

Distributed Path Selection Strategies for Integrated Access and Backhaul at mmWaves

Michele Polese^o, Marco Giordani^o, Arnab Roy[†], Douglas Castor[†], Michele Zorzi^o

email:{polesemi,giordani,zorzi}@dei.unipd.it, {arnab.roy,douglas.castor}@interdigital.com

^oConsorzio Futuro in Ricerca (CFR) and University of Padova, Italy

[†]InterDigital Communications, Inc., USA

Abstract—The communication at mmWave frequencies is a promising enabler for ultra high data rates in the next generation of mobile cellular networks (5G). The harsh propagation environment at such high frequencies, however, demands a dense base station deployment, which may be infeasible because of the unavailability of fiber drops to provide wired backhauling. To address this issue, 3GPP has recently proposed a Study Item on Integrated Access and Backhaul (IAB), i.e., on the possibility of providing the wireless backhaul together with the radio access to the mobile terminals. The design of IAB base stations and networks introduces new research challenges, especially when considering the demanding conditions at mmWave frequencies. In this paper we study different path selection techniques, using a distributed approach, and investigate their performance in terms of hop count and bottleneck Signal-to-Noise-Ratio (SNR) using a channel model based on real measurements. We show that there exist solutions that decrease the number of hops without affecting the bottleneck SNR and provide guidelines on the design of IAB path selection policies.

Index Terms—5G, millimeter wave, Integrated Access and Backhaul, 3GPP, NR.

I. INTRODUCTION

The next frontier of wireless communications is at mmWave frequencies [1]: the availability of large chunks of untapped spectrum makes it possible to exploit a large bandwidth and to satisfy the demand for multi-gigabit-per-second data rates in fifth generation (5G) cellular networks [2]. The first field trials have confirmed the high potential of this technology [3], and for the first time 3GPP is standardizing mobile networks at mmWave frequencies. The new 5G Radio Access Network (RAN) specifications (i.e., 3GPP NR) will indeed support carrier frequencies up to 52.6 GHz, with a bandwidth per single carrier up to 400 MHz [4].

The communication at such high frequencies, however, introduces new challenges and issues that must be taken into account when designing and deploying mmWave cellular networks [5]. The first is related to the high propagation loss, which is proportional to the square of the carrier frequency for a given effective antenna area, and limits the communication range of mmWave base stations. Nonetheless, the short mmWave wavelength makes it possible to pack a large number of antenna elements in a limited area, thus enabling directional transmissions with a high beamforming gain that makes up for the high propagation loss [6]. Therefore, 3GPP NR supports directional transmissions in its Physical (PHY) and Medium Access Control (MAC) layer specifications, with procedures for a directional initial access and tracking of the

best beam pair between users and base stations [7], [8]. The second issue is related to the blockage by common materials, such as brick, mortar and the human body [9]. While Non-Line-of-Sight (NLOS) communications are possible also at mmWave frequencies [10], the presence of obstacles reduces the received signal power by up to three orders of magnitude, thus greatly increasing the probability of being in outage.

The combination of the high propagation loss and the blockage phenomenon advocates for a high-density deployment. With such network architecture, mmWave base stations would be deployed as small cells. Despite the limited coverage range, each single mobile terminal would be in Line-of-Sight (LOS) with respect to multiple links, at any given time, and therefore its outage probability would decrease [5]. Such ultra-dense deployment, however, can be costly for network operators [11], because of the capital and operational expenditures and the need for a reliable and high capacity backhaul between the base stations and the operator core network. This issue motivated the approval of a new Study Item (SI) for 3GPP Release 15 [12], which will analyze the feasibility of an IAB deployment for NR, in which the backhaul links are wireless and operated in the same context of the RAN access.

In this paper we present novel results related to the choice of the backhaul path in an IAB setup, using a mmWave channel based on real measurements, with a realistic beamforming model and a sectorized deployment. We compare how different greedy policies perform with respect to the number of hops and the bottleneck SNR, i.e., the SNR of the weakest wireless backhaul link, relying only on local information, without the need for a centralized coordinator. Moreover, we discuss the usage of a function that biases the link selection towards base stations with a wired backhaul to the core network, and show that, for a certain set of parameters for this bias, it is possible to decrease the number of hops without affecting the average bottleneck SNR. This study can be used as a guideline for the choice and the design of backhaul path selection policies in IAB mmWave networks.

The remainder of the paper is organized as follows. Sec. II describes the characteristics of the 3GPP SI on IAB and the potential of this solution for NR deployments. Sec. III presents the link selection policies analyzed in this paper, while Sec. IV introduces the system model and the results of the performance evaluation. Finally, Sec. V concludes the paper and discusses possible extensions of this work.

II. INTEGRATED ACCESS AND BACKHAUL IN 3GPP NR

The research on wireless backhaul solutions has spanned the last two decades, with the goal of replacing costly fixed links with more flexible wireless connections. For example, mesh and multihop wireless backhaul architectures have been extensively studied for IEEE 802.11 networks [13], [14]. However, in the cellular domain, integrated solutions that provide both access and backhaul functionalities have not been widely adopted yet. There exists a relay functionality integrated in the Long Term Evolution (LTE) specifications, which however has not been extensively deployed due to its limited flexibility [15]: the resource configuration is fixed, it supports only single-hop relaying, and there is a fixed association between the relay and the parent base station that connects it to the wired core network. On the other hand, the wireless backhaul links that are actually used to complement fiber optic cables for backhauling traffic in sub-6 GHz cellular networks are usually custom point-to-point solutions, not integrated with the RAN.

Nonetheless, the integration of the wireless backhaul with the radio access is being considered as a promising solution for 5G cellular networks. Papers [16], [17] provided preliminary results on wireless backhaul for 5G, using also mmWave links, and showed that such solutions can meet the expected increase in mobile traffic demands. However, they did not consider a tight integration between the access and the backhaul, which is instead the focus of the more recent 3GPP SI on IAB for 3GPP NR [12]. The goal of this study item is to design an advanced wireless relay, which overcomes the limitations of the LTE relay, and makes it possible to deploy self-backhauled NR base stations in a *plug-and-play* manner.

According to [12], NR cellular networks with IAB relays will be characterized by (i) the integration of the access and backhaul technologies; (ii) a higher flexibility in terms of network deployment and configuration with respect to LTE; and (iii) the possibility of using the mmWave spectrum. In particular, the design goal for IAB is to simplify both the installation and the management of dense NR networks, exploiting the self-backhauling functionality integrated with the access, for example with plug-and-play IAB nodes capable of self-configuring and self-optimizing themselves [18]. As stated in [12], [18], 5G IAB relays will be used in both outdoor and indoor scenarios, also with multiple wireless hops, in order to extend the coverage, and should be able to reconfigure the topology autonomously in order to avoid service unavailability. Moreover, a flexible split between the access and the backhaul resources is envisioned, in order to increase the efficiency of the resource allocation. Both in-band and out-of-band backhaul will be considered, with the first being a natural candidate for a tighter integration between access and backhaul.

Furthermore, the usage of mmWave frequencies for IAB nodes introduces new opportunities and challenges. In particular, the directionality of mmWave links implies a higher spatial reuse, possibly enabling a spatial division multiple access scheme and a higher throughput, as discussed in [19].

On the other hand, the harsh propagation environment in the mmWave band requires a prompt adaptation of the topology and a fast link selection in case of outage, together with a dynamic scheduling process that adjusts the resource partition between access and backhaul according to the respective load. Therefore, mmWave IAB nodes can fully benefit from the flexibility and the self-organizing properties envisioned in the 3GPP SI for IAB.

In this regard, some papers recently analyzed the performance of IAB deployments at mmWaves, focusing however primarily on scheduling. In [20], the authors consider a centralized scheduling and routing problem, and show its performance in terms of throughput and computational run time required to find the optimal solution. Similarly, paper [21] considers a joint optimization of the scheduling and the power, with the energy efficiency of the system as a target. In [22], the authors focus on the resource split between access and backhaul, without considering link selection for IAB nodes. None of these works, however, considers a channel characterized by the full channel matrix, with large and small scale fading phenomena, nor realistic beamforming, in the performance evaluation.

III. PATH SELECTION POLICIES FOR IAB AT MMWAVES

In this paper, we use the NYU channel model for mmWave frequencies described in [23] to analyze the performance of different path selection policies for the backhaul. In the following paragraphs, we will use the term (i) *wired* Next Generation Node Base (gNB) or *donor* to identify gNBs which are connected to the core network with a wired backhaul; (ii) IAB node or relay to label gNBs which do not have a wired backhaul link; and (iii) parent gNB to name a gNB which provides a wireless backhaul link to an IAB node. The parent can be itself a wireless IAB node, or a wired gNB.

For all of the policies, the IAB node that has to find the path towards the core network initiates the procedure by applying the selection policy on the first hop, and then the procedure continues iteratively at each hop until a suitable wired gNB is reached. Therefore, the strategies we evaluate are greedy, i.e., consider local information¹ to perform the hop-by-hop link selection decisions, and do not need a centralized controller. These policies can be used to re-route backhaul traffic on the fly, in case of a link failure, and to connect (possibly via multiple hops) an IAB node which is joining the network for the first time to a suitable wired gNB in an autonomous and non-coordinated fashion.

In Sec. III-A, we will describe each single strategy, while in Sec. III-B we will introduce the bias functions that we designed in order to improve the forwarding performance in terms of hops.

A. Path Selection Policies

The considered policies differ from one another because of the metric used to measure the link quality (SNR or rate), and

¹With the exception of information related to the position and the backhaul technology, which can however be shared in advance.

Policy	Metric	Selection rule	Pros	Cons
HQF	SNR	Select the link with the highest SNR	High bottleneck SNR	High probability of not reaching a wired gNB
WF	SNR	Select the wired gNB, if available, otherwise apply HQF	Low number of hops	Low bottleneck SNR
PA	SNR	Select the link with the highest SNR among those with parents which are closer to a wired gNB	Low number of hops	Possible ping-pong effects
MLR	Load and Shannon rate	Select the link with the highest achievable rate	High bottleneck rate, traffic balancing	High probability of not reaching a wired gNB

TABLE I: Comparison between the different link selection policies studied in this paper.

because of the ranking criterion of the different available links at each hop. For every policy, and at each hop, we consider an SNR threshold Γ_{th} , i.e., for the link selection, we compare only backhaul connections with an SNR Γ higher than or equal to this threshold. If Γ_{th} is small, then it is possible to select and compare a larger number of base stations as parent candidates, and possibly increase the probability of successfully reaching a wired gNB, at the price of a lower data rate on the bottleneck link. For the access network, Γ_{th} is usually set to -5 dB [7], i.e., access links with an SNR smaller than -5 dB are usually considered in outage. However, this choice is not valid in a backhaul context, where the link is required to reliably forward high-data-rate traffic from the relay to its parent gNB. Therefore, we select a higher value for Γ_{th} , i.e., 5 dB, which corresponds to a theoretically achievable Shannon rate of 830 Mbit/s, on a single carrier with a bandwidth $B = 400$ MHz [8]. Moreover, we avoid loops, i.e., if an IAB node was used as a relay in a previous hop, it cannot be selected again.

Table I sums up the main properties of each policy, which are described in detail in the following paragraphs.

Highest-quality-first (HQF) policy: At each hop, the HQF strategy compares the SNR Γ of the available links towards each possible parent gNBs (either wired or wireless), and selects that with the highest SNR, without considering any additional information. It is a very simple selection rule, which can be implemented only by measuring the link quality using synchronization signals. Moreover, by always selecting the best SNR, the bottleneck link, i.e., the link with the lowest SNR among the hops towards the wired gNB, will have a high SNR when compared to other policies. On the other hand, given that this policy follows a greedy approach, it may happen that the parent gNB with the best SNR leads further away from a wired gNB, thus increasing the number of hops. Moreover, in some cases, the highest SNR leads to the choice of another relay gNB which however is not within reach of any other possible wireless parent or wired donor, thus failing to connect to a wired gNB.

Wired-first (WF) policy: The WF policy is designed to reduce as much as possible the number of hops needed to reach a wired gNB. Indeed, if at a given hop one of the available backhaul links is toward a wired gNB, i.e., if a wired gNB is reachable from the current IAB node with an SNR higher than the threshold Γ_{th} , then the wired gNB is selected

even if it is not associated to the connection with the highest SNR. If instead no wired gNB is available, then the HQF policy is applied. The IAB node would need to know which candidate parents are wired or wireless, and this can be done by extending the information directionally broadcasted (using Synchronization Signal (SS) blocks [24]) by each gNB in the Master Information Block (MIB) or Secondary Information Block (SIB). While this policy increases the probability of reaching a wired gNB, even with a greedy approach, it may cause a degradation in the quality of the bottleneck link.

Position-aware (PA) policy: This strategy uses additional context information related to the position of the IAB node that has to perform the link selection and the wired gNB in the scenario. This information can be available in advance and pre-configured in the relays (especially if non-mobile relays are considered [12]), or shared on directional broadcast messages. The goal is to avoid selecting a parent gNB that is more distant from the closest wired gNB than the current IAB node. Therefore, the IAB node divides the neighboring region into two half-planes, identified by the line which is perpendicular to the one that passes through the IAB and the wired gNBs positions. Then, it considers for its selection only the candidate parents which are in the half-plane with also the wired gNB, and selects that with the highest SNR. This policy should strike a balance between HQF and WF.

Maximum-local-rate (MLR) policy: The MLR policy does not consider the SNR as a metric, but at each hop selects the candidate parent with the highest achievable Shannon rate. Consider IAB node i , and the candidate parent j , with N_j among users and IAB nodes attached. Then, given a bandwidth B and the SNR $\Gamma_{i,j}$ between the IAB node and the candidate parent, the Shannon rate is computed as $R_j = B/N_j \log_2(1 + \Gamma_{i,j})$. Finally, the IAB node selects the parent with the highest achievable rate R . Once again, we assume that the information on the load (in terms of number of users N_j) of candidate parent j is known to the IAB node, for example through extension of the MIB or SIB, or with a passive estimation of the power ratio between the resources allocated to synchronization signals and data transmissions. This strategy is designed to take into account the load information in the decision, but has the same drawbacks of the HQF policy, i.e., it may yield a high number of hops and/or connection failures.

B. Wired Bias Function

For multi-hop scenarios, one of the Key Performance Indicators that is considered in the 3GPP SI for IAB is the number of hops from a certain wireless IAB node to the first wired gNB it can reach. However, as discussed in the previous section, some of the proposed policies may need a high number of hops, or even never reach the target wired gNB. In order to solve this issue, it is possible to apply a Wired Bias Function (WBF) to the SNR of the wired gNBs during the evaluation of the metric for the link selection. Consequently, a wired gNB may be chosen as parent even though it is not the candidate with the highest considered metric.

The bias is not fixed, but is a function $W(N)$ of the number of hops N traveled from the IAB node that is trying to connect to a wired gNB. The idea is that as N increases, it becomes more and more convenient to select as a parent a wired gNB with respect to another wireless IAB node (that would otherwise add up to the number of hops) even though the wired gNB is not the best according to the metric considered. The WF policy is a particular case of a decision with bias, with $W(N)$ large enough so that the wired gNB is always selected if above the Γ_{th} threshold.

We compare two different WBFs, which are respectively polynomial and exponential in the number of hops N . The first is defined as follows:

$$W_p(N) = \left(\frac{N}{N_{h,t}} \right)^k \Gamma_{gap} + \Gamma_H, \quad (1)$$

where k is the degree of the polynomial, $N_{h,t}$ is a threshold on the number of hops, Γ_{gap} a tolerable SNR gap, and Γ_H an SNR hysteresis. The idea is that, if N is smaller than $N_{h,t}$, then the SNR gap parameter Γ_{gap} is multiplied by a number smaller than 1, and the WBF $W(N)$ does not impact too much the link choice. When the number of hops N reaches the threshold $N_{h,t}$, then $W(N)$ assumes values which are greater than or equal to Γ_{gap} , increasing the weight of the bias in the link selection. The SNR hysteresis Γ_H is set to 2 dB, and slightly offsets the choice towards a wired gNB in case the best wireless relay candidate and the wired gNB have a very similar SNR. Very conservative WBF would use a large $N_{h,t}$, and a small k and Γ_{gap} , and vice versa for an aggressive parameter tuning.

Similarly, the exponential WBF is defined as

$$W_e(N) = \gamma^{\left(\frac{N}{N_{h,t}} \right)} \Gamma_{gap} + \Gamma_H, \quad (2)$$

with γ the basis of the exponential function. Notice that γ must be greater than or equal to 1, otherwise $\gamma^{\left(\frac{N}{N_{h,t}} \right)}$ would decrease with the number of hops. Moreover, for any γ , the exponential WBF $W_e(N)$ is larger than the polynomial $W_p(N)$, for the same choice of the other parameters. For example, if $N_{h,t} = 6$ and $N = 1$, with $\gamma = 1.5$ we have $\gamma^{\left(\frac{N}{N_{h,t}} \right)} = 1.07$, while with $k = 1$ we have $\left(\frac{N}{N_{h,t}} \right)^k = 0.17$.

Parameter	Value	Description
B	400 MHz	Bandwidth of mmWave gNBs
f_c	28 GHz	mmWave carrier frequency
P_{TX}	30 dBm	mmWave transmission power
NF	5 dB	Noise figure
M	$\{8 \times 8, 16 \times 16\}$	gNB UPA MIMO array size
S	3	Number of sectors for each gNB
λ_g	$\{30, 60\}$ gNB/km ²	gNB density
p_w	$\{0.1, 0.3\}$	Fraction of wired gNB

TABLE II: Simulation parameters.

IV. PERFORMANCE EVALUATION

In this section, we first provide some details on the system model used for the performance evaluation and then discuss the simulation results and compare the different policies described in Sec. III.

A. System Model

The performance evaluation for this paper is done with Monte Carlo simulations with 20000 independent repetitions for each single configuration. The main parameters for the simulations are reported in Table II.

The gNBs (both wired and wireless) are deployed with a Poisson Point Process (PPP) with density $\lambda_g \in \{30, 60\}$ gNB/km², and a fraction $p_w \in \{0.1, 0.3\}$ is configured with a wired backhaul link to the core network. Therefore, the density of the wired gNBs is $\lambda_{w,g} = p_w \lambda_g$ gNB/km², while the IAB nodes have a density $\lambda_{i,g} = (1 - p_w) \lambda_g$ gNB/km². For the evaluation of the MLR policy, we also deploy User Equipments (UEs) with a PPP and a density of λ_{UE} UE/km². They are associated to the gNB with the smallest pathloss, in line with previous studies [22].

We assume that the IAB are equipped with S uniform planar antenna arrays, with the same number $M \in \{64, 256\}$ of isotropic antenna elements at both endpoints of the connection. Each antenna array covers a sector of $2\pi/S$ degrees. Moreover, node i can monitor the link quality of the neighboring gNB $j \in \mathcal{N}_i$, where \mathcal{N}_i is the set of wired or wireless gNBs whose reference signals can be received by node i . The IAB node can then select the best beam to communicate with j using the standard beam management procedures of 3GPP NR².

Table III summarizes the main parameters used for the WBF. In particular, we identify a conservative policy, with $N_{h,t} = 6$, $\Gamma_{gap} = 5$ dB and $k = 1$ or $\gamma = 1.5$ for the polynomial and the exponential policies, respectively, and an aggressive one, with $N_{h,t} = 1$, $\Gamma_{gap} = 15$ dB and $k = 3$ or $\gamma = 3$.

B. Results and Discussion

The performance of the IAB path selection schemes will be evaluated by comparing the Cumulative Distribution Functions (CDFs) of (i) the number of hops required to forward the

²One of the goals of the IAB SI, indeed, is to reuse the NR specifications for the access links also for the backhaul. In any case, enhancements related to the backhaul functionality can be introduced, thanks to the more advanced capabilities of an IAB node with respect to a mobile UE [12].

Configuration	Parameters
Aggressive $W_e(N)$	$N_{h,t} = 1, \gamma = 3, \Gamma_{gap} = 15 \text{ dB}, \Gamma_H = 2 \text{ dB}$
Conservative $W_e(N)$	$N_{h,t} = 6, \gamma = 1.5, \Gamma_{gap} = 5 \text{ dB}, \Gamma_H = 2 \text{ dB}$
Aggressive $W_p(N)$	$N_{h,t} = 1, k = 3, \Gamma_{gap} = 15 \text{ dB}, \Gamma_H = 2 \text{ dB}$
Conservative $W_p(N)$	$N_{h,t} = 6, k = 1, \Gamma_{gap} = 5 \text{ dB}, \Gamma_H = 2 \text{ dB}$

TABLE III: Wired Bias Function parameters.

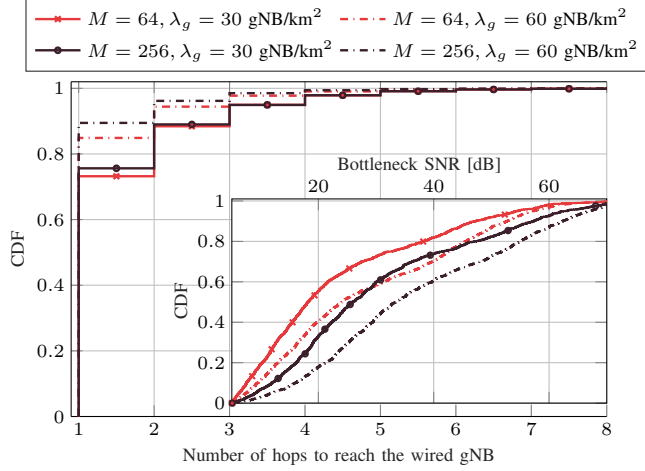


Fig. 1: Performance of the WF policy with different number of antennas M and gNB density λ_g .

backhaul traffic from a wireless to a wired gNB, and (ii) the bottleneck SNR, i.e., the SNR of the weakest link.

Antenna and deployment configurations – In Fig. 1 we investigate how the relaying performance evolves as a function of different setup configurations, i.e., the number of antenna elements M each gNB is equipped with and the gNB density λ_g . The WF strategy is considered. As expected, increasing the MIMO array size has beneficial effects on both the number of hops and the bottleneck SNR. In the first case, the narrower beams that can be steered and the resulting higher gains that are produced by beamforming enlarge the discoverable area of each gNB, thereby increasing the probability of detecting a wired gNB with sufficiently good signal quality and through a limited number of hops. In the second case, sharper beams guarantee better signal quality and, consequently, stronger received power.

Similarly, enhanced backhauling performance is achieved by densifying the network since the gNBs are gradually closer and thus establish more precise and, in general, more accurate communications. Of course, if we persistently keep on increasing λ_g , the performance gain would progressively reduce because of the increasingly higher impact of the interference from the surrounding base stations.

Finally, notice that the $M = 64, \lambda_g = 60 \text{ gNB/km}^2$ and the $M = 256, \lambda_g = 30 \text{ gNB/km}^2$ configurations show, on average, comparable performance in terms of bottleneck SNR. However, for low SNR regimes, i.e., when considering farther nodes and more demanding signal propagation characteristics, densification is more effective than directionality.

Path selection policies – Fig. 2 compares the performance

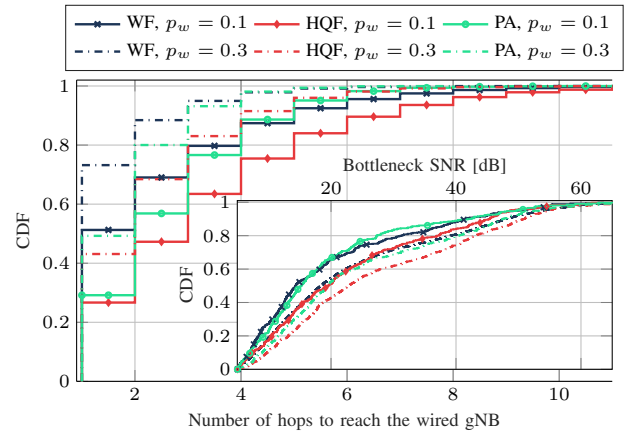


Fig. 2: Comparison of WF, HQF and PA policies, without WBF, for $M = 64$ antennas at the gNBs, $\lambda_g = 30 \text{ gNB/km}^2$ and $p_w = 0.3$.

of the different path selection algorithms presented in Sec. III for different values of p_w , without the WBF. In general, increasing p_w makes it possible to minimize the number of hops required to forward the backhaul traffic from a wireless node to the core network and, at the same time, guarantees more efficient relaying operations. However, the trade-off oscillates between more robust backhauling and more expensive network deployment and management. Moreover, although the HQF policy delivers the best bottleneck SNR performance, it exhibits the worst behavior in terms of number of hops, as it greedily selects the strongest available gNB as a relay regardless of the nature (i.e., wired or wireless) of the destination node. On the other hand, both WF and PA mechanisms have the potential to reduce the number of hops since the selection is biased by the availability of the wired gNB (independent of the quality of other surrounding cells) and by context information related to the position of the wired nodes, respectively. Conversely, both approaches degrade the quality of the bottleneck link as they may end up selecting a suboptimal node among all the candidate relays within reach.

Interestingly, we observe that, when the number of available wired gNBs is very low (i.e., $p_w = 0.1$ and for low SNR regimes), the PA policy performs better than the WF in terms of both number of hops and bottleneck SNR. As can be seen in Fig. 2, indeed, the PA policy needs a smaller number of hops than WF (and also HQF) for 15% of the paths with 4 or more hops. In low SNR and $\lambda_{w,g}$ regimes, the WF scheme asymptotically operates as the HQF and, therefore, the best choice is to select the parent which is geographically closer to a wired gNB with the PA strategy.³

WBF configurations – In Fig. 3a we compare the behavior of the HQF and the WF policies when considering different WBF configurations to bias the path selection results. First, we see that, since the WF approach is designed to minimize the number of hops to reach a wired gNB, it generally outperforms any other architecture for the hop-count metric. However, the

³For $p_w = 0.3$ this phenomenon is obviously less pronounced but still the PA and WF paradigms reveal comparable performance in low SNR regimes.

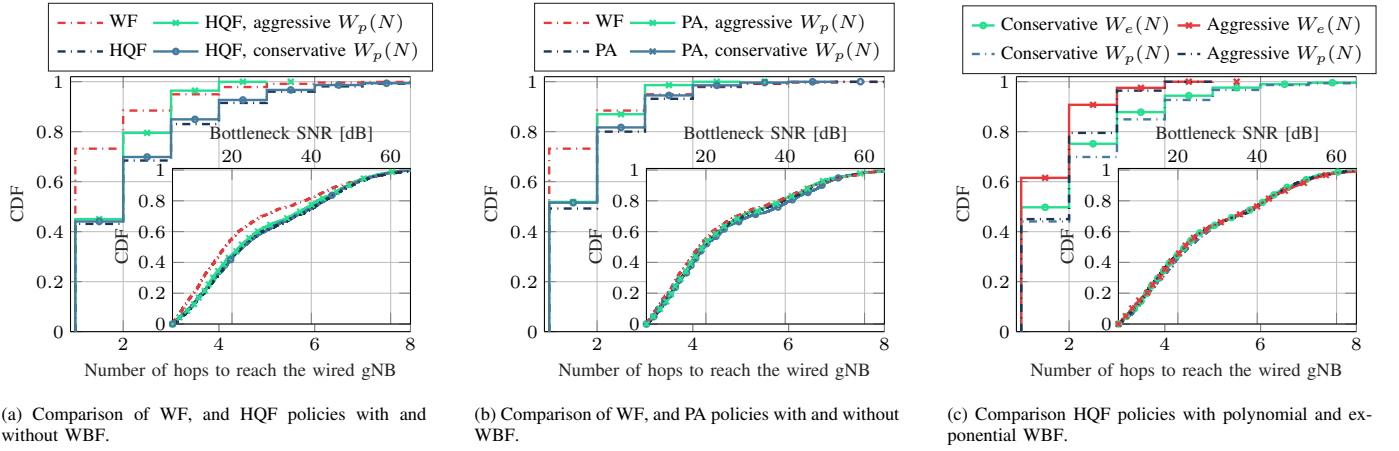


Fig. 3: Impact of the WBF (aggressive or conservative, polynomial or exponential) on the performance.

quality of the bottleneck link inevitably decreases (on average by more than 4 dB compared to its HQF counterpart), thereby increasing the risk of communication outage between the endpoints. Moreover, for bad SNR regimes (i.e., as the probability of detecting valid wired nodes reduces) the HQF scheme implementing aggressive WBF achieves the best performance in terms of both number of hops and bottleneck SNR.

Second, we observe that, albeit a conservative WBF applied to an HQF scheme does not provide any significant performance improvements with respect to a pure HQF approach, a more aggressive design of the bias function has the ability to remarkably reduce the number of hops required to forward the backhaul traffic to a wired gNB, without any visible degradation in terms of SNR. We deduce that it is highly convenient to configure very aggressive⁴ WBF functions since, for a multi-hop scenario, they deliver more efficient relaying operations without affecting the quality of the communication.

The same conclusions can be drawn by comparing the performance of the PA and the WF policies as a function of the different WBF configurations. In this regard, Fig. 3b illustrates how the biased PA approach guarantees very fast and high-quality backhauling thanks to the low number of hops that needs to be made before successfully forwarding the traffic to the core network and the relatively large bottleneck SNR that is experienced. In particular, the reduction in the number of hops is even beyond the capabilities of the biased HQF counterpart, at the cost of a slight reduction in the bottleneck SNR (in the order of 2 dB on the 50% percentile). Moreover, as already mentioned before, both biased and unbiased PA architectures outperform the WF scheme in the case of low SNR regimes.

Finally, in Fig. 3c we compare the behavior of the HQF policy with polynomial and exponential WBFs. Based on the design choices presented in Tab. III and according to Eqs. (1) and (2), the exponential bias function is more aggressive than

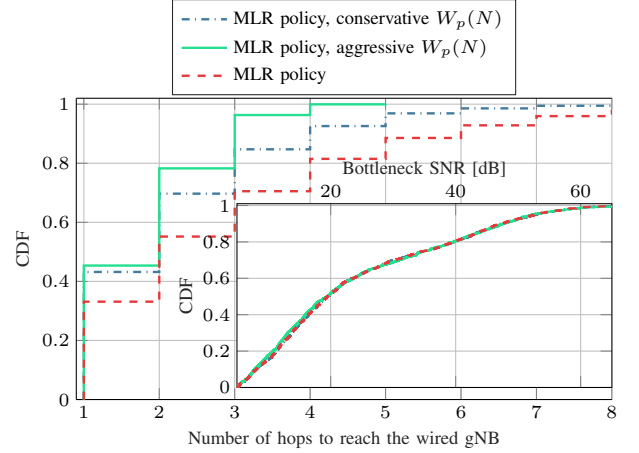


Fig. 4: Comparison of MLR policy with and without WBF.

the polynomial one for all values of N , i.e., the current number of hops. However, the exponentially-biased HQF approach, because of its inherently aggressive nature, is affected by SNR deterioration, though moderate (i.e., smaller than 1 dB on average), with respect to its polynomially-biased counterpart.

MLR performance – While the IAB results presented in the previous paragraphs were based on SNR considerations, i.e., the candidate parent is chosen according to the instantaneous quality of the received signal, the CDF curves displayed in Fig. 4 analyze the performance of the MLR backhauling approach which relies on the instantaneous cell load and the Shannon rate as a metric for the path selection operations. We observe that Fig. 4 leads to the same conclusions previously set out, i.e., the design of aggressive polynomial bias functions has the potential to significantly reduce the number of hops without affecting the quality of the communication (in terms of bottleneck SNR). Aggressive exponential WBFs are able to further reduce the number of relaying events, though this may slightly undermine the quality of the weakest link.

⁴Of course, if the WBF parameters are too aggressively configured, the HQF approach will more likely operate as a WF policy, with all that this implies (including, but not limited to, a detrimental degradation of the bottleneck SNR).

C. Final Considerations

Based on the above discussion, in the following we provide guidelines on how to optimally configure the path selection policies presented in the previous sections to maximize the performance of the IAB traffic relaying operations.

We state that a WF approach, although minimizing the number of hops required to connect to a wired gNB, is affected by performance degradation in terms of bottleneck SNR. Moreover, this scheme has been proven particularly inefficient when reducing the number of wired nodes (i.e., for low values of p_w) and for low SNR regimes (i.e., when configuring very wide beams and considering sparsely deployed networks).

In this context, a PA strategy may deliver improved performance leveraging on context information (e.g., the position of the surrounding wired gNBs) that is periodically distributed throughout the network. Furthermore, it is possible to design aggressive polynomial and exponential WBFs to bias the relay selection procedures and further reduce the overall number of hops without significant performance degradation in the quality of the weakest link.

V. CONCLUSIONS AND FUTURE WORK

Motivated by the fact that the integration between mmWave access and wireless backhaul is becoming a reality, in this paper we compared the performance of different distributed path selection strategies to efficiently forward the backhaul traffic (possibly through multiple hops) from a wireless gNB to a wired gNB connected to the core network. The investigated policies may or may not leverage on a function that biases the link selection towards base stations with wired backhaul capabilities, to minimize the latency of the relaying operations. We showed through simulations that it is always possible to decrease the number of hops required to connect to a wired gNB by designing aggressive bias functions without affecting the average bottleneck SNR (i.e., the quality of the weakest link). Moreover, we demonstrated that a WF strategy that always selects a wired gNB as the next hop, if available, is ineffective in case of sparsely deployed networks and for low SNR regimes. Conversely, a PA scheme which uses context information to perform the path selection has the potential to significantly improve the overall performance in terms of both number of hops and communication quality.

As part of our future work, we will set up ns-3 based simulations to evaluate the end-to-end performance of the presented IAB policies in terms of experienced throughput, latency, and packet loss ratio, and considering realistic traffic models.

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