

Interference Between 5G Indoor Micro Operators Utilizing Beamforming and Dynamic TDD in 26 GHz Band

Kimmo Hiltunen¹, Marja Matinmikko-Blue², Matti Latva-aho²

¹Ericsson Research, Oy L M Ericsson Ab, Finland

kimmo.hiltunen@ericsson.com

²Centre for Wireless Communications (CWC), University of Oulu, Finland

{marja.matinmikko, matti.latva-aho}@oulu.fi

Abstract—Future 5G networks will increasingly target local small cell deployments complementing the coverage of the existing outdoor networks. Moreover, the establishment of building-specific high-quality 5G networks by different stakeholders through local spectrum availability has gained increasing attention and new concepts, such as the micro operator, have emerged. To make these kinds of local 5G networks a reality, feasible spectrum sharing models are needed, which calls for a thorough understanding of the impact of the inter-operator interference on the performance of the victim micro operator. This paper presents system simulation results evaluating the feasibility of the local 5G micro operator concept for a scenario where two uncoordinated micro operators, sharing the same channel in the 26 GHz band, have deployed their networks on the same floor. The obtained results indicate that such highly local deployment is feasible in the given band if the penetration loss of the wall separating the micro operators is at least equal to 57 dB, corresponding approximately to a 17 cm thick concrete wall. The required isolation between the operators depends highly on the deployment scenario and therefore, feasible operation is possible in some deployments even with lower wall penetration losses. This highlights the fact that the worst case inter-operator interference levels alone do not properly model the specifics of the co-existence scenario, and can lead to overly protective requirements regarding the channel assignments.

Keywords—5G, micro operator, radio network performance, beamforming, dynamic TDD, mmWave spectrum

I. INTRODUCTION

Mobile communication networks have traditionally been deployed by mobile network operators (MNO) with exclusive spectrum licenses to provide wide area coverage. Future 5G networks will increasingly target local in-building deployments in higher frequency bands, which has the potential to change the traditional mobile communication market roles [1]. Locally deployed high-quality 5G networks will also play an increasing role in the provisioning of new traffic-heavy services in vertical sectors' use cases. Instead of relying solely on the networks deployed by the MNOs, an emerging solution gaining increasing attention in research, regulation and industry is to allow other stakeholders, for example the venue owners, to deploy and operate their own in-building networks to satisfy local capacity and coverage needs [1]. These local high-quality wireless

networks aim at providing guaranteed quality of service addressing the service requirements of different vertical sectors in confined areas [2]. It is further envisioned that the deployment of these kind of local networks will take place on shared spectrum bands [3]. In fact, regulators are discussing new spectrum authorization models for 5G including more dynamic ways of spectrum sharing [4] to make spectrum available for niche players to allow them to offer specific applications [5]. From the spectrum bands planned for 5G deployments in Europe, new local operator models are envisioned especially for the 26 GHz band (24.25-27.5 GHz) [5,6].

A micro operator concept has recently been introduced to allow different stakeholders to deploy local high-quality 5G networks [7-9]. The emergence of new spatially confined micro operators for reliable service delivery requires that the availability of local spectrum is secured with the help of some form of micro licensing model [8]. Micro operators aim at serving their own restricted customer segments such as machines in factories, or they can act as neutral hosts for the customers of the overlying MNOs, or at the same time handle both kinds of customer sets [8,9]. The introduction of a potentially large number of local indoor micro operators requires some form of interference coordination between local license holders and the potential incumbent spectrum users to guarantee that their operations remain free from harmful interference, while at the same time enabling an efficient use of spectrum. In particular this will be the case if the aim is to allow the micro operators to fully benefit from the flexibility offered by the dynamic time division duplex (TDD), which is one of the key features of 5G New Radio (NR) [10]. For the deployment of such interference coordination mechanisms, interference characterization between the involved systems is critical.

The impact of the interference between adjacent indoor micro operator deployments in the 3.6 GHz band has already been analyzed in [11] and [12]. The previous studies have among other things demonstrated that in order to secure a sufficient isolation between the uncoordinated micro operators, the required minimum separation distance (MSD) between the adjacent micro operator buildings can in some scenarios be as high as 400-500 meters. However, the required MSD will depend on the density and the load of both the victim and the interfering network.

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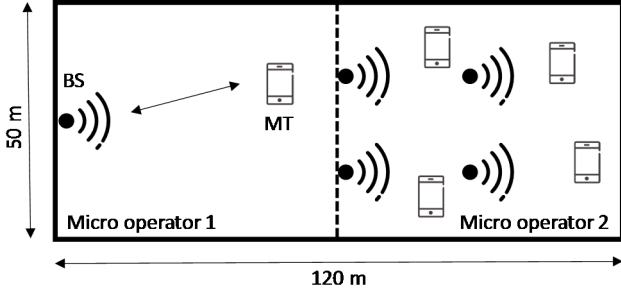


Fig. 1. Assumed network layout with two micro operators.

To the best of our knowledge, this paper is the first one to evaluate the feasibility of establishing local 5G indoor micro operator networks in the 26 GHz band. Since the interference between adjacent buildings is estimated to be low at this frequency band [13], the impact of the inter-operator interference is assessed for a scenario where two uncoordinated micro operators, sharing the same channel, have deployed their networks within the same floor. The goal of this study is to evaluate which conditions are required to make such co-channel micro operator deployment feasible.

The rest of this paper is organized as follows. To start with, Section II introduces the assumed system model. System simulation results evaluating the performance of the victim micro operator are presented and analyzed in Section III. Finally, future research topics are discussed in Section IV and some conclusions are drawn in Section V.

II. SYSTEM MODEL

This section describes the assumed system model for a deployment of local 5G indoor micro operator networks that are sharing the same spectrum band. To start with, a brief description of the network layout is given, followed by a discussion of the applied inter-operator interference and propagation models. Finally, models for radio resource management and average user performance are introduced.

A. Network Layout

The evaluated network deployment consists of a building with a size equal to 50 m × 120 m, as shown in Fig. 1. Micro operator 1 (uO1) and micro operator 2 (uO2) are assumed to be serving users in different parts of the same floor, and the operators are assumed to be separated by a wall. Furthermore, the networks are assumed to be sharing the same channel in the 26 GHz band. It is also assumed that uO1 has deployed only one base station, while uO2 has deployed four base stations. The base station locations and antenna boresight directions are varied during the evaluations so that a few different network layout alternatives can be compared with each other. Finally, the base station antenna height is assumed to be equal to 3 m above the floor and the mobile terminal antenna height is assumed to be equal to 1 m above the floor.

B. Inter-Operator Interference Model

Local small cell deployments face various interference scenarios depending on the spectrum where they operate and

operational characteristics of the networks. For example, neighboring cells of the local networks can be either coordinated or uncoordinated. In case of TDD, a coordinated (or synchronized) deployment means that the neighboring cells are following the same TDD pattern and that the uplink (UL) slots in one cell are always aligned with the uplink slots in the other cells. Hence, there will never be time instants when the uplink transmissions in one cell are interfered by downlink (DL) transmissions in neighboring cells. However, that kind of cross-link interference scenarios are visible in uncoordinated (or unsynchronized) TDD deployments when different TDD patterns have been applied in neighboring cells.

Assuming that the cells within a micro operator's network are coordinated, while the cells belonging to different micro operators are uncoordinated, the following four interference scenarios are considered in the assumed system model [11,12]:

- Interference from base station (BS) to mobile terminal (MT) (DL-to-DL interference), valid for both intra- and inter-operator interference.
- Interference from MT to BS (UL-to-UL interference), valid for both intra- and inter-operator interference.
- Interference from BS to BS (DL-to-UL interference), valid for inter-operator interference.
- Interference from MT to MT (UL-to-DL interference), valid for inter-operator interference.

Moreover, a random allocation of downlink and uplink slots is assumed for both networks, resulting in a 50:50 UL:DL ratio in average. In practice this means that when calculating the average user performance, each uplink (or downlink) slot will in average be interfered 50% of the time by uplink slots and the other 50% of the time by downlink slots from the neighboring micro operator.

C. Propagation Model

In order to model the propagation both within a micro operator's network and between the neighboring micro operators, the coupling loss $C_{m,b,n}$ between mobile terminal m and base station b on beam n is calculated as:

$$C_{m,b,n,dB} = L_{m,b} - G_m^{ant} - G_{b,n}^{ant} + X_{m,b} + \omega_{m,b}L_w \quad (1)$$

where $L_{m,b}$ is the path loss, G_m^{ant} is the mobile terminal antenna gain, $G_{b,n}^{ant}$ is the base station antenna gain on beam n , and $X_{m,b}$ is a log-normally distributed random value modeling the impact of shadow fading. Furthermore, parameter $\omega_{m,b}$ is a binary variable that indicates whether mobile terminal m and base station b belong to different micro operators, and L_w is a penetration loss for the wall separating the micro operators.

Path loss $L_{m,b}$ is based on the *3GPP Indoor Hotspot – Mixed Office* propagation model as defined in [14]. The model includes both a line-of-sight (LOS) and a non-line-of-sight (NLOS) component, and the LOS probability is defined to decrease as a function of the distance between the nodes. The mobile terminal antenna is assumed to be omnidirectional with an antenna gain equal to 0 dBi. The base station antenna is assumed to consist of

4×16 cross-polarized antenna elements. Furthermore, analog beamforming is applied so that a grid of 48 different candidate beams within the range of approximately ±55 degrees in azimuth and ±13 degrees in elevation is generated. The half-power beamwidth of each beam is approximately 8 degrees and the maximum antenna gain is equal to 23 dBi.

D. Radio Resource Management and User Performance

During the simulations, a mobile terminal is assumed to be connected to the base station with the strongest beam belonging to the serving micro operator. Furthermore, a round robin scheduler operating in the time domain is assumed for both the downlink and the uplink.

Downlink signal-to-interference-and-noise-ratio (SINR) for mobile terminal m , served by base station b on beam n , is calculated as

$$\gamma_{m,b,n}^{DL} = \frac{P_b^{BS}}{C_{m,b,n}(I_{m,b}^{own} + I_m^{b2m} + I_m^{m2m} + N_m^{MT})} \quad (2)$$

where the different downlink interference components are expressed as

$$I_{m,b}^{own} = \sum_{j=1}^J \sum_{q=1}^Q \frac{P_j^{BS} \tau_{j,q}}{C_{m,j,q}} \quad (3)$$

$$I_m^{b2m} = \varepsilon_{d2d} \sum_{k=1}^K \sum_{q=1}^Q \frac{P_k^{BS} \tau_{k,q}}{C_{m,k,q}} \quad (4)$$

$$I_m^{m2m} = \varepsilon_{u2d} \sum_{k=1}^K \sum_{s=1}^{u_k} \frac{P_{s,k}^{MT} \tau_{s,k}}{C_{m,s}} \quad (5)$$

In (2)-(5), P_b^{BS} is the transmission power of base station b and $C_{m,b,n}$ is the coupling loss between mobile terminal m and base station b on beam n . Furthermore, I^{own} is the received power from all the base stations belonging to the serving micro operator, while I^{b2m} is the received power from all base stations and I^{m2m} is the received power from all mobile terminals belonging to the other micro operator. Parameters ε_{d2d} and ε_{u2d} indicate the assumed inter-operator interference scenario. In case of the DL-to-DL interference, $\varepsilon_{d2d} = 1$ and $\varepsilon_{u2d} = 0$, while for the UL-to-DL interference: $\varepsilon_{d2d} = 0$ and $\varepsilon_{u2d} = 1$. Parameter N_m^{MT} is the thermal noise power of mobile terminal m and u_k is the number of uplink users simultaneously served by base station k . Finally, in case of I^{own} and I^{b2m} , $\tau_{j,q}$ is an activity factor indicating the probability that beam q of base station j is being transmitted during a downlink slot ($1 \leq q \leq Q, Q = 48$). In case of I^{m2m} , $\tau_{s,k}$ indicates the average probability that mobile terminal s , served by base station k , is scheduled during an uplink slot.

The total transmission power for mobile terminal s , served by base station k on beam n is calculated as

$$\begin{aligned} P_{s,k,n,dBm}^{MT} &= P_{0,k} + 10 \log_{10}(\beta) + \alpha_k C_{s,k,n,dB}, \\ P_{min}^{MT} &\leq P_{s,k,n}^{MT} \leq P_{max}^{MT} \end{aligned} \quad (6)$$

where $P_{0,k}$ is the target for the received uplink power at base station k , β is the channel bandwidth and α is the path loss compensation factor.

Uplink SINR for mobile terminal m , served by base station b on beam n is calculated as

$$\gamma_{m,b,n}^{UL} = \frac{P_{m,b,n}^{MT}}{C_{m,b,n}(I_{b,n}^{own} + I_{b,n}^{m2b} + I_{b,n}^{b2b} + N_b^{BS})} \quad (7)$$

where

$$I_{b,n}^{own} = \sum_{j=1}^J \sum_{s=1}^{u_j} \frac{P_{s,j}^{MT} \tau_{s,j}}{C_{s,b,n}} \quad (8)$$

$$I_{b,n}^{m2b} = \varepsilon_{u2u} \sum_{k=1}^K \sum_{s=1}^{u_k} \frac{P_{s,k}^{MT} \tau_{s,k}}{C_{s,b,n}} \quad (9)$$

$$I_{b,n}^{b2b} = \varepsilon_{d2u} \sum_{k=1}^K \sum_{q=1}^Q \frac{P_{b,n,k,q}^{BS} \tau_{k,q}}{C_{b,n,k,q}} \quad (10)$$

For the UL-to-UL interference, $\varepsilon_{u2u} = 1$, and $\varepsilon_{d2u} = 0$. However, for the DL-to-UL interference, $\varepsilon_{u2u} = 0$ and $\varepsilon_{d2u} = 1$. Furthermore, coupling loss $C_{b,n,k,q}$ in (10) takes into account the impact of beamforming both at the interfering base station k and the victim base station b .

The calculated SINR values are mapped to corresponding average user throughput values as

$$R_{m,b,n} = \frac{0.8 \cdot \mu \cdot \beta \cdot \min(R_{max}, \log_2(1 + \gamma_{m,b,n}))}{u_b} \quad (11)$$

In (11), it is assumed that the average overhead due to control channels and data retransmissions is equal to 20%. Parameter μ indicates the average usage of the downlink and the uplink as a fraction of time. The maximum spectral efficiency R_{max} is defined by both the highest available modulation and coding rate, and the maximum number of parallel data streams for each link. Finally, the impact of round robin scheduling on the average user throughput is taken into account via parameter u_b .

III. EVALUATION RESULTS

This section presents system simulation results for the impact of inter-operator interference between two uncoordinated micro operators. The main simulation parameters have been listed in Table I. It is assumed that uO1 has deployed only one base station and is serving only one user, while the uO2 network consists of four base stations, and the number of active users is set so that the average network load becomes equal to 90%. Furthermore, based on the results from the previous studies [11,12], uO1 is assumed to be the victim operator, while uO2 is the interfering operator.

In this paper, four different deployment alternatives, as shown in Fig. 2, are compared from the victim operator's performance point of view. In general, the performance of each

TABLE I. ASSUMED PARAMETER VALUES

Parameter	Value
Propagation model	3GPP InH, Mixed Office [14]
Std of the shadow fading	3 dB (LOS), 8 dB (NLOS) [14]
Center frequency	26 GHz
Channel bandwidth	100 MHz
Base station transmission power	24 dBm
Mobile terminal minimum and maximum transmission power	-40 dBm (min), 23 dBm (max)
Receiver noise figure	7 dB (BS), 10 dB (MT) [15]
Antenna gain	23 dBi (BS), 0 dBi (MT)
Mechanical downtilt angle of the base station antenna	7 degrees (uO1, 1 BS) 11 degrees (uO2, 4 BS)
Maximum spectral efficiency (DL: 256 QAM, 2 streams) (UL: 256 QAM, 1 stream)	14.2 bps/Hz (DL) 7.1 bps/Hz (UL)
Uplink power control target (P_0)	-144 dBm (uO1, 1 BS) -136 dBm (uO2, 4 BS)
Path loss compensation factor	0.8

deployment alternative is evaluated by looking at the average downlink and uplink throughput losses, when the penetration loss (L_w) of the wall separating the micro operators is increased from 0 dB to 60 dB. Moreover, the different deployment alternatives are compared also by evaluating the required L_w so that the observed average user throughput within the victim network is not degraded more than the desired threshold of 0.1%, 1%, 2% or 5%. For all evaluations, the throughput loss values are calculated by comparing the average throughput of the multi-operator scenario to the average throughput of the corresponding single-operator scenario.

To start with, Fig. 3 presents the results for average downlink and uplink throughput losses in case of deployment alternative A. Three different curves are shown: average throughput loss for the synchronized slots (DL-to-DL and UL-to-UL), average throughput loss for the unsynchronized slots (UL-to-DL and DL-to-UL) and average throughput loss taking all the slots into account. Looking at the results, it becomes clear that both the downlink and the uplink experience the highest throughput losses during the slots when the inter-operator interference is caused by base stations. Furthermore, the results demonstrate that in case of deployment alternative A the average performance losses are higher for the uplink compared to the downlink. The performance losses become smaller as the value of L_w is increased, and the performance losses can in fact be avoided if L_w is higher than 50 dB. If an average throughput loss up to 1% is allowed, L_w equal to 28 dB is sufficient. Similarly, if the requirement for the maximum allowed throughput loss is increased to 2% or 5%, the required L_w can be reduced to 23 dB or 15 dB. Finally, the results in Fig. 3 indicate also how the situation would change if the networks would be synchronized to avoid the cross-link interference between the downlink and the uplink. As a result, the uplink losses would be dramatically reduced, while the downlink losses would be increased. In all, the required L_w would remain at 28 dB, 23 dB, and 15 dB for average throughput losses equal to 1%, 2% and 5%,

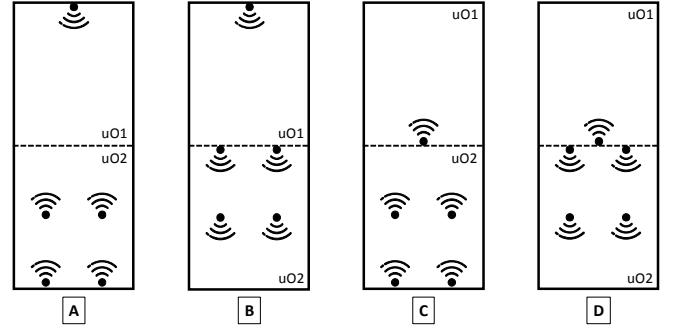


Fig. 2. Evaluated deployment alternatives.

respectively. In practice this means that synchronization would reduce the required L_w only for the deployments, which are limited by the uplink throughput losses with a clear margin.

Results for the comparison between the different deployment alternatives are shown in Fig. 4, where the average downlink and uplink throughput losses (calculated over all the slots) are depicted as a function of the wall penetration loss L_w . Furthermore, the required minimum L_w values to satisfy the requirements for the maximum allowed average downlink and uplink throughput losses are summarized in Table II, highlighting also the link that is limiting the required L_w . In case of downlink, deployment alternatives A and C suffer from a considerably higher level of BS-to-MT interference compared to deployment alternatives B and D, and hence, the corresponding downlink throughput losses, as well as the required L_w values, become higher as well. Interestingly, the average downlink performance of uO1 is quite similar for both alternative A and C, even though the location of the serving base station is completely different with respect to the interfering base stations. The reasons behind this can be explained by the impact of beamforming: in case of alternative A the most interfered users are served the main lobes, while in case of alternative C they are served by the side lobes.

In case of uplink, the results look completely different. It becomes obvious that deployment alternative B is fairly good, while deployment alternative D is very bad from the uplink performance point of view. The reason why alternative B is so good is that there the level of BS-to-BS interference is very low, both due to the fact that the neighboring base stations are located far from each other and the fact that the interfering base stations are pointing away from the victim base station. In case of deployment alternative D, also the victim base station is pointing away from the interfering base stations, which means that the combined antenna gain is even smaller than in case of alternative B, but at the same time the neighboring base stations have been deployed right next to each other. Therefore, the level of BS-to-BS interference becomes high, resulting in large throughput losses for the unsynchronized uplink slots.

When it comes to the required minimum wall penetration losses to satisfy both the downlink and the uplink average throughput loss requirements, deployment alternative B requires the lowest L_w values, while deployment alternative D requires by far the highest L_w values. For example, if an average throughput loss of up to 1% is allowed, L_w should be at least equal to 15 dB for deployment alternative B, while it has to be

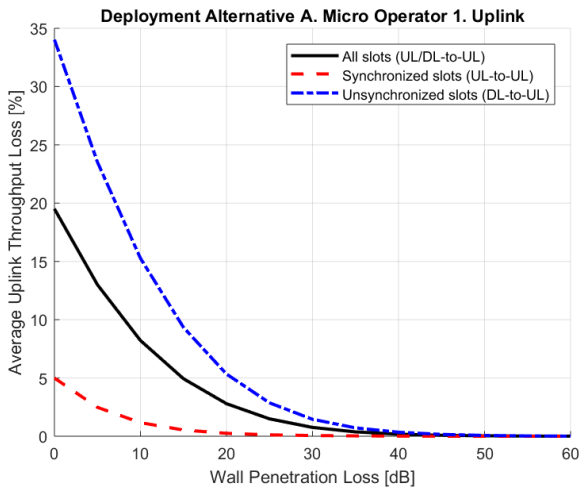
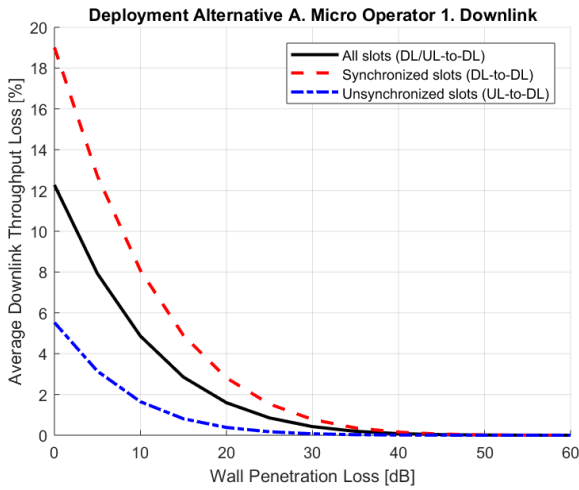


Fig. 3. Average downlink and uplink throughput loss as a function of the wall penetration loss for uO1, assuming deployment alternative A.

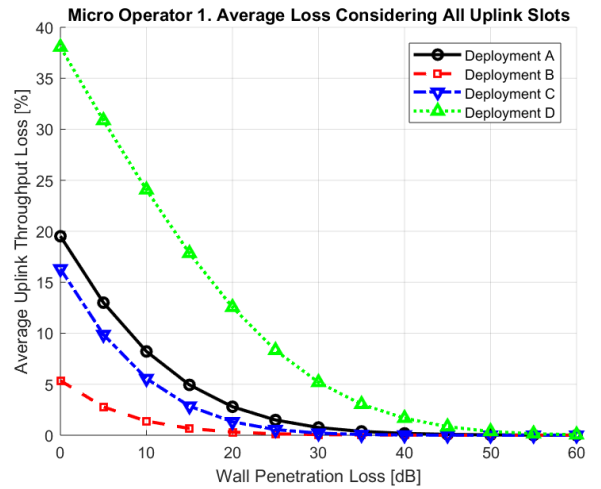
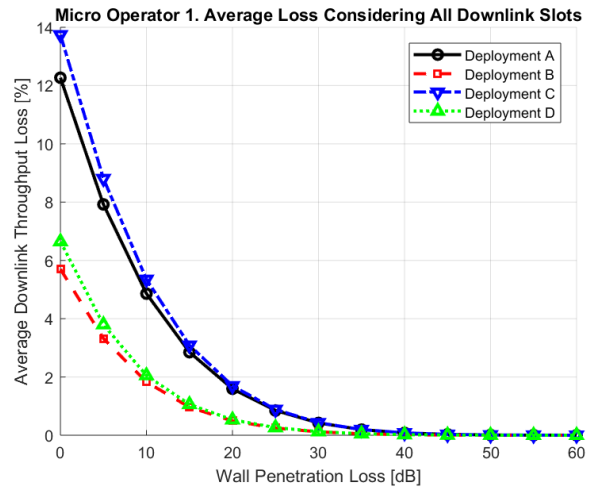


Fig. 4. Average downlink and uplink throughput loss as a function of the wall penetration loss for the different deployment alternatives.

at least equal to 44 dB for deployment alternative D. On the other hand, an interference-free operation can be secured for all four deployment alternatives if the wall penetration loss is at least equal to 57 dB, corresponding approximately to a 17 cm thick concrete wall [16]. An interesting detail is that from the received downlink inter-operator interference point of view alternatives B and D would look equal, and could be seen as less harmful deployments compared to alternatives A and C. Hence, it is clearly not sufficient to consider only the received downlink interference levels, but also the impact of the inter-operator interference on both the downlink and the uplink performance, when evaluating if the neighboring micro operators can share the same channel or if the operators should be assigned separate channels. It is also shown that the minimum required L_w values are highly deployment-specific. If the same wall penetration loss requirement is applied for all possible deployment alternatives to secure an operation free from harmful interference, that requirement should be based on the worst case deployment scenario, which means that the requirement becomes unnecessary restrictive for the other deployment alternatives, resulting in an inefficient use of spectrum. Finally, it is worth mentioning that a synchronized micro operator deployment would reduce the required L_w values only for deployment

alternative D, while for the other deployment alternatives the required L_w values would either stay the same (A), or increase (B and C).

IV. DISCUSSION ABOUT FUTURE RESEARCH TOPICS

This study has opened the discussion on the deployment of local indoor 5G networks with guaranteed quality in the 26 GHz band. A highly imbalanced deployment between the operators has been considered where one micro operator has deployed one base station while the other micro operator has deployed four base stations inside the same building. To obtain a more complete view of the overall inter-operator interference situation, the evaluations should consider also more balanced scenarios, both in terms of the number of deployed base stations and the average network load.

Another topic for future research is the interference coordination between the neighboring micro operators. When it comes to the static coordination in form of spectrum allocation, the main question is whether, and in which scenarios, it would be better for the micro operators to share the channel, or to use their own dedicated, but narrower channels to reduce the level

TABLE II. MINIMUM WALL PENETRATION LOSSES TO SATISFY THE REQUIREMENTS FOR THE MAXIMUM ALLOWED AVERAGE THROUGHPUT LOSSES

	0.1% Loss		1% Loss		2% Loss		5% Loss	
	DL	UL	DL	UL	DL	UL	DL	UL
A	39 dB	44 dB	24 dB	28 dB	18 dB	23 dB	10 dB	15 dB
B	31 dB	28 dB	15 dB	13 dB	9 dB	8 dB	1 dB	1 dB
C	39 dB	34 dB	24 dB	22 dB	19 dB	18 dB	11 dB	11 dB
D	32 dB	57 dB	16 dB	44 dB	10 dB	39 dB	3 dB	30 dB

of the inter-operator interference. In case of dynamic interference coordination in the time domain, performance of a coordinated scheduling scheme to avoid the most harmful beam collisions between the neighboring micro operators could be evaluated. Finally, it could be interesting to develop and evaluate mechanisms for interference coordination in the power domain, where the base station and mobile terminal transmission powers are controlled to limit the amount of inter-operator interference.

It would also be interesting to extend the micro operator concept into other use cases as well, for example into deployments for ultra-reliable low-latency communication (URLLC). In case of URLLC it is no longer sufficient to evaluate the impact of the inter-operator interference on the average performance, but the impact on the much lower percentiles of the user performance becomes important.

Finally, the feasibility of the micro operator concept should be investigated for other types of deployments as well, e.g., for deployments where an indoor micro operator is interfered by an adjacent outdoor micro operator.

V. CONCLUSIONS

Local high-quality small cell deployments by different stakeholders complementing the coverage of MNOs' outdoor networks have gained increasing attention in the development of future 5G networks. Furthermore, regulators are investigating the introduction of local networks with new business models by developing new spectrum authorization models that allow different stakeholders to become 5G micro operators and obtain local spectrum access rights with quality guarantees. In these deployments, interference between the different micro operators becomes a critical aspect to consider. The main challenge is to be able to identify the deployment scenarios where the neighboring micro operators can share the same channel, instead of having a need to assign separate channels to guarantee an operation without any harmful interference.

This paper has evaluated the impact of inter-operator interference on the performance of the victim micro operator for a scenario where two uncoordinated micro operators have deployed their networks within the same floor. The micro operators are assumed to be separated by a wall, and they are assumed to be sharing the same channel in the 26 GHz band. Furthermore, both operators are assumed to be utilizing beamforming and dynamic TDD. The obtained system simulation results indicate that such deployment scenario is

feasible if the penetration loss of the wall separating the micro operators is at least equal to 57 dB, corresponding approximately to a 17 cm thick concrete wall. This confirms the feasibility of assigning very local spectrum access rights within buildings to allow new local 5G network deployments by potential micro operators. The results demonstrate also that the minimum required wall penetration loss is highly dependent on the locations and the boresight directions of both the victim and the interfering base stations, which highlights the importance of considering also the impact of the inter-operator interference on both the downlink and the uplink performance before assigning channels to the neighboring micro operators.

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