VNNs outperforms the fixed picocell deployments of HetNets and the macrocell-only deployment, in terms of the mean user throughput as well as the 10^{th} and 50^{th} percentile throughput levels. The results of this study support the utilization of VNNs as a promising enhancement to HetNets by enabling flexible, demand-driven and dynamic networks that are envisioned by 5G systems.

Acknowledgment

Part of this work has been performed in the framework of the H2020 project METIS-II co-funded by the EU. Authors would like to acknowledge the contributions of their colleagues from METIS-II although the views expressed are those of the authors and do not necessarily represent the views of the METIS-II project.

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