Impact of Interference Between Neighbouring 5G Micro Operators

Kimmo Hiltunen, Marja Matinmikko-Blue, Matti Latva-aho

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

Corresponding author: Kimmo Hiltunen, kimmo.hiltunen@oulu.fi, +358504018897

Abstract: Local small cell deployments will become an important part of the future 5G networks, in particular in the higher frequency bands. In order to speed up the wide-spread deployment of such ultra-dense networks, new business and spectrum authorization models are needed. The recently proposed concept of micro operators with local spectrum micro licensing has gained significant interest in research, industry and regulation to complement the traditional models based on networks deployed and operated by the mobile network operators (MNOs). While assessing the applicability of the proposed micro operator concept, one important aspect is to evaluate the impact of the inter-operator interference on the performance of the victim network when deployed in the same or adjacent channel. To support such interference evaluations between micro operators, this paper proposes a deployment scenario including two neighbouring buildings, propagation models for connections both within a building and between the buildings, and a criteria for the required minimum separation distance based on the observed throughput loss. Finally, system simulations are performed to evaluate the impact of the key deployment aspects on the required minimum separation distance between the micro operators in the 3.5 GHz band. The obtained results indicate that the required minimum separation distances are highly scenario-specific, which needs to be considered in the overall local spectrum micro licensing model development and the setup of appropriate rules to coordinate the interference.

Keywords: 5G; micro operator; spectrum sharing; radio wave propagation; interference management; radio network performance;

Acknowledgments: Authors would like to acknowledge Business Finland for funding the “Micro-operator concept for boosting local service delivery in 5G (uO5G)” project.

1 Introduction

Next generation mobile communication networks known as 5G are expected to open prospects for wide-spread digitalization and new innovative business models by forming the ground for high quality mobile broadband and new types of high-demand applications. Provisioning of high quality wireless connectivity in specific high-demand areas such as campuses, transport hubs, public service providers' units and enterprises has become a key societal objective in Europe as the enabler for new services [1]. Customized access for different stakeholders has become a major design criteria in the development of 5G networks and their applications in different vertical sectors to address location specific needs for wireless connectivity [2]. Furthermore, the growing need for locally operated wireless network deployments by different stakeholders has become a reality in 5G to meet the ever increasing requirements for higher capacity, higher data rate, lower latency, massive device density, and reduced capital and operational costs [3-5].

Deployment of new mobile communication networks is highly dependent on the timely availability of 5G spectrum which in turn is dependent on the regulatory decisions. While the 5G networks are expected to be deployed in a wide range of frequency bands ranging from below 1 GHz and between 1-6 GHz, major efforts are spent on making new spectrum bands available above 6 GHz especially in the millimetre wave range (24-86 GHz). With the global commitment to make new 5G spectrum available the debate on suitable spectrum authorization models to gain access to 5G spectrum has started in the regulatory domain by addressing a mix of licensed and unlicensed models [1, 6]. The regulatory community has recently adopted several sharing-based spectrum authorization models to allow additional users in the band while protecting the incumbent spectrum users. Recent European developments include a two-tier Licensed Shared Access (LSA) model which is discussed for allowing mobile communication networks to use the 2.3-2.4 GHz and 3.6-3.8 GHz bands while protecting the existing incumbents [7]. In the US a three-tier sharing model provides Citizens Broadband Radio Service (CBRS) by introducing two layers of additional users in local areas under licensed and general authorization regimes in the 3.55-3.7 GHz band while protecting the incumbents [8]. These sharing-based models become increasingly important for the deployment of 5G networks.

The research community has started to address new 5G deployments in the millimetre wave bands where the challenge is to achieve sufficient indoor coverage and capacity. At lower frequency bands, general indoor coverage can be obtained with outdoor base stations, while the local high capacity needs can be satisfied by deploying dedicated in-building solutions, such as distributed antenna systems and pico base stations, within the traffic hotspots. The problem with these kind of operator-deployed in-building solutions is that they do not scale so well when the number of buildings requiring in-building solutions is increasing, either due to increased capacity requirements or due to increased center frequencies. Instead of relying solely on the networks deployed separately by each of the mobile network operators (MNOs), a more efficient solution could be to allow also special micro operators, for example the venue owners, to deploy and operate their own in-building solutions in order to satisfy local capacity and coverage needs [4]. This kind of micro operator concept [3] with local spectrum micro licensing model [9, 10] has been recently introduced for local 5G network deployments for serving its own restricted customer set and acting as neutral host for the customers of the overlying MNOs [11]. Further discussion on sharing-based based spectrum access models for millimetre wave bands can be found in [12] and [13] for uncoordinated and restricted sharing, respectively.

The recently proposed locally issued spectrum micro licenses [9, 10] require some form of interference coordination between the different license holders and potential incumbent spectrum users in the band to guarantee that their operations are within the predefined interference conditions. For the development of such interference coordination mechanisms, interference characterization between the involved systems is critical. Therefore, proper modelling of the radio wave propagation characteristics in the specific frequency bands and deployment scenarios is required. An initial analysis of the interference between adjacent micro operator deployments in 3.5 GHz was presented in [9] where the minimum separation distances were calculated between an interfering base station and a victim mobile terminal based on a fixed interference criterion. This paper continues the work in [9] by enhancing the models for the micro operator deployment scenario, radio wave propagation and the criterion for harmful interference to consider more realistic deployments.

The main contributions of this paper include the following:

- We introduce a novel deployment scenario for modelling the interference between micro operators located within neighbouring buildings. To the best of our knowledge, modelling of the building-to-building wave propagation has not been widely discussed in the literature. One such model, the so-called 3GPP dual-strip model, has been introduced in [14]. However, the 3GPP dual-strip model has its weaknesses: it is tailored for 2 GHz or 3.5 GHz and is not valid for higher frequencies, the building penetration model considers only one of the building walls, the impact of both the wall material and the angle of incidence on the penetration loss is not taken into account, and the outdoor path loss between the buildings is to a large extent based on a macro cellular non-line-of-sight model even at relatively short distances. The model proposed in this paper aims to consider also these aspects when modelling the path losses between the neighbouring micro operators.
- We develop a new criteria for determining the minimum separation distance between the micro operators. Traditionally, the minimum separation distance is based on an absolute interference threshold, for example 6 dB below the thermal noise floor of the victim receiver. In this paper, we propose a new kind of approach, where the impact on the performance of the victim system is evaluated instead. The aim of the new method is to obtain a more realistic view on the actual interference situation, and in that way to make the reuse of spectrum more efficient.
- Finally, we investigate the impact of building wall material, spectrum reuse, wave propagation conditions (line-of-sight versus non-line-of-sight) and victim network deployment on the required minimum distance between the neighbouring micro operators.

The rest of this paper is organized as follows. In Section 2 the concept of local micro operators is introduced and the different inter-operator interference scenarios are discussed. Section 3 describes the proposed system model including the assumed network layout, building-to-building propagation model and a model for the user performance. Simulation results evaluating the impact of inter-operator interference are presented and analysed in Section 4. Finally, the obtained results are summarized in Section 5 and a few additional topics for future research are discussed.

2 Local 5G micro operator deployments

It is expected that 5G will introduce very dense small cell deployments in specific locations to serve the versatile needs of different vertical sectors [2]. There is a growing interest for different stakeholders to deploy these local cellular networks in addition to the currently dominant MNOs as discussed in [4]. In this section the new micro operator concept [3] is presented and the resulting inter-operator interference scenarios are characterized.

2.1 Micro operator concept

The spectrum authorization models to assign spectrum access rights to those who are requesting them will shape the future 5G mobile communication market. Traditional spectrum authorization models for providing mobile services including individual access rights typically obtained through auctions have led to a small number of MNOs to deploy nation-wide networks with high infrastructure investments. Currently, the only option for non-MNOs to deploy local networks is through the general authorization (unlicensed) model for the establishment of wireless local area networks (WLAN) without quality guarantees. These spectrum authorization models will need to be rethought in 5G as the networks are envisaged to operate also in considerably higher frequency bands with smaller coverage areas while fulfilling more stringent performance requirements, which calls for the development of new sharing-based spectrum authorization models. An unlicensed model where the facility owner would deploy local ultra-dense networks was discussed in [4]. Alternative network deployment models by different stakeholders were presented in [5] to make internet access affordable for all.

The concept of micro operators was recently proposed in [3] to allow different stakeholders to exploit their domain specific knowledge and establish locally operated small cell networks in various places such as shopping malls, hospitals, sports arenas, campuses and enterprises based on local spectrum availability. Motivated by the need for high-quality guaranteed wireless connectivity in these different deployment areas, the micro operators were proposed to obtain spectrum micro licenses with a predefined level of local exclusivity in [9, 10] to deploy and operate small cell networks in a specific location for a given license duration. The local spectrum micro licensing model combines the benefits of both exclusive licensing and unlicensed models by allowing a larger number of stakeholders to get quality-guaranteed local spectrum access rights. The micro licensing model has the potential to become a key enabler to new entry to the mobile communication market by allowing various stakeholders to become micro operators. With local spectrum availability they can deploy and operate 5G small cell networks in specific high-demand areas for tailored service delivery to complement MNO offerings to realize the 5G deployment plans set for example in [6].

2.2 Interference between neighbouring micro operators

Spectrum for 5G networks is planned to be made available from various frequency ranges including existing bands below 1 GHz and between 1-6 GHz, and particularly the new bands above 6 GHz [6]. For the regulators to allow 5G mobile communication networks to be deployed in these bands, there is a need for careful sharing and co-existence studies to ensure the feasibility of spectrum sharing between entrant 5G networks and incumbent systems. In addition, sharing and coexistence between different entrant system deployments in co-channel and adjacent channel cases need to be studied. The recently proposed locally issued spectrum micro licenses in [9, 10] will need to define the level of protection from interference which results in the need for some form of interference coordination between the different license holders and potential incumbent spectrum users.

In order to study the interference between local micro license holders, a reasonable assumption is that while the base stations within a micro operator network are coordinated (or synchronized), the neighbouring base stations belonging to different micro operators will be uncoordinated (or unsynchronized). In case of dynamic time division duplex (TDD) [15], a synchronized deployment means that the neighbouring cells have the same uplink:downlink (UL:DL) ratio and that the uplink slots in one cell are always aligned with the uplink slots in the other cells. Hence, in case of small cell deployments, there will never be time instants when the uplink slots in one cell will be interfered by downlink slots in other cells. However, that kind of interference scenarios are visible in unsynchronized TDD deployments, for example when dynamic TDD with different UL:DL ratios have been applied in neighbouring cells. In all, four different inter-operator interference scenarios can be listed, as shown in Fig. 1:

- Interference from base station to mobile terminal (downlink-to-downlink interference), valid for both synchronized and unsynchronized TDD deployments as well as for frequency division duplex (FDD) deployments. This will impact mostly the users located closest to the interfering base stations, for example the users located next to the outer walls of the buildings. Since the transmission power of a base station is typically considerably higher than the average transmission power of a power-controlled mobile terminal, this interference scenario is estimated to be highly critical for the assumed multi-operator scenario.

- Interference from mobile terminal to base station (uplink-to-uplink interference), valid for both synchronized and unsynchronized TDD deployments as well as for FDD deployments. Due to the fact that the typical transmission power of a mobile terminal is quite low, in particular if the mobile is served by a small cell, and that the interfering mobile terminal is located quite far from the victim base station, this kind of interference scenario is estimated to be less critical.
- Interference from base station to base station (downlink-to-uplink interference), valid for unsynchronized TDD deployments. Due to the higher transmission power, and higher antenna gain, this kind of interference scenario is more critical than the previous one, and should be evaluated more carefully. However, the impact of the interference on the uplink performance can potentially be reduced by adjusting the uplink power control settings within the victim cell as discussed in [16].
- Interference from mobile terminal to mobile terminal (uplink-to-downlink interference), valid for unsynchronized TDD deployments. This kind of interference scenario can be seen as less critical, due to the lower transmission power levels and the fact that the interferer and the victim are typically not located that close to each other.

The motivations listed above may differ for different types of multi-operator deployment scenarios, for example if the micro operators are located within the same building. Therefore, for a complete interference analysis, the impact of all four inter-operator interference scenarios should be considered. However, in this paper the focus is only on the first one, i.e., on the scenario where the transmissions from base stations belonging to one micro operator (uO2) are interfering the downlink reception of a mobile terminal belonging to another micro operator (uO1). This interference scenario is selected as it is estimated to represent the most critical type of inter-operator interference for the assumed deployment scenario. This is motivated both by the higher transmission power of a base station compared to a mobile terminal, and by the higher receiver sensitivity of a mobile terminal compared to a pico base station.

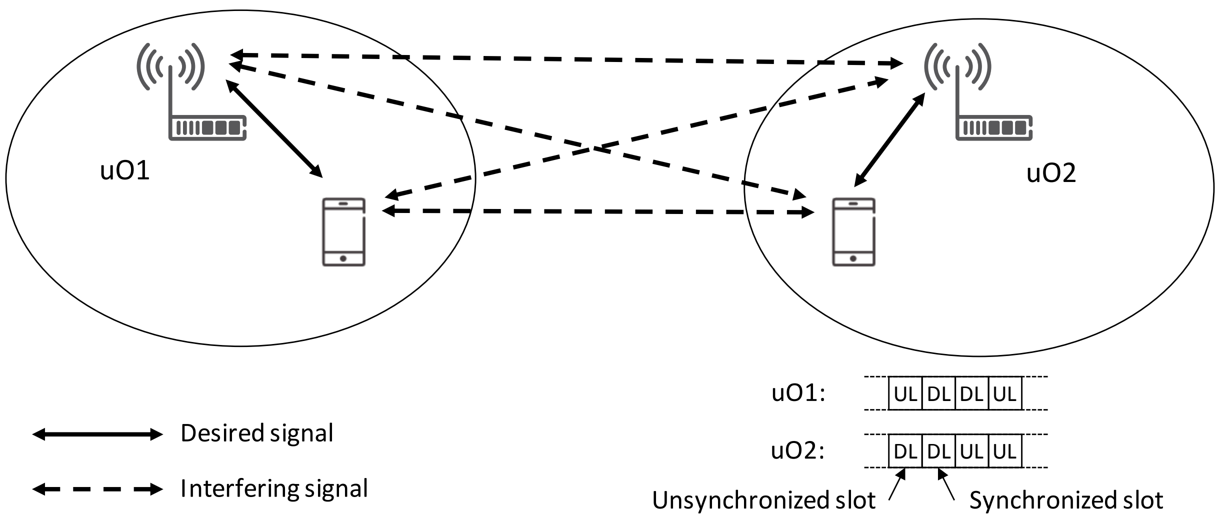

Fig. 1 Different inter-operator interference scenarios between neighboring micro operators

3 System model

This section provides a brief description of the assumed network layout for a scenario with two neighbouring micro operators. Furthermore, the applied propagation models, both for the indoor propagation within the micro operator building and for the building-to-building propagation between the micro operator buildings are presented. Finally, a model for the user performance, i.e., the average user throughput, is discussed.

3.1 Network layout

The evaluated micro operator network deployment model consists of two equally-sized buildings (50 x 120 m, based on the indoor deployment scenario defined in [17]), located at a distance D from each other, see Fig. 2. In this initial study, the buildings are assumed to be in line-of-sight (LOS) with each other and only one floor per building is modelled. Micro operator 1 (uO1) is assumed to be serving users within the first building, while micro operator 2 (uO2) is serving users within the second building. Finally, it is assumed that uO2 has deployed 12 pico base stations per floor, while the density of pico base stations belonging to uO1 is varied between 1 and 12 pico base stations per floor. In case of 12 base stations per floor, the base station locations are the same as defined in [17], and for the lower base station densities the base stations have been deployed so that a roughly uniform coverage can be obtained throughout the floor area. In this initial study focusing on the downlink performance, mobile terminals are modelled only within the uO1 building, assuming a uniform user density over the floor area.

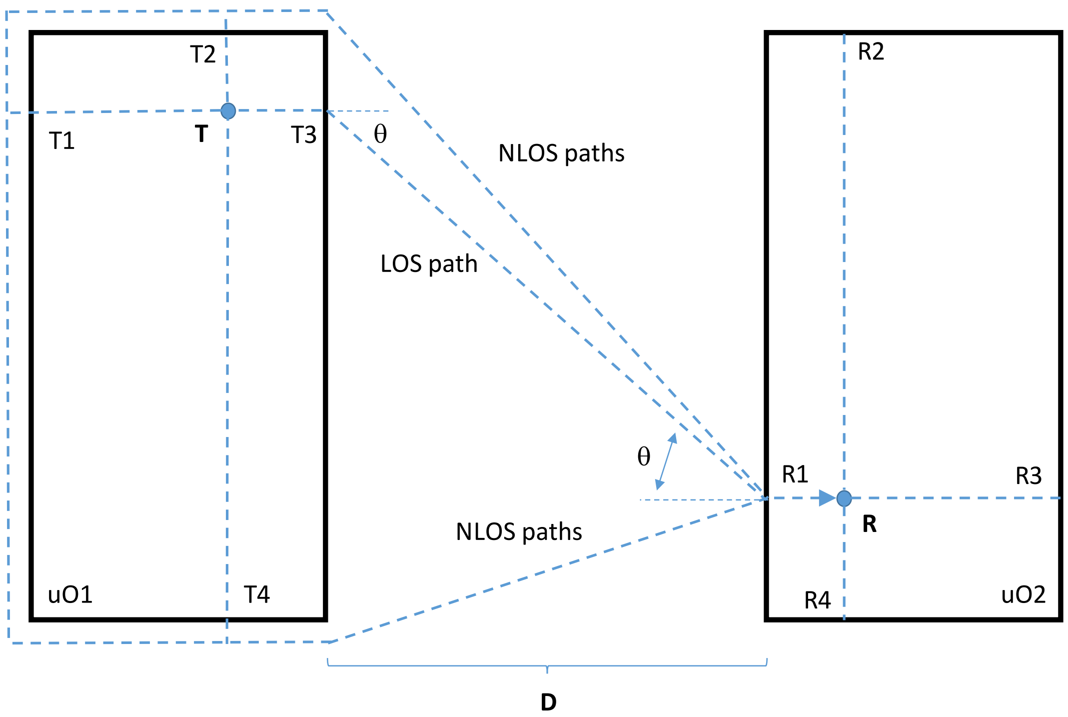

Fig. 2 Description of the assumed network layout with two micro operators, uO1 and uO2

3.2 Propagation models

When evaluating the impact of interference between neighbouring micro operators, path losses between the different nodes (base stations and mobile terminals) have to be estimated first. Hence, appropriate wave propagation models for both the desired links within the building (indoor wave propagation) and the interfering links between the buildings (building-to-building wave propagation) are needed. In the propagation model proposed in this paper, the coupling loss $C_{m,b}$ between a mobile terminal m and a base station b is calculated as

$$C_{m,b,dB} = L_{m,b,dB} - G_{BS,m,b,dB} - G_{MT,m,b,dB} + X_{m,b,dB} \quad (1)$$

where $G_{BS,m,b}$ and $G_{MT,m,b}$ are the base station and mobile terminal antenna gains, respectively, and $X_{m,b}$ is a log-normally distributed random value modelling the impact of shadow fading. Next, the assumed modelling of the path loss $L_{m,b}$ is discussed in more detail.

The indoor propagation is modelled using the *3GPP Indoor - Mixed Office* propagation model as defined in [17]. The model includes both a LOS (L_{LOS}) and a non-line-of-sight (NLOS) component (L_{NLOS}), and the LOS probability (P_{LOS}) is defined to decrease as a function of the distance between the base station and the mobile terminal. The standard deviation of the shadow fading is assumed to be equal to 3 dB (LOS) or 8 dB (NLOS). Furthermore, both the shadow fading and the LOS probability are spatially correlated, assuming correlation distances equal to 10 m or 6 m (shadow fading in LOS or NLOS), and 10 m (LOS probability) [17].

While there are several different types of indoor propagation and building penetration models described in the literature, building-to-building propagation models have received much less attention. One such model is the 3GPP dual-strip model described in [14]. Unfortunately, the 3GPP dual-strip model has its weaknesses, as demonstrated also by the measurements presented in [18]: it is tailored for 2 GHz or 3.5 GHz and is not valid for higher frequencies, the building penetration model considers only one of the building walls, the impact of both the building wall material and the angle of incidence on the building penetration loss is not taken into account, and the outdoor path loss between the buildings is to a large extent based on a macro cellular NLOS model even at relatively short distances.

In order to consider the weaknesses of using the 3GPP dual-strip model in the micro operator deployment scenario, a new type of building-to-building propagation model has been defined for this study. The overall model is composed of a number of different components taking into account free space propagation in LOS, diffraction modelling in NLOS, building penetration loss and indoor loss. The basis for each of these components has been taken by selecting appropriate models described in the literature. These include the recursive microcell model for outdoor propagation [19-20], the general building penetration model [20], the model for LOS building penetration [20-22] including the impact of the angle of incidence, the model for NLOS building penetration [17] and the linear attenuation model for indoor propagation [17]. Furthermore, the building wall loss is assumed to depend both on the frequency (f_c) and on the wall material as defined in [17].

The main principle of determining the path loss from an indoor node to another indoor node located in the neighbouring building is described in Fig. 2. For both buildings, four different sub-paths, one through each outer wall, are evaluated [20]. Hence, for each link between a transmitter and a receiver, the total received power is calculated as a linear sum of the received powers from all the 16 different sub-paths. Each sub-path takes into account both the outdoor loss between the outer wall reference points (T1-T4 and R1-R4 in Fig. 2), and the building penetration and indoor losses for both buildings. In all, the path loss per sub-path is calculated as

$$L_{dB} = L_{in,1} + L_{ow,1}(f_c) + L_{out}(f_c) + L_{ow,2}(f_c) + L_{in,2} \quad (2)$$

In (2), L_{in} is the indoor loss, modelled as $L_{in} = 0.5d_{2D-in}$, where d_{2D-in} is the two-dimensional distance between the indoor node and the outer wall reference point [17]. Parameter L_{ow} models the building wall loss and it consists of two components: one that depends on the angle of incidence θ and the other that depends on the wall material and center frequency f_c. Depending on the desired building penetration model (LOS or NLOS), L_{ow} is calculated either as described in (3) [22] or in (4) [17].

$$L_{ow,LOS} = 20(1 - \cos\theta)^2 + L_{material}(f_c) \tag{3}$$

$$L_{ow,NLOS} = 5 + L_{material}(f_c) \tag{4}$$

Since a LOS propagation condition is assumed between the buildings, L_{ow} is based on (3) for wall reference points T3 and R1, while it is based on (4) for all the other wall reference points. In higher frequency bands, the material characteristics of the building have a major impact on defining the penetration loss pattern, which means that the value of $L_{material}(f_c)$ can be significantly different for different buildings, see for example the discussion and measurement results in [17, 22-25]. In this paper, $L_{material}(f_c)$ follows the model in [17], i.e., two different frequency-dependent wall loss values have been assumed: low-loss (old buildings with 30% standard multi-pane windows, and 70% concrete) and high-loss (modern buildings with 70% infrared reflective (IRR) glass windows, and 30% concrete).

Parameter L_{out} in (2) is the outdoor path loss between the outer wall reference points. In case of a LOS path (sub-path between T3 and R1 in Fig. 2), L_{out} is based on a free space propagation model, and the applied distance is the sum of the outdoor and the indoor distances [20, 21]. In case of NLOS paths, L_{out} considers only the path loss between the outer wall reference points, and the path loss is based on the recursive microcell model [19], assuming a breakpoint for the path loss exponent at 300 m. Finally, when it comes to the shadow fading model for the building-to-building penetration, standard deviation equal to 6 dB and correlation distance equal to 10 m are assumed.

While the main assumption in this paper is that the buildings are in LOS with each other, it is also possible to model a NLOS propagation condition for the outdoor environment surrounding the buildings. For that case, the proposed building-to-building model can be modified by replacing the recursive microcell model for example with the *3GPP Urban Micro – Street Canyon* model defined in [17], and applying the NLOS building penetration model for all wall reference points. Furthermore, standard deviation of the shadow fading is increased to 8 dB and the correlation distance is increased to 13 m [17].

An example of the resulting received signal strength (RSS) heat maps is visualized in Fig. 3 for a scenario with low-loss building walls, center frequency equal to 3.5 GHz, distance D equal to 50 m, isotropic base station and mobile terminal antennas, and base station transmission power equal to 24 dBm. The impact of shadow fading has not been taken into account, which means that the different colours in Fig. 3 illustrate the median RSS values for each location. As can be seen by looking at the building on the left (uO1), one pico base station deployed in the middle of the floor is sufficient to provide RSS higher than -70 dBm throughout the investigated area. A denser deployment improves the coverage, and therefore, the median RSS within the building on the right (uO2) is better than -50 dBm for all locations. When it comes to the total downlink interference from uO2 to uO1, the highest interference levels (approximately equal to -70 dBm) can be found next to the wall facing the neighbouring building. Furthermore, it is clearly visible that the inter-operator interference gets weaker when moving farther away from the illuminated wall. One can also notice that at the upper and lower right corner of the uO1 building the level of interference is quite close to the RSS from the serving base station, which suggests that for those locations the impact of inter-operator interference on the user performance will be quite dramatic. At the same time the downlink interference from uO1 to uO2 is much weaker, which is due to fact that the interference is caused by just one pico base station located much farther away from the building wall compared to uO2.

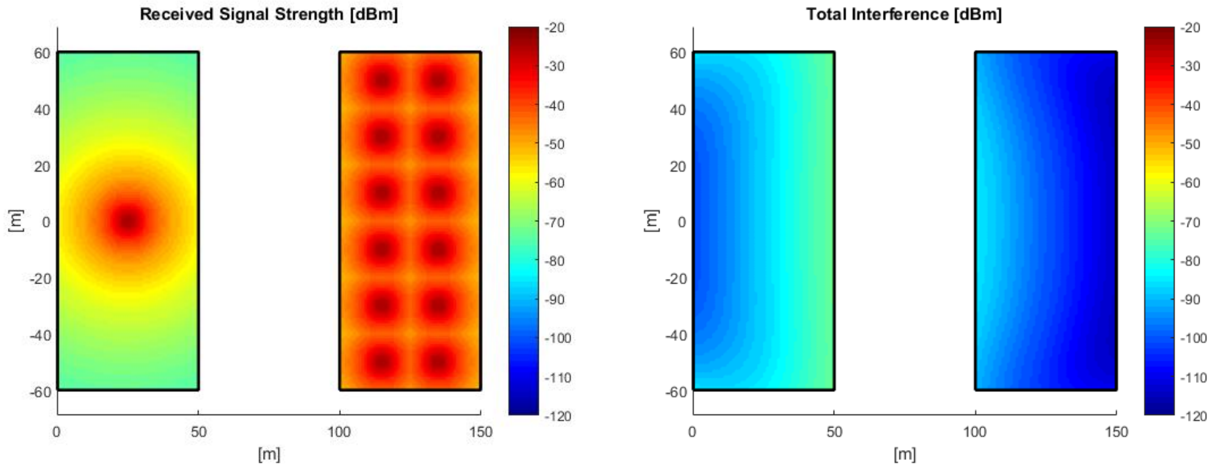

Fig. 3 Received signal strength for the desired signal (figure on the left) and for the total inter-operator interference (figure on the right)

3.3 User performance

The main output from the evaluations is the impact of inter-operator interference on the user performance, or more specifically, on the average user throughput. Generally speaking, average user throughput takes into account both the impact of scheduling and link adaptation. Furthermore, one key input for the link adaptation is the received signal-to-interference-and-noise-ratio (SINR).

The downlink SINR for mobile terminal m, being served by base station b, can be calculated as

$$\gamma_{m,b} = \frac{P_{m,b}C_{m,b}^{-1}}{I_{own,m,b} + I_{other,m} + N_m} = \frac{P_{m,b}C_{m,b}^{-1}}{\sum_{\substack{j=1 \\ j \neq b}}^{B} \alpha_j P_j C_{m,j}^{-1} + \sum_{k=1}^{K} \alpha_k P_k \rho_k^{-1} C_{m,k}^{-1} + N_m} \qquad (5)$$

In (5), I_{own} is the received power from all the other base stations belonging to the serving micro operator (having a total of B base stations), while I_{other} is the received power from all the base stations belonging to the other micro operators (a total of K base stations). Furthermore, $P_{m,b}$ is the transmission power from base station b towards mobile terminal m, $C_{m,b}$ is the coupling loss between base station b and mobile terminal m, N_m is the thermal noise power of mobile terminal m, and ρ_k is the adjacent channel interference ratio (ACIR) taking into account the appropriate adjacent channel attenuation between the micro operators when applicable [26]. Finally, the activity factor α_j is equal to 1 when base station j is transmitting at the same time and on the same frequency resources as base station b, otherwise α_j is equal to 0.

For simplicity, only time-domain scheduling of users is assumed, which means that when mobile terminal m is scheduled, $P_{m,b}$ becomes equal to the total base station output power (P_{BS}). Furthermore, when defining the coupling loss towards the serving base station ($C_{m,b}$), the user is always assumed to be served by the base station, which has the smallest coupling loss towards the mobile terminal.

The SINR is mapped to a bit rate using the Shannon-Hartley theorem:

$$\tau_{m,b} = \beta \log_2(1 + \gamma_{m,b}) \tag{6}$$

where β is the bandwidth of the channel. Finally, assuming a Round Robin scheduling algorithm, and that base station b is simultaneously serving a total of u_b users, the average user throughput becomes equal to

$$R_{m,b} = \frac{\tau_{m,b}}{u_b} = \frac{\beta \log_2(1 + \gamma_{m,b})}{u_b} \tag{7}$$

This initial study investigates the impact of inter-operator interference on the user performance within a scenario, where the victim micro operator (uO1) is serving only one active user, i.e., the activity factor α_j in (5) is equal to zero for all the other base stations ($I_{own} = 0$), and parameter u_b in (7) is equal to one. At the same time, the interfering micro operator network (uO2) is assumed to be fully loaded, i.e., $\alpha_k = 1\ \forall k$. Taking all this into account, the average user throughput can now be written as

$$R_{m,b} = \beta \log_2\left(1 + \frac{P_{BS} C_{m,b}^{-1}}{N_m + \frac{P_{BS}}{\rho} \sum_{k=1}^{K} C_{m,k}^{-1}}\right) \tag{8}$$

4 Evaluation results

In order to evaluate the impact of the inter-operator interference from a micro operator network inside a building to another micro operator network in a neighbouring building, system simulations have been carried out using the system and performance models from Section 3. The main simulation parameters are listed in Table I. It should be noted that the ACIR parameter takes into account both the adjacent channel leakage power ratio (ACLR) of the transmitter, assumed to be equal to 45 dB [27], and the adjacent channel selectivity (ACS) of the receiver, equal to 27 dB [28].

During the Monte-Carlo simulations, the evaluated victim user is dropped in random positions inside the uO1 building and coupling loss values are calculated towards all the base stations within both buildings. Based on the obtained coupling losses, the serving base station is defined, and the level of the total inter-operator interference (I_{other}) is calculated. Finally, the SINR and the corresponding average user throughput are obtained.

Table I List of the main simulation parameters

Parameter	**Value**
Center frequency (f_c)	3.5 GHz
Channel bandwidth (β)	20 MHz
Base station transmission power (P_{BS})	24 dBm
Mobile terminal noise power (N)	-92.4 dBm
Adjacent channel interference ratio (ρ)	0 dB (co-channel) 26.9 dB (adjacent channel)
Base station antenna gain (G_{BS})	5 dBi (omnidirectional)
Mobile terminal antenna gain (G_{MT})	0 dBi (omnidirectional)
Building wall loss ($L_{material}$)	7.7 dB (low-loss wall) 21.8 dB (high-loss wall)

A summary of the simulation results with different deployment options is shown in Fig. 4, Fig. 5 and Fig. 6, where the received total inter-operator interference (I_{other}), the average user performance (calculated as the average over the obtained $R_{m,b}$ values) and the performance of the worst 5th percentile are studied, while increasing the distance D between the buildings from 10 m to 900 m. The inter-operator interference is evaluated by calculating the probability that the level of I_{other} is higher than $N-6$ dBm, which has quite often been applied as the threshold for harmful interference, see for example [29]. Furthermore, the downlink throughput loss values in Fig. 5 and Fig. 6 have been obtained by comparing the user throughput values of the multi-operator scenario to the corresponding values within the single operator scenario (when $I_{other}=0$).

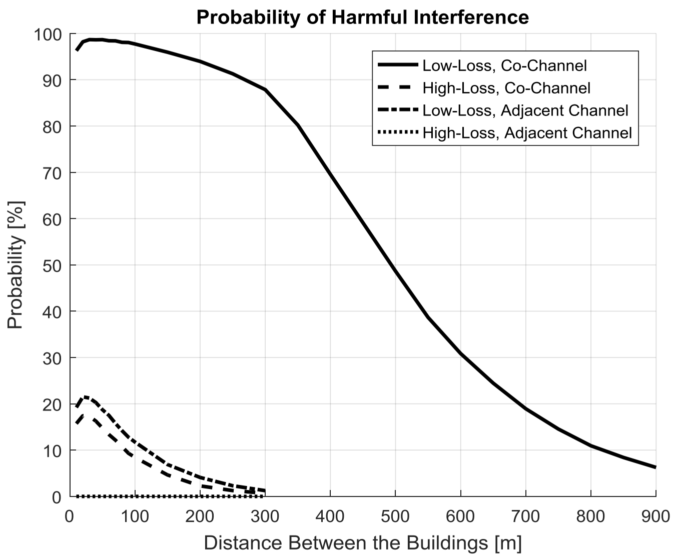

Fig. 4 Probability that the received total inter-operator interference is higher than the threshold for harmful interference

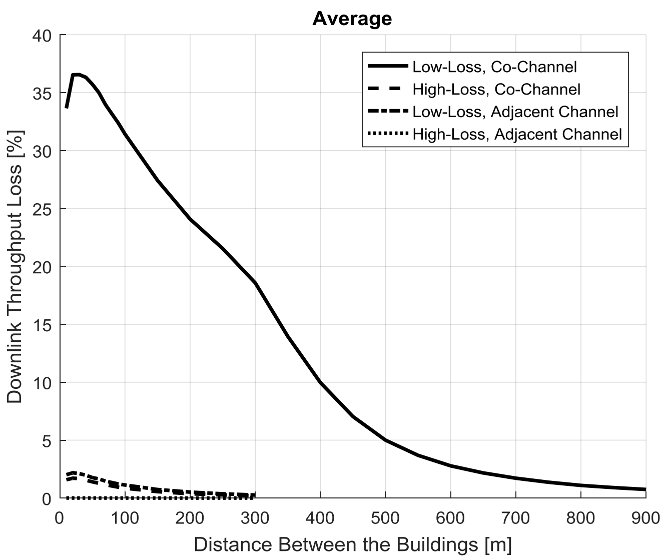

Fig. 5 Average downlink throughput loss within the uO1 building as a function of the distance between the buildings

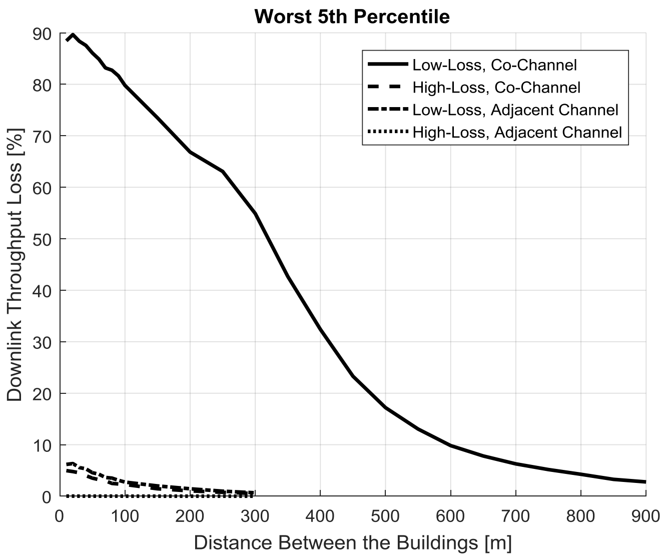

Fig. 6 Downlink throughput loss for the worst 5th percentile of users within the uO1 building as a function of the distance between the buildings

In order to set the limit for the maximum allowed performance degradation, the approach taken in [26] can be adopted. Thus, in this paper the minimum separation distance D_{min} between the two buildings is defined so that the average user performance is not degraded more than 1%, and at the same time the performance of the worst 5th percentile is not degraded more than 5%.

Looking at the curves in Fig. 4, I_{other} seems to exceed the threshold for harmful interference with a very large probability when a co-channel deployment with low-loss building walls is assumed. This corresponds also nicely to the findings in Fig. 5 and Fig. 6, which show that the required D_{min} becomes as large as 830 m. Furthermore, if the required D_{min} is compared to the results in Fig. 4, one can notice that it matches roughly to the situation when I_{other} exceeds the threshold for harmful interference with 10% probability.

In case of the other deployment scenarios, the level of I_{other} is much lower, exceeding the interference threshold in less than 20% of the time even when the buildings are located close to each other. In all, the required D_{min} values become equal to: 80 m (high-loss, co-channel), 120 m (low-loss, adjacent channel) and less than 10 m (high-loss, adjacent channel). Again, if these values are compared to the curves in Fig. 4, they seem to match quite well the results when I_{other} exceeds the interference threshold with 10% probability.

When the buildings are in NLOS with each other, the level of I_{other} is attenuated much faster, and the required D_{min} becomes considerably smaller as can be seen in the results shown in Fig. 7. The required D_{min} is now equal to 180 m for the co-channel deployment with low-loss walls, and less than 50 m for all the other deployment scenarios.

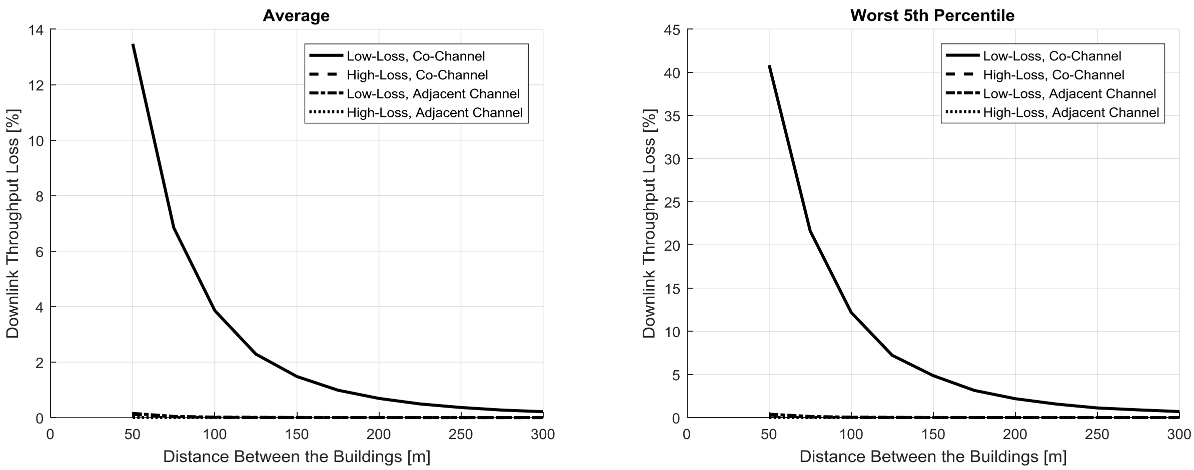

Fig. 7 Downlink throughput loss within the uO1 building as a function of the distance between the buildings. The buildings are assumed to be in NLOS with each other

The final thing to study is the impact of the base station density within the victim building on the required D_{min}. With the traditional approach based on I_{other}, there would not be any difference, but with the proposed approach based on the user performance, some kind of impact could be expected. Generally speaking, when the base station density is increased, coupling loss from the mobile terminal towards the serving base station is reduced, improving the signal-to-noise-ratio (SNR). Since the users, in particular the worst ones, experience now much higher bit rates (users are higher up on the Shannon-Hartley curve), a certain I_{other} will then have a smaller relative impact on the user performance compared to the users experiencing lower SNR values. Alternatively, the victim users can tolerate a higher I_{other} for a certain level of performance degradation. However, the improvement may not be as large from the average system performance point of view.

Looking at the curves in Fig. 8 for the adjacent channel deployment with low-loss building walls this indeed seems to be the case. When the base station density is increased from 1 to 12 pico base stations per floor, the required D_{min} is reduced from 120 m to 60 m. Furthermore, it is very clear that the D_{min} becomes more and more limited by the average performance and not by the performance of the worst users. A very similar conclusion can be drawn also for the co-channel deployment with low-loss building walls, where the required D_{min} is reduced from 830 m to 710 m. Finally, from the I_{other} statistics point of view, the maximum tolerable probability of harmful interference is at the same time increased from 10% to 18%, as indicated by the results in Fig. 4.

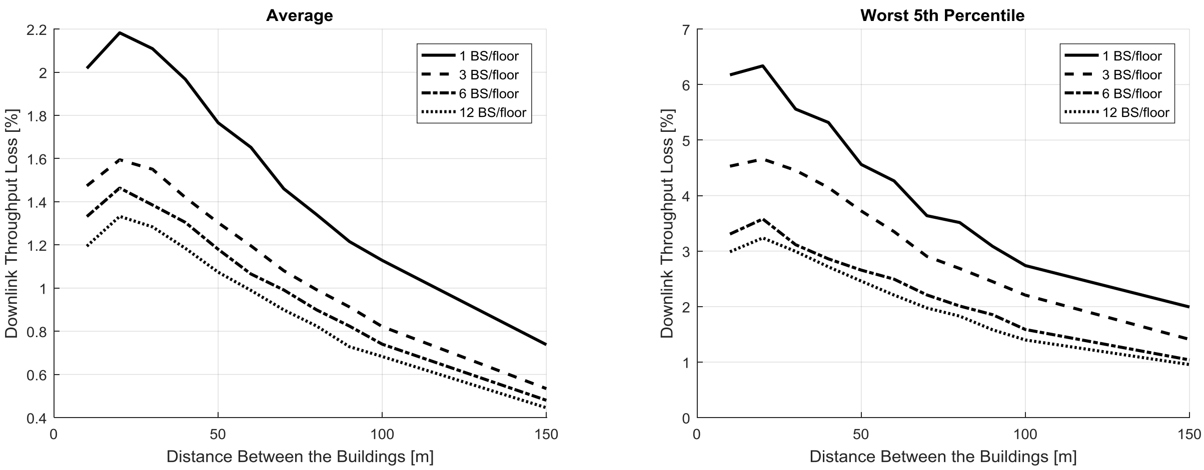

Fig. 8 Downlink throughput loss within the uO1 building as a function of the distance between the buildings, assuming different base station densities

5 Conclusions and further work

Local small cell deployments will become an important part of the future 5G networks, in particular for the deployments within higher frequency bands. In order to make such ultra-dense network deployments more cost-efficient, new business and spectrum authorization models are needed in addition to the traditional models based on networks deployed and operated by the MNOs. One such model is the recently introduced concept for 5G micro operators for allowing different stakeholders to deploy and operate their own networks in specific buildings using locally issued micro licensed spectrum with pre-defined level of quality guarantees.

One important aspect of the proposed concept is the required minimum separation distance between the micro operators in co-channel and adjacent channel deployments so that the level of inter-operator interference is still sufficiently low. To characterize such interference, and in particular the impact of the interference on the performance of the victim network, models for appropriate micro operator network deployments, radio wave propagation and user performance are needed. To support such interference evaluations, this paper has proposed a deployment scenario including two neighbouring buildings, propagation models for connections both within a building and between the buildings, and a criteria for the required minimum separation distance based on the observed throughput loss. Finally, system simulations have been performed to evaluate the impact of the key deployment aspects on the required minimum separation distance between the micro operators including building type, spectrum allocation, surrounding outdoor environment and base station density.

The obtained results in the case of 3.5 GHz band indicate that if the building wall loss is low (old buildings with traditional windows) and the buildings are in line-of-sight with each other, the level of inter-operator interference becomes high, and a large minimum separation distance (up to 830 m) is required if the micro operators are operating on the same frequency channel. In case of modern buildings with modern infrared reflective windows the building wall loss becomes much higher, and hence, the required minimum separation distance is reduced to 80 m. Furthermore, if the operators are assigned adjacent channels, the minimum separation distance becomes equal to 120 m (low-loss building walls) or less than 10 m (high-loss building walls). If the buildings are not in line-of-sight with each other, the outdoor environment surrounding the buildings will attenuate the interference much faster, and thus, the required minimum distance is reduced to 180 m even for a scenario with a co-channel deployment and low-loss building walls. Finally, the impact of the inter-operator interference is shown to depend on the base station density within the victim building:

the required minimum separation distance is reduced from 830 m to 710 m (co-channel, low-loss building walls) and from 120 m to 60 m (adjacent channel, low-loss building walls) when the base station density within the victim building is increased from 1 to 12 base stations per floor.

As a summary, the obtained results suggest that both the maximum tolerable level of inter-operator interference (I_{other}) and the required minimum separation distance between two micro operators will be highly scenario-specific. Therefore, the traditional approach of defining a certain fixed interference threshold dimensioned for the worst case scenario, is no longer feasible for shared spectrum access as it results in less efficient reuse of the spectrum. This will need to be taken into account in the development of future 5G spectrum authorization models, such as the new micro licensing model, and the setup of appropriate rules to define and coordinate the resulting interferences. Future research is therefore needed to characterize the inter-operator interference even further. For example, the impact of center frequency, base station density and the base station transmission power of the interfering network, traffic load within the victim network (i.e., the impact of I_{own}), more advanced interference coordination mechanisms, beamforming, and signalling capabilities between the micro operators should be investigated. Furthermore, it would be valuable to include also the other interference scenarios, in addition to the downlink-to-downlink interference discussed in this paper, into the overall interference analysis. Finally, the analysis could be extended also to a deployment scenario, where the micro operators are located within the same building.

References

1. EC. (2016). Communication from the Commission to the Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Connectivity for a competitive digital single market – Towards a European gigabit society. COM (2016) 587 Final. European Commission.
2. 5GPPP. (2017). 5G innovations for new business opportunities. The 5G Infrastructure Public Private Partnership.
3. Matinmikko, M., Latva-aho, M., Ahokangas, P., Yrjölä, S. & Koivumäki, T. (2017). Micro operators to boost local service delivery in 5G. *Wireless Personal Communications, 95*(1), 69-82.
4. Zander, J. (2017). Beyond the ultra-dense barrier: Paradigm shifts on the road beyond 1000x wireless capacity. *IEEE Wireless Communications, 24*(3), 96-102.
5. Saldana, J., et al. (2017). Alternative networks: Toward a global access to the Internet for all. *IEEE Communications Magazine, 55*(9), 187-193.
6. EC. (2016). 5G for Europe: An action plan. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. COM (2016) 588 Final. European Commission.
7. CEPT ECC. (2014). Licensed shared access. ECC Report 205. European Conference of Postal and Telecommunications, Electronic Communications Committee.
8. FCC. (2016). Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band, Order of Reconsiderations and Second Report and Order. FCC-16-55. Federal Communications Commission.
9. Matinmikko, M., Roivainen, A., Latva-aho, M. & Hiltunen, K. (2017). Interference study of micro licensing for 5G micro operator small cell deployments. Conference on Cognitive Radio Oriented Wireless Networks and Communications (CrownCom), Lisboa, Portugal, 20-21 September 2017.
10. Matinmikko, M., Latva-aho, M., Ahokangas, P. & Seppänen, V. (2018). On regulations for 5G: Micro licensing for locally operated networks. *Telecommunications Policy* (to appear).
11. Ahokangas, P., Moqaddamerad, S., Matinmikko, M., Abouzeid, A., Atkova, I. Francis Gomes, J., & Iivari, M. (2016). Future micro operators business models in 5G. In *International conference on Restructuring of the Global Economy (ROGE).*

12. Gupta, A. K., Andrews, J. G. & Heath, R. W. (2016). On the feasibility of sharing spectrum licenses in mmWave cellular systems. *IEEE Transactions on Communications,* 64(9), 3981-3995.
13. Gupta, A. K., Alkhateeb, A., Andrews, J. G. & Heath, R. W. (2016). Gains of restricted secondary licensing in millimeter wave cellular systems. *IEEE Journal on Selected Areas in Communications,* 34(11), 2935-2950.
14. 3GPP. (2013). Small cell enhancements for E-UTRA and E-UTRAN – Physical layer aspects. 3GPP TR 36.872, V12.1.0. 3rd Generation Partnership Project.
15. Parkvall, S., Dahlman, E., Furuskär, A. & Frenne, M. (2017). NR: The new 5G radio access technology. *IEEE Communications Standards Magazine*. 1(4), 24-30.
16. Hiltunen, K. (2014). The performance of dense and heterogeneous LTE network deployments within an urban environment. Doctoral dissertation. Aalto University.
17. 3GPP. (2017). Study on channel model for frequencies from 0.5 to 100 GHz. 3GPP TR 38.901, V14.1.1. 3rd Generation Partnership Project.
18. Lehtomäki, J., Vuohtoniemi, R., Matinmikko-Blue, M. & Hiltunen, K. (2018). Building-to-building propagation loss measurements at 3.5 GHz with application to micro operators. In *IEEE Wireless Communications and Networking Conference* (to appear).
19. Berg, J.-E. (1995). A recursive method for street microcell path loss calculations. In *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*.
20. Damosso, E. & Correia, L. M., Eds. (1999). Digital mobile radio towards future generation systems. Final report. European Commission. http://www.lx.it.pt/cost231/final_report.htm. Accessed 15 May 2017.
21. Berg, J.-E. (1996). Building penetration loss along street microcells. In *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*.
22. Semaan, E., Harrysson, F., Furuskär, A. & Asplund, H. (2014). Outdoor-to-indoor coverage in high frequency bands. In *IEEE Globecom 2014 Workshop – Mobile Communications in Higher Frequency Bands*.
23. Ökvist, P., Asplund, H., Simonsson, A., Halvarsson, B., Medbo, J. & Seifi, N. (2015). 15 GHz propagation properties assessed with 5G radio access prototype. In *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC) – Workshop on 5G Channel Measurements and Modeling*.
24. ITU-R. (2016). Compilation of measurement data relating to building entry loss. Report ITU-R P.2346-1. International Telecommunication Union Radiocommunication sector.
25. Aalto University, AT&T, BUBT, CMCC, Ericsson, Huawei, Intel, KT Corporation, Nokia, NTT DOCOMO, New York University, Qualcomm, Samsung, University of Bristol, University of Southern California. (2015). 5G channel model for bands up to 100 GHz. White paper. http://www.5gworkshops.com/5GCM.html. Accessed 15 May 2017.
26. 3GPP. (2017). Radio Frequency (RF) system scenarios. 3GPP TR 36.942, V14.0.0. 3rd Generation Partnership Project.
27. 3GPP. (2017). Base station (BS) radio transmission and reception. 3GPP TS 36.104, V14.4.0. 3rd Generation Partnership Project.
28. 3GPP. (2017). User equipment (UE) radio transmission and reception. 3GPP TS 36.101, V14.4.0. 3rd Generation Partnership Project.
29. CEPT ECC. (2012). Broadband wireless systems usage in 2300-2400 MHz. ECC Report 172. European Conference of Postal and Telecommunications, Electronic Communications Committee