RAN Moderation in 5G Dynamic Radio Topology

Ömer Bulakci, Alexandros Kaloxylos, Josef Eichinger, Chan Zhou
Huawei Technologies GRC, Munich, Germany
{oemer.bulakci, alexandros.kaloxylos, josef.eichinger, chan.zhou}@huawei.com

***Abstract*—The standardization for the fifth generation (5G) of mobile and wireless networks is at its early phase and has recently completed the first study item in Release 14. Nevertheless, there is a consensus that 5G will address the diverse service requirements of high-variety use cases. The network shall cope with such variation effectively and cost-efficiently even though the requirements can change over space and time. The design of the radio topology for the peak service demand is, thus, not desirable for network operators. As a consequence, the trend is towards more flexible network deployment. In this context, dynamic radio topology through vehicular nomadic nodes (VNNs) is an emerging concept towards 5G to efficiently address non-uniformly distributed traffic. VNNs are aimed to overcome the lack of flexibility induced by small cells that are deployed at fixed locations via network planning in current wireless networks. A VNN is a low-power access node with wireless self-backhaul, which can be activated temporarily to provide additional system capacity and/or coverage on demand. VNNs can be integrated into vehicles, e.g., in car-sharing fleets. In this paper, we evaluate the performance of radio access network (RAN) moderation of VNNs in a multi-cell environment considering composite fading/shadowing environments with co-channel interference, where active VNNs are selected from a set of available candidate VNNs based on the signal-to-interference-plus-noise ratio (SINR) on the wireless backhaul link. The results show that RAN moderation can significantly improve the end-to-end rate and SINR performances along with clear amount-of-fading (AoF) reduction.**

Keywords—5G; Dynamic Radio Topology; HetNet; METIS-II; Moving Networks; RAN Moderation; Vehicular Nomadic Node

I. Introduction

In current mobile and wireless networks, one approach for addressing increased coverage and/or capacity demands is to deploy fixed small cells. Small cells are typically deployed by network operators at certain locations, where the locations can be determined by network planning. However, the full operation of such dense fixed small cell deployment is not always needed due to the inhomogeneous distribution of traffic over time and space. Hence, fixed network deployment has the disadvantage of increased capital expenditure (CAPEX), e.g., due to deployment of additional wireless access nodes, and operational expenditure (OPEX), e.g., due to the incurred site leasing costs, although small cells need to be operated only partially. In addition, the need for proper site locations, e.g., due to power supply facility, can further limit the achievable network topology.

Towards the Fifth Generation (5G) system, the concept of dynamic radio topology has emerged [1]-[9]. Within the framework of dynamic radio topology, the network shall react quickly and dynamically to fulfill the increased service requirements in a certain time period and at a target service region. On this basis, one component to enable dynamic radio topology is vehicular nomadic node (VNN) operation, which provides a complementary approach to fixed small cells. A VNN is a movable access node with wireless backhaul link, which can provide coverage extension and/or capacity improvement on demand. VNNs can be integrated into vehicles as shown in Fig. 1, e.g., within a car-sharing fleet. 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 driver needs, and, hence, the term “nomadic” is applied. Furthermore, as VNNs are integrated into vehicles, due to low height of 1.5 m like the one of user equipments (UEs), severe fading characteristics can be expected on the wireless backhaul link as opposed to well-elevated small cells (e.g., 5-10 m for fixed relay nodes). Accordingly, to ensure the expected benefits of VNN operation, active VNNs shall be properly selected such that the wireless backhaul link quality is optimized.

In this work, RAN moderation of VNNs is presented in a cellular wireless network to determine the active VNNs, where the radio channels are modeled by composite fading/shadowing. Performance of the proposed RAN moderation strategies are shown in terms of the resultant signal-to-interference-plus-noise ratio (SINR) on the wireless backhaul link, end-to-end rates, and severity of fading via amount-of-fading (AoF) metric.

The remainder of the paper is organized as follows. Section II sets the scene for RAN moderation strategies in dynamic radio topology along with the channel and system models. In Section III, performance results are provided. Finally, Section IV concludes the paper.

II. RAN Moderation Schemes

A. System and Channel Models

The considered system model is depicted in Fig. 1, where the network is represented by a regular hexagonal layout with seven macrocells served by base stations (BSs) deployed in the centers of hexagons. In the exemplary illustration, there are three candidate VNNs available in the target service region, i.e., three vehicles are parked in the region of interest and can be activated to serve the UEs in the proximity of the active VNN on the access link (VNN-UE link). It is worth noting that the target service regions can be determined by the operators, e.g., based on UE density due to an event. In order to take into account the uncertainty for the availability of VNNs, we utilize the parking lot model given in [1], [4], [10], which is based on continuous-time Markov chains. We consider a parking lot

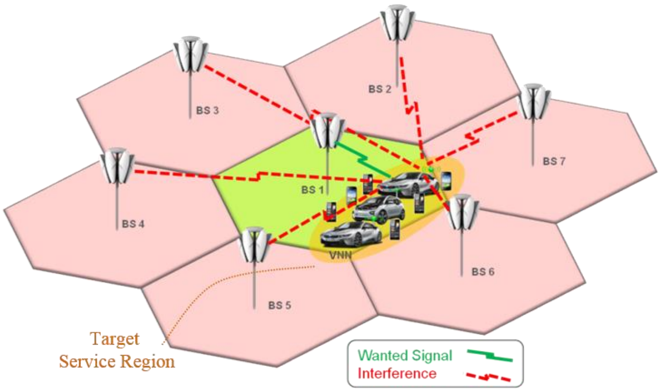

Fig. 1. The considered system model with UEs, VNNs and macro BSs. The active VNN to serve the target service region and the associated serving BS are selected based on the backhaul link SINR.

where a maximum of $M_{\max} \in \{5, 15\}$ places are available on a line road. The distance between two nearby VNNs is taken as 6 m. Moreover, we set the parking lot model parameters, i.e., departure and arrival rates, such that a regular day time (09:00-17:00) is simulated [1]. The flexible wireless backhaul (BS-VNN link) is realized by in-band half-duplex relaying in this work, while different relaying options can also be considered for the VNN operation, such as, full-duplex and out-band relaying.

The channel models pertain to a two-hop decode-and-forward relaying operation through VNNs, where end-to-end performance is degraded also by interference on the backhaul link. The direct link (BS-UE) and backhaul link are modelled by Rayleigh-lognormal (a.k.a. Suzuki) composite distribution, and the access link is modeled by Rician-lognormal composite distribution, which are the two common models in the literature [11]. Interfering signals on the backhaul link are assumed to be subject to Rayleigh-lognormal composite fading/shadowing. It is worth noting that severe fading characteristics are also assumed on the backhaul link due to low height of VNNs like the UEs. Further, a single UE is connected to a single VNN on the access link and is communicating via this VNN with a BS. The shadowing standard deviation is set to 8 dB on direct and backhaul links, unless otherwise stated. The rest of the system parameters are in line with [4]. Besides, the simulations are conducted using MATLAB R2011a as the computational environment.

B. Problem Formulation and Selection Schemes

RAN moderation strategies take into account the backhaul link qualities at different candidate VNNs towards the available K BSs. At a given time instant, there are M available VNN candidates in cell k out of which we select the VNN m^* (VNN selection) and associate it with the BS k^* (serving BS selection) such that downlink SINR γ on the backhaul link is maximized as

$$\gamma^{\text{opt}}_{m^*,k^*} = \max_{m,k}\{\gamma_{m,k} : m = 1, 2,..., M \ \& \ k = 1, 2,..., K\} \quad (1)$$
$$\text{subject to } M \le M_{\max}$$

Accordingly, the serving BS may not necessarily be the closest BS to the candidate VNNs. For instance, the closest BS may be shadowed due to a large obstacle and, thus, a neighbor BS may provide the best backhaul link conditions. Two VNN selection schemes are considered within the RAN moderation framework. Namely, in case of *optimal VNN selection*, both shadowing and multi-path fading are considered in SINR measurement in (1). On the other hand, in case of *coarse VNN selection* only shadowing is factored in the SINR measurement in (1). That is, optimal VNN selection takes into account short-term changes in radio conditions, whereas coarse VNN selection is focusing on the long-term radio conditions. Consequently, the optimal selection requires more frequent channel quality indications to be sent.

In [1] and [4], the analyses on were limited to VNN selection schemes, where the selected VNN was assumed to be served by the midmost BS only (k*=1). Herein, the analyses are conducted such that VNN and serving BS selections are jointly optimized, and the impact of serving BS selection is highlighted. On this basis, in the following, *single BS* refers to the case where the selected VNN is served by the midmost BS only, and the *multi BS* refers to the case where the serving cell of the VNN can be any of the available K=7 BSs based on the selection criterion given in (1).

III. Performance Evaluation

In this section, the performance assessment of different selection schemes is performed in terms of downlink SINR, end-to-end rates, and AoF. Random VNN selection is taken as reference, where no particular channel knowledge is utilized.

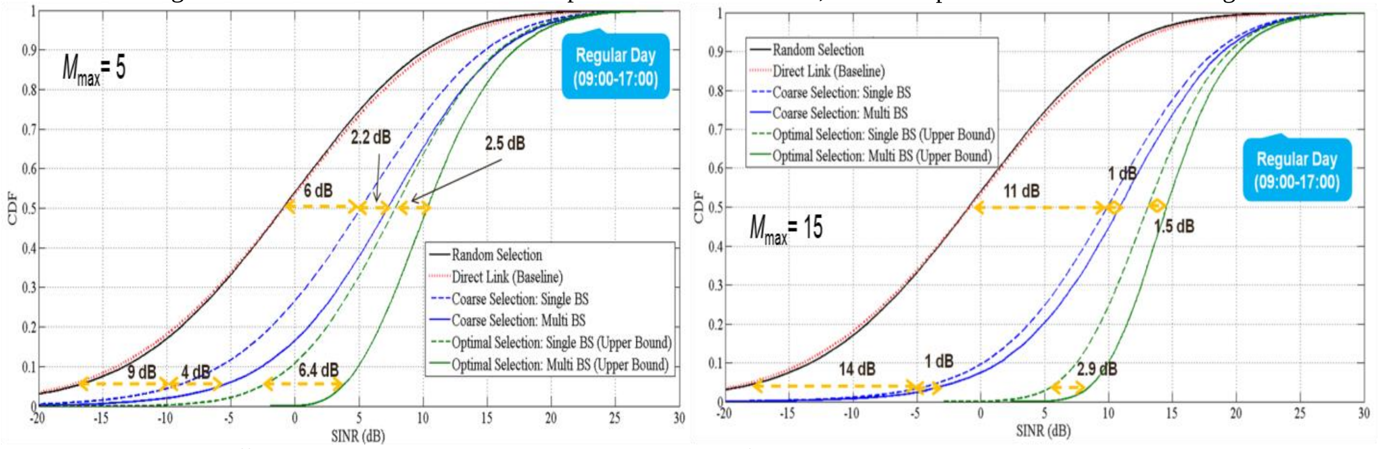

Fig. 2. SINR gains with different RAN moderation strategies considering $M_{\max}$ = 5 (left) and $M_{\max}$=15 (right).

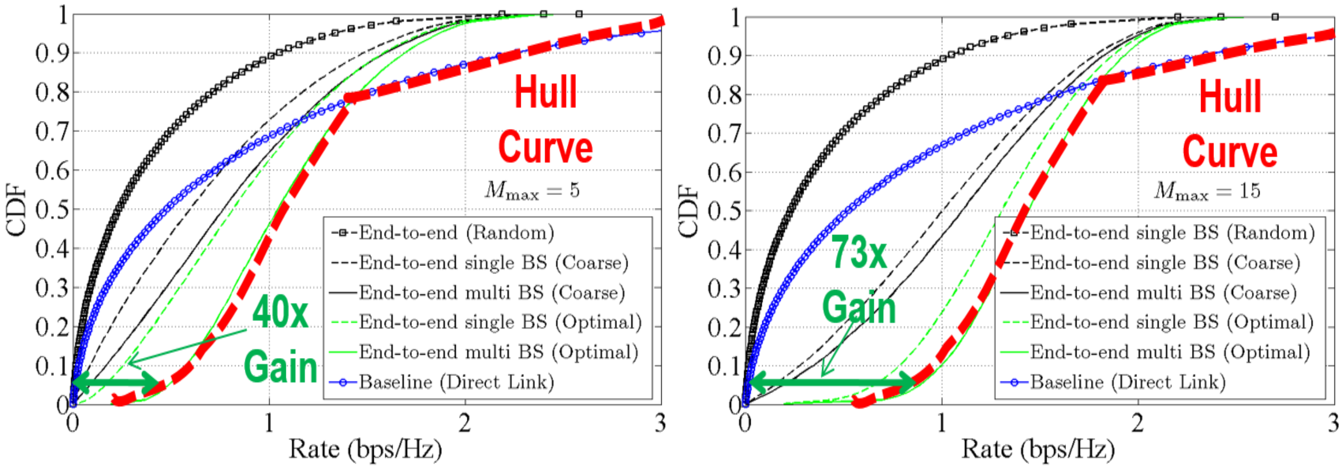

Fig. 3. End-to-end rate gains with different RAN moderation strategies considering $M_{\max}$ = 5 (left) and $M_{\max}$=15 (right). The *Hull Curve* indicates the upper bound of achievable gains when the cell selection for the UE (BS or VNN) is optimized.

A. SINR Distributions

The cumulative distribution function (CDF) plots of SINR values on the backhaul link and on the direct link are illustrated in Fig. 2 for $M_{\max}$=5 and 15. It is first observed that the performances of random VNN selection and direct link are comparable. This is due to the assumption of the severe fading characteristics on the backhaul link similar to the direct link. This outcome motivates the need for proper VNN selection schemes to attain the promised benefits of the dynamic radio topology. In this regard, it can be seen that VNN selection schemes can clearly improve the performance especially at the low SINR regime. For instance, in case of $M_{\max}$ = 5, single-BS coarse selection can increase the SINR at 5%-ile CDF level by 9 dB relative to the direct link, while the joint optimization considering the serving BS selection (i.e., multi BS) can provide an additional 4-dB SINR gain. Optimal VNN selection can further improve the SINR performance at the cost of increased measurement overhead. In particular, the optimal VNN selection results mark the upper bound of achievable SINR gains in a given scenario.

Additionally, when there are more available VNNs in the parking lot (see, $M_{\max}$ = 15), the achievable SINR gains can be clearly improved, e.g., the SINR gain at the 5%-ile SINR CDF is then increased to 14 dB in case of single-BS coarse VNN selection. Nevertheless, the extra gains obtained via multi-BS optimization are decreased when the available number of VNNs increases, as the probability of having the best backhaul link toward the midmost BS increases.

B. End-to-end Rate Distributions

The CDF plots of end-to-end rates are illustrated by Fig. 3 for $M_{\max}$=5 and 15. Herein, equal-time resource operating point is assumed between backhaul and access links, e.g., in a long-term evolution (LTE) system, this would correspond to the case where five subframes of a ten-subframe radio frame are allocated to each of the backhaul and access links. The results further highlight that VNN selection is vital because without VNN selection (see random selection), the VNN performance becomes worse than that of the direct link due to half-duplex constraint, i.e., the total time resources are shared between backhaul and access links.

The previously observed SINR gains translate into end-to-end rate gains. The VNN selection schemes can significantly improve the end-to-end rate performance particularly at the low and mid throughput regimes. When serving BS is jointly determined with the VNN selection, clear gains can be observed, where these gains are higher in case of optimal VNN selection (compare single BS and multi BS). In case of multi BS (Optimal) and $M_{\max}$=5, the rate performance can be improved by 40 times at 5%-ile rate level compared to the direct link. Yet, VNN performance is worse than the direct link as of 80%-ile because of the half-duplex limitation; yet, by optimal cell selection the shown hull curve performance can be approached.

Moreover, in case of a larger number of available VNNs (see, $M_{\max}$=15), the overall performance can be further improved. In particular, the rate performance is improved by 73 times at 5%-ile rate level compared to the direct link. Nevertheless, the extra gain through multi-BS optimization decreases, as also observed for the SINR gains in Section III-A.

C. AoF

The AoF, which reflects the severity of fading, can be calculated from the first and the second moments of the SINR as [11]

$$AoF = \frac{\mathrm{var}(\gamma)}{[E(\gamma)]^2}, \tag{2}$$

where var(·) denotes variance. Accordingly, AoF provides further insights into fading mitigation via the proposed RAN moderation strategies.

The AoF values on the backhaul link are depicted in Fig. 4 as a function of the shadowing standard deviation for $M_{\max}$=5 and 15. The case of zero shadowing standard deviation indicates the absence of shadowing, where the channel is impaired by multi-path fading only. It is seen that AoF on the backhaul link decreases clearly when selection schemes are applied. In particular, when the shadowing standard deviation

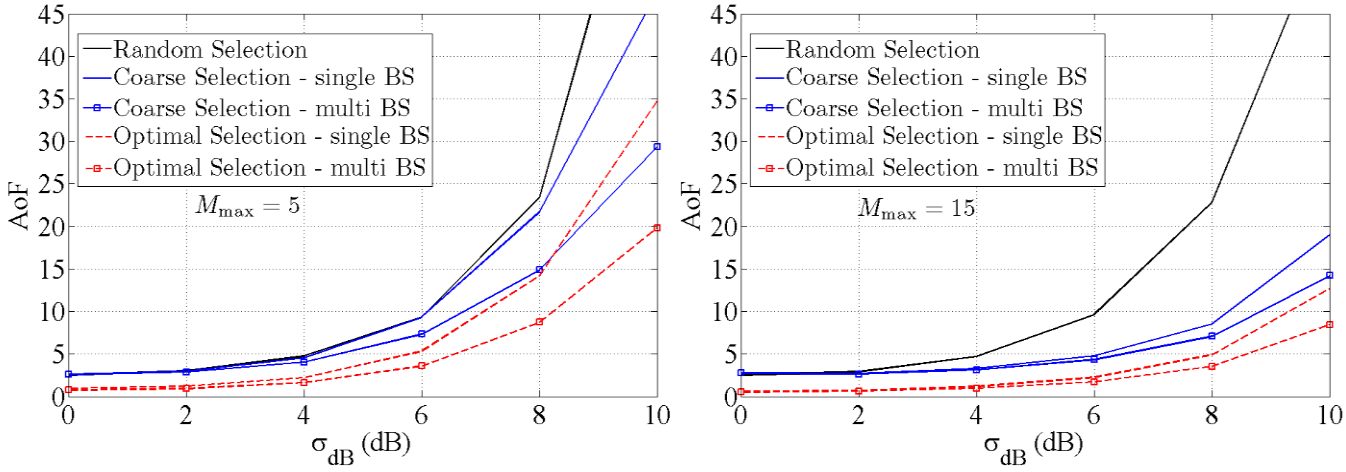

Fig. 4. AoF on the backhaul link as a function of the shadowing standard deviation (σ_{dB}) on the backhaul link with different RAN moderation strategies considering M_{max} = 5 (left) and M_{max}=15 (right).

is large, i.e., heavy shadowing, the selection schemes can effectively reduce AoF. Coarse VNN selection performs well in mitigating the deleterious impact of shadowing on the backhaul link, while optimal VNN selection can yield further reduction. That is, the lower bound for AoF is reached when optimal NN selection is utilized. With the increasing number of available VNNs, more AoF reduction can be observed (see, M_{max}=15). In addition, multi-BS optimization can assist in reducing the AoF, where its impact is more pronounced in case of smaller number of available VNNs (see, M_{max}=5 and compare single BS and multi BS) compared to a larger number of available VNNs (see, M_{max}=15 and compare single BS and multi BS).

IV. Conclusion

In this paper, RAN moderation is demonstrated in dynamic radio topology consisting of VNNs. Various RAN moderation strategies are analyzed, and their implications on the SINR and end-to-end rate distributions as well as AoF are shown. First of all, the vital role of the considered selection schemes on the VNN operation is highlighted taking into account different performance metrics. The results indicate that coarse VNN selection is a promising practical scheme that can substantially improve the overall performance with less-frequent link quality measurements. Optimal VNN selection would, however, require frequent measurements to be able to follow the changes in the channel conditions; thus, it can be considered illustrative for showing the achievable gains via VNN selection schemes. Additionally, serving BS selection together with the VNN selection schemes can clearly improve the performance, particularly when a small number of VNNs are available in the target service region. The achieved gains, even in case of a small number of available VNNs, motivate the utilization of VNNs as a promising enhancement to heterogeneous networks (HetNets) by enabling demand-driven dynamic radio topology in 5G mobile and wireless communication networks.

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.

References

[1] Ö. Bulakci, *et al*., "Dynamic Nomadic Node Selection for Performance Enhancement in Composite Fading/Shadowing Environments," *2014 IEEE VTC Spring, Seoul*, 2014, pp. 1-5.

[2] Z. Ren, S. Stanczak and P. Fertl, "Activation of nomadic relay nodes in dynamic interference environment for energy saving," 2014 IEEE Global Communications Conference, Austin, TX, 2014, pp. 4466-4471.

[3] METIS Deliverable D6.6, "Final report on the METIS 5G system concept and technology roadmap," April 2015.

[4] Ö. Bulakci et al., "Towards flexible network deployment in 5G: Nomadic node enhancement to heterogeneous networks," *2015 IEEE ICC*, London, 2015, pp. 2572-2577.

[5] NGMN Alliance 5G Initiative Team, "NGMN 5G White Paper," NGMN LTD., Frankfurt, 2015.

[6] METIS-II Deliverable D5.2, "Final Considerations on Synchronous Control Functions and Agile Resource Management Framework for 5G," March 2017.

[7] G. Tsoulos, et al., "Performance of Vehicular Nomadic Node Operation in Realistic Multicellular Environments," *2nd International Workshop on Research Advancements in Future Networking Technologies (RAFNET 2017) at 2017 IEEE VTC Spring*, Sydney, Australia, 2017.

[8] G. Tsoulos, et al.,, "Dynamic Wireless Network Shaping via Moving Cells: The Nomadic Nodes Case," *Wiley Transactions on Emerging Telecommunications Technologies (ETT)*, January 2017.

[9] T. Sahin, et al. "Nomadic Nodes for Dynamic Radio Topology in 5G Wireless Networks: System-level Performance Evaluation," *2017 IEEE VTC Spring*, Sydney, Australia, 2017.

[10] M. Caliskan, et al., "Predicting parking lot occupancy in vehicular ad hoc networks," in IEEE VTC2007-Spring, Dublin, Ireland, April 2007.

[11] M. Simon and M. Alouini, *Digital communication over fading channels*, 2nd ed. New York: John Wiley & Sons Inc., 2005.