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Identification of Wave Scatterers in an Urban MicroCellular Environment at 32 GHz

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Abstract—In this paper, we present a method to analyse the millimeter-wave (mm-wave) radio channel scatterers applied to channel sounding at 32 GHz in an urban micro-cell (UMi) environment in the city of Espoo (Finland). The proposed method is based on a geometric single bounce assumption for recovering the scatterer positions. A simple formulation exploiting the discovered scatterer positions allows quantifying the excess-loss to free space for each scatterer. We found that large building walls, as well as small urban furniture such as metallic sign-board reflectors, are objects producing reflections and strong scattering. Finally, their radar cross-section and equivalent scattering area are estimated.

Index Terms: radio propagation, millimeter wave propagation, UMi, scattering environment, channel sounding, plates radar cross section, flashing points, 5G.

I. INTRODUCTION

The field of wireless cellular communication systems has been stimulated by the fifth generation (5G) system. It is characterized by a drastic growth of the mobile traffic that has been tremendously scaled-up by the emerging of smart devices as well as applications such as virtual reality, augmented reality, autonomous cars that need large throughput while being exigent in terms of latency. One key enabling technology for 5G is the use of the millimeter-wave (mm-wave) bands [1]. The wavelength in mm-wave bands is shorter as well as the radio range, thus the mm-wave roll-out in the radio access is most likely in a dense deployment of base stations (BSs) of a small-cell. The evaluation of the radio frequency (RF) performances relies on the link simulation and the coverage design performed by using deterministic tools. These tools, as any other RF planning tools exploit environment data to build the geographical footprint where the simulations will be run. Each object of the environment can impact on the link performance and especially in mm-wave bands where the wavelength is shorter than legacy RF. It is then useful to study which are the important level of detail of the environment to be taken into account for good deterministic channel prediction. Focusing on the dense

urban environment, authors in [2] demonstrated that metallic objects as small as several tenths of wavelength located in the environment at a radius of 100 m are a potential source of significant scattering. They proposed a method to investigate the scatterers related to the single bounce reflection/scattering point calculations based on radio propagation measurements conducted in an urban canyon at 3.35 GHz. Besides, work in [1] conducted several measurement campaigns in UMi at 28 GHz RF. They demonstrated that the mm-wave BS deployment in radio access is feasible up to several meters provided that the BS communicates to the mobile station (MS) via the line-of-sight (LOS) path and the specular reflected path from large buildings. However, they do not investigate in detail the effect of the scattering environment that we can take advantage for improving deterministic radio wave propagation simulations.

In this contribution, we present a method introduced in [2] for wave scatterer identification. Channel sounding was conducted in Espoo city center, Finland at the frequency range of 31.8 – 33.4 GHz. We use reflected/scattered path estimated from the 32 GHz UMi scattering environment. The scatterer identification method is described and applied to the measured data. Results show that buildings and UMi urban furnitures are contributing significantly in the 32 GHz UMi scattering environment. Furthermore, urban furniture presenting a metallic planar surface are objects producing reflections and strong scattering at 32 GHz.

The remainder of the paper is structured as follows. Section II describes the channel sounder used during the measurement trial and the measurement environment. Section III is dedicated to the investigation of the UMi scattering environment where a simple method to highlight the effect of scatterers is introduced. Section IV analyses the scattering power. Section V presents selected results applied to the measured data findings and Section VI concludes this paper.

Fig. 1: View of the investigated UMi environment from Open Street Map buildings. 13 links were measured in LOS conditions (green markers). Red circle is the 6 m height rotating receiving horn antenna (BS).

II. CHANNEL MEASUREMENT CAMPAIGN

The 32 GHz UMi channel sounding was conducted in the city center of Espoo (Finland) by using the wideband channel sounder from Aalto University. The instrument relies on a vector network analyzer (VNA) that measures the transfer response function (TRF) of the radio channel. The BS part is made of the horn antenna designed in vertical polarization with 10° half power beam-width in azimuth, the down-converter integrating the low noise amplifier and an active double multiplier fed by the splitter of the local oscillator (LO). An electric-optical box is used to convert the LO signal and the intermediate frequency to the optic signal. On the link end, the MS consists of a bi-conical antenna designed for vertical polarization followed by the up-converter, which has a mixer with an internal frequency doubler and integrated LO amplifier and the optical-electric box. The IF and the LO port of the up-converter are fed with extra amplifiers of 10 dB and 30 dB, respectively and a single laptop MATLAB platform is used to trigger the VNA and to manage the rotation of the horn antenna at the BS. The BS and the MS are linked with a 200 m optical cable. The RF frequency was 31.8 – 33.4 GHz with a bandwidth (BW) of 1.6 GHz meaning that the sounder delay resolution is $\frac{c}{BW} = 0.1875$ m where c (in m/s) is the speed of light.

The measurement site of Espoo is presented in the Fig. 1. The addressed environment presents resemblance with the identified generic Madrid-Grid of the METIS project [3] and the UMi-open area of the 3GPP [4] scenario. As illustrated in Fig. 1, the MSs deployed at a pedestrian level (1.65 m) are distributed around the flat open parking area and surrounded by buildings made of cement, tiles, and window at different heights varying from 10 m to 35 m. The streets in this area are about 20

m wide. Furthermore, urban furniture such as metallic lamp-post, road-sign and publicity-boards made of glass and metal are also key features of the environments, as shown in Section II. The BS was deployed near the building R at a height of 6 m from the ground while covering a 225 degrees wide angular sector towards the open area (see angular sector coloured in black in Fig. 1).

III. BACK-PROJECTION METHOD

A. Fine Specular Peak Search

Multi-path detection is based on locating the local maxima in the power angular delay profiles (PADPs) as in [5]. The PADP is the inverse Fourier transform of the measured TRFs for each pointing angle of the BS horn antenna. As the azimuth rotation step size of 5° is less than the beam-width of the antenna (10°), the PADP effectively has the horn antenna pattern recorded for every incoming multi-path. Therefore, the amplitude, delay, and angle $(\hat{a}_s, \hat{\tau}_s, \hat{\varphi}_s)$ of the detectable multi-path components (MPCs), can be found by detecting the local maximums in the PADPs.

B. Single Bounce Geometrical Transformation

Fig. 2: Geometrical description of scattering point determination based on single bounce assumption.

Let us denote $\mathbf{p}_u^\perp$ and $\mathbf{p}_u$ the projected and 3D positions of the MS, BS and a given scatterer expressed in the global coordinate system of the scene where index $u \in \{m, b, s\}$ as:

$$\mathbf{p}_u^\perp = [x_u, y_u]^T, \quad (1)$$

$$\mathbf{p}_u = [\mathbf{p}_u^\perp, z_u]^T. \quad (2)$$

We assume a single bounce meaning that the path is resulting from a 1^{st} order interaction from the scatterer localized in position $\mathbf{p}_s$. The geometry problem is summarized in Fig.2. The positions of the BS and MS are assumed to be known. The goal is to determine for each estimated path parameters $(\hat{\tau}_s, \hat{\varphi}_s)$, the corresponding scatterer position $\hat{\mathbf{p}}_s^\perp$ and to overlay it in the environment map for physical analysis and identification. As the

measured delay depends to the 3D distance, a projected value is evaluated as:

$$\tau_s^\perp = \tau_s \cos \left(\arcsin \left(\frac{|z_m - z_b|}{c\tau_s} \right) \right). \quad (3)$$

The estimated planar scatterer position $\hat{\mathbf{p}}_s^\perp$ is obtained by minimizing a cost function exploiting the non-linear set of 2 equations provided by the estimated path delay and angle:

$$\|\mathbf{p}_m^\perp - \mathbf{p}_s^\perp\|_2 + \|\mathbf{p}_b^\perp - \mathbf{p}_s^\perp\|_2 = d_{ms}^\perp + d_{bs}^\perp = c\tau_s^\perp, \quad (4)$$

$$\arctan \left(\frac{(\mathbf{p}_s^\perp - \mathbf{p}_b^\perp)^T \hat{\mathbf{y}}}{(\mathbf{p}_s^\perp - \mathbf{p}_b^\perp)^T \hat{\mathbf{x}}} \right) = \varphi_s, \quad (5)$$

where $\|\cdot\|_2$ is the 2-norm.

IV. SCATTERING POWER ANALYSIS

We are interested in evaluating the scattering loss of an individual scatterer in a link. First, let us define L_s as the estimated path-loss for scatterer s in dB scale obtained from the measured PADP

$$L_s = 20 \log_{10} |\hat{a}_s|, \quad (6)$$

and L_{msb} , the free-space losses over distance $d_{ms} + d_{bs}$ with the combined broadside gain of the transmitter and the receiver antenna G_{tot} as

$$L_{msb} = 32.4 + 20 \log_{10}((d_{bs} + d_{ms}) \cdot f_{\text{GHz}}) - G_{tot}. \quad (7)$$

We are now going to compare the received power for two different situations. The first situation corresponds to a limiting case of a large perfectly conducting mirror, and the second one is the situation of interest presented in Fig. 2. Let us define Pr_{lim} the received power after a spherical wave reflection on the large perfectly conducting mirror placed tangentially to the ellipsoid for the distance of interest $d_{ms} + d_{bs}$. In the second situation, Pr_s is defined as the power received after the interaction with the scatterer of interest with cross-section σ_s placed in the same condition at distance d_{ms} and d_{bs} of the 2 link foci. As the received level from a perfect reflector should be greater than the one from any scatterer we have $Pr_{lim} \geq Pr_s$ and the dependency with distance d_{bs} and d_{ms} are

$$Pr_{lim} \propto \frac{1}{(d_{bs} + d_{ms})^2}, \quad (8)$$

$$Pr_{msb} \propto \frac{\sigma_s}{4\pi d_{ms}^2 d_{bs}^2}. \quad (9)$$

We define the scatterer s loss as

$$l_{msb} = 10 \log_{10} \left(\frac{Pr_{lim}}{Pr_{msb}} \right) = 10 \log_{10} \left(\frac{4\pi}{\sigma_s} \left(\frac{d_{ms} d_{bs}}{d_{ms} + d_{bs}} \right)^2 \right), \quad (10)$$

which can also be obtained from (6) and (7) as

$$l_{msb} = L_{msb} - L_s. \quad (11)$$

The previous relations allow to get access to the bi-static scatterer cross-section expressed in m^2

$$\sigma_s = 10^{-\frac{l_{msb}}{10}} 4\pi \left(\frac{d_{ms} d_{bs}}{d_{ms} + d_{bs}} \right)^2. \quad (12)$$

If we assume the limiting situation of a perfectly conducting surface, the scatterer cross-section, is proportional to the squared area as presented in [6] and [7]

$$\sigma_s = 4\pi \frac{S^2}{\lambda^2} \cos^2 \alpha_s, \quad (13)$$

where λ is the wavelength and α_s the angle of the single bounce ray with the planar scatterer normal.

In the following we consider this area S (in m^2) as being an equivalent area S_{eq} because the encountered scatterers are neither perfect electric conductor nor to produce only specular reflection. Equating (12) and (13), the scatterer cross-section can be translated to the equivalent area S_{eq} as

$$S_{eq} = 10^{-\frac{l_{msb}}{20}} S_{lim}, \quad (14)$$

with

$$S_{lim} = \frac{\lambda}{\cos \alpha_s} \left(\frac{d_{ms} d_{bs}}{d_{ms} + d_{bs}} \right). \quad (15)$$

As $l_{msb} \geq 0$, we always have $S_{eq} \leq S_{lim}$. S_{lim} can be seen as a planar surface made of perfect electric conductor behaving as a perfect mirror. This area S_{lim} depends only on λ , the scatterer position on the constant delay ellipse through parameters d_{ms}, d_{bs} and α_s . A small object which is a weak scatterer for a longer wavelength can become a strong reflector as the wavelength is getting shorter depending on its dimension w.r.t S_{lim} .

V. SCATTERER LOCATION AND CROSS SECTIONS

Fig. 3 shows the identified scatterers from the back-projection method applied to the measurements. All the 13 LOS links have been superimposed with a different marker shape. The choice of this marker shape and size representation allows to keep track of the involved radio link for each scatterer. The strong LOS component, which do not correspond to a scattering effect, has not been included. The l_{msb} levels is encoded with the area of the marker. The larger the marker¹, the smaller the losses. The zoomed observation of those two figures is advantageously assisted by a street view visualization at coordinates (60.204428°, 24.659430°) which allows to appreciate the density and the effect of many scatterers

¹A 30 dB level difference, means a ratio of $\sqrt{1000} \approx 31$ between the two corresponding marker radius. Markers have been set a transparency of 30% which allows to observe those scatterers which intervene in several links and are superposed in the same region. This is the case of street lamps and metal road-signs. A marker with a red border indicates that the scatterer is situated on the same direction than LOS path.

#	$\hat{r}_s$ (ns)	$\hat{\varphi}_s$ (deg)	x_s (m)	y_s (m)	L_s (dB)	L_{msb} (dB)	l_{msb} (dB)	S_{lim} (m ²)	$\cos \alpha_s$	S_{eq} (m ²)
1	296.9	115	216.8	139.7	89.3	80.7	8.7	0.230	0.908	0.084
2	126.9	180	187.4	172.2	82.1	73.2	8.9	0.079	0.317	0.028
3	298.8	115	216.8	139.3	91.1	80.7	10.4	0.231	0.909	0.070
4	521.3	110	221.4	103.9	98.6	85.5	13.0	0.376	0.972	0.084
5	527.5	105	228.4	105.0	102.6	85.6	17.0	0.381	0.972	0.054
6	360.0	60	251.9	159.6	102.4	82.3	20.1	0.247	0.967	0.024
7	300.0	115	216.8	139.1	100.9	80.7	20.1	0.231	0.910	0.023

TABLE I: Extracted parameters of the 7 relative strongest scatterers for the link BS-MS3 ordered by increasing l_{msb} . $\mathbf{p}_m = (186, 159.9, 1.65)$, $\mathbf{p}_b = (220, 185, 6)$, $\hat{\varphi}_s$ is referred w.r.t LOS direction (i.e in second line $\hat{\varphi}_s = 180^\circ$ corresponds to a scatterer placed along the LOS direction).

#	$\hat{r}_s$ (ns)	$\hat{\varphi}_s$ (deg)	x_s (m)	y_s (m)	L_s (dB)	L_{msb} (dB)	l_{msb} (dB)	S_{lim} (m ²)	$\cos \alpha_s$	S_{eq} (m ²)
1	470.0	335	186.1	224.2	93.0	84.6	8.4	0.309	0.997	0.118
2	205.0	175	237.7	138.5	89.4	77.4	12.0	0.087	0.998	0.022
3	144.4	350	219.0	187.0	88.5	74.4	14.1	0.020	0.998	0.004
4	733.8	235	146.0	93.8	103.9	88.5	15.4	0.520	0.987	0.089
5	131.2	180	228.2	156.1	89.7	73.6	16.1	0.561	0.119	0.088
6	206.9	180	233.8	137.0	93.7	77.5	16.2	0.089	0.997	0.014
7	215.6	180	234.2	135.7	96.7	77.9	18.8	0.098	0.997	0.011

TABLE II: Extracted parameters of the 7 relative strongest scatterers for the link BS-MS5 ordered by increasing l_{msb} . $\mathbf{p}_m = (232.5, 148.5, 1.65)$, $\mathbf{p}_b = (220, 185, 6)$, $\hat{\varphi}_s$ is referred w.r.t LOS direction (i.e in line 5,6,7 $\hat{\varphi}_s = 180^\circ$ corresponds to scatterers placed along the LOS direction).

Fig. 3: Scatterers losses l_{msb} for all measured LOS links. The size of blue markers reflects the reflectivity of each scatterer. Green and red markers are the same MS and BS positions shown in Fig. 1.

of the environment. Fig. 3 provides insights about the distribution of scatterer losses for all measured links. The glass wall of building B is the strongest reflector in the environment even though the power is still much weaker than the LOS contribution. Moreover, the single bounce assumption is clearly wrong for some scatterers such as those in the shadow of building R and are most likely second order reflections. Furthermore, some scatterer locations located inside the buildings are identified as a 2nd order specular reflection (specular reflection from the building plus ground reflection). However except for those cases, the single bounce assumption is justified and yields valid scatterer positions on the map.

An other important scatterer that delivers energy between the BS and the MS is urban furniture especially of metallic nature. To illustrate this point, Table I and Table II detail the 7 strongest paths for the selected links BS-MS3 and BS-MS5; l_{msb} for the selected links is presented in Fig. 4.

The relative strongest scatterer of the link BS-MS3 comes from a compound of a vertically orientated publicity-board and a road-sign as shown at the top part of Fig. 4. The determined effective surface is $S_{eq} = 0.084$ m² which corresponds to a perfectly oriented metallic square mirror of 0.29 m side length. This value is compatible with the dimension of the actual objects at this position. The value of $S_{lim} = 0.23$ m² means that any perfectly conducting area above 0.48 m would not increase the received power. Those data are presented in top of Fig. 4. Notice that the excess-loss reflects both the color-scale and the size of the marker.

The relative strongest scatterer for the link BS-MS5 comes from a small metallic sign-board which is tangent to the constant delay ellipsoid. The determined effective surface is $S_{eq} = 0.118$ m² corresponding to a square of side 0.34 m. The length is close to the approximate dimension of the metallic sign-board in the environment as shown in bottom of Fig. 4.

To present a general view from the whole dataset, Fig.5 presents box plots of the scatterers reflectivity $-l_{msb}$. The choice has been made to organize the horizontal distribution w.r.t each link LOS distance. A linear regression applied to the median and the minimum value makes visible the linear dependency between scatterers reflectivity and the link distance. At short distance the distribution of scatterers reflectivity is broad, while as the distance increases this distribution is getting narrow as

Fig. 4: Back-projection method applied to the link BS-MS3 (top) and BS-MS5 (bottom): the figure shows a scatter-plot of $-l_{msb}$ the opposite of scatterers excess-loss to the free-space. For the most important relative scatterer on each figure, its constant delay ellipsoid (in blue) and the corresponding picture of its region are superimposed for facilitating the physical interpretation. Numbers correspond to the scatterers reflectivity order.

low reflectivity scatterers become no longer detectable.

Fig. 5: Box plots of $-l_{msb}$ for the 13 measured LOS links organized w.r.t LOS distance. The link index is indicated in the bottom axis while the distance is indicated on the top axis. A regression plot for the median and minimum values has been superimposed to emphasise the observed linear trend. Medians and outliers are in red. The 2 studied reflectors of links MS3 and MS5 have been distinguished.

VI. CONCLUSION

Since cellular mm-wave technology can be considered as a site-specific technology, the local context in terms of scatterers is going to be different from one place to another and will likely require large adaptivity from the network and the mobile.

In this paper, we proposed a method to illustrate the effect of the scatterers and we presented results applied to data gathered from an experimental trial conducted in an UMi scenario in the city of Espoo at 32 GHz. The method relies on a single bounce assumption which is well justified by the identified scatterers positions. The assessment of the estimated position of the scatterers allows to recover also their radar cross-section and equivalent area. A linear dependency between the scatterers reflectivity with the LOS distance has been observed, showing how the mm-wave channel is getting sparser as the link distance increases. The proposed method shows that the energy in the UMi environment comes as expected from the walls and windows buildings and ground reflection. Furthermore, urban furniture in the environment such as publicity-board, sign-board and lamp-post were found to deliver non-negligible energy. Such flat metallic planar surfaces from the urban furnitures, if opportunistically exploited, could be used in a dense deployment of 5G mm-wave in small cells as relays to extend the coverage.

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