Millimeter-Wave Small-Cell Deployment Scenarios as an Enabler for 5G Applications and Use Cases

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Abstract—The millimeter-wave band is a much discussed candidate as additional access technology of the fifth generation of mobile radio networks (5G). This paper gives a background on the fundamentals of mm-wave propagation and then investigates a set of reference scenarios, where the new bands will enable new applications and use cases.

Index Terms—millimeter-wave, 5G, reference scenarios

I. INTRODUCTION

The ever growing mobile traffic demand is one of the major drivers of the current discussion on the next (fifth) generation of mobile radio networks, often called 5G. Spectrum extension in the form of utilizing previously unused frequency bands is one of the proposed solutions for this [1]. During the recent years there has been increasing interest and research on the bands above 6 GHz for wireless communication.

In this paper we give an overview over the fundamental properties of millimeter-wave bands and their relation to a set of relevant scenarios that have been identified for possible 5G deployments. A variety of use cases building on these and similar scenarios is part of the current 5G discussion [2].

II. MILLIMETER-WAVE BAND FUNDAMENTALS

Radio wave propagation is affected by diverse physical mechanisms. To what extend each mechanism contributes to the overall signal attenuation and distortion highly depends on the scenario and radio frequency. Millimeter-wave mobile communication will take place at frequencies far above the classical bands – a fact which necessitates a closer look at the principles of propagation.

The free-space path loss scales with the square of link distance and carrier frequency. Hence a signal at 60 GHz undergoes an almost 36 dB higher attenuation on the same way to the receiver compared to a signal at 1 GHz. Atmospheric effects mainly involve oxygen absorption (peak at 60 GHz) and water vapor absorption (peak at 183 GHz) as well as fog and precipitation. They scale exponentially with the link distance. They become relevant for millimeter-wave links exceeding 100 m and crucial for longer distances

like 1 km. Furthermore, penetration losses drastically increase with frequency. Whereas up to several GHz, it is possible to achieve good coverage inside buildings from a base station outside, solid walls are practically impenetrable for millimeter-waves.

The frequency dependence of reflections, which are the main reason for multipath propagation, is mainly related to surface roughness. The roughness of typical exterior building materials only moderately affects propagation in the lower GHz range. However, in the millimeter-wave band it may decide between receiving a beneficial near-specular reflection path and none at all. Diffraction effects decrease rapidly as frequency increases. In the millimeter-wave band they are typically only relevant if the size of the obstacle is quite small like in the order of tens of cm. As a result even human body shadowing can cause severe losses exceeding 30 dB [3].

Recently, characterization of millimeter-wave outdoor channels has been emerging as important research topic [4], [5]. The most important finding of previous studies is that multipath propagation is an issue for outdoor scenarios as it is for indoor propagation. Buildings, the ground, cars and also small objects like trash cans or signs act as reflectors. Measurements consistently confirm that the path loss exponent is close to two for LOS propagation.

Though mainly LOS scenarios are focused for millimeter-wave mobile communication, the presence of specular reflections with significant power in relation with highly directional steerable antennas also motivates the investigation of millimeter-wave usage under obstructed LOS (OLOS) or NLOS conditions. NLOS path loss behavior was found to be similar to that at lower frequencies, but keeping in mind that the results are related to much smaller cell sizes [6].

Within the framework of the MiWEBA project a quasi-deterministic channel model was proposed, that was developed based on channel measurements in several urban environments [7], [8].

III. REFERENCE SCENARIOS & USE CASES

A total of five reference scenarios has been defined in the MiWEBA project. Each scenario features specific requirements and properties that are related to

possible use cases, as well as the physical limits of mm-wave communication.

A. Indoor coverage scenarios

1) Isolated rooms: This scenario consists of a single room, possibly large, covered with traditional cellular technologies (LTE, LTE-A) small cells or WiFi, and a number (depending on size) of mm-wave nano-cells providing full coverage of the space (Figure 1). The typical situation described by this scenario is an exhibition hall, an office open space, a garage or a production workshop, where devices can be user equipment or machines.
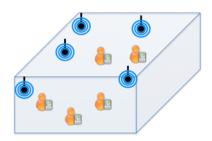

Figure 1. Isolated room scenario

Mm-wave small-cells are used to improve the indoor coverage of traditional cellular technology. The focus of the mm-wave small-cells is on coverage, therefore small-cell planning and beamforming optimization must be carried out in order to provide coverage to places where devices are expected to stay, using LOS and NLOS transmissions. Low interference among small-cells is expected, cooperative transmissions or advanced antenna systems could be used to cover the area reducing the number of deployed small-cells. The separated control plane facilitates user mobility within the room, small-cells can be placed in fixed points with presence of users, while traditional cellular technology can be used as fallback during mobility. The scenario has limited mobility, no stringent timing or very smart algorithm should be provided.

2) Large public areas: This scenario consists in an area of multiple open spaces and rooms covered with traditional cellular technologies (LTE, LTE-A) small cells or WiFi, and a large number of mm-wave nano-cells providing full coverage of the space (Figure 2). The typical situations described by this scenario are malls, shopping centers, sport facilities, airports, stations, undergrounds, etc.

Mm-wave small-cells are used to increase the capacity and limit interference strategies. Cooperative small-cell transmissions and coordination with traditional cellular base station could help in covering difficult areas. Small-cell placement optimization is required to provide high-capacity to the whole area, cooperative beamforming and interference coordination optimization must be used as well. Small-cells are characterized by very high rates and high interference, we have typically LOS transmissions. The separated control plane facilitates user mobility within the whole area.
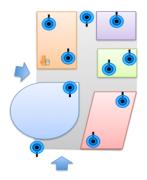

Figure 2. Public indoor area scenario

Traditional cellular technologies should be seldom used because of limited capacity.

B. Outdoor coverage scenarios

1) High-rate hot-spots: This scenario consists in a mobile network of traditional LTE/LTE-A base stations which are in charge of providing full coverage through macro/micro cells. Additionally, a number of mm-waves isolated hot-spots are placed within the urban area such as parking lots or far away from the center in emergency refuge on a motorway. Those mm-waves hot-spots cover just tens of meters with a very high transmission rate. The scenario is illustrated by means of Figure 3.
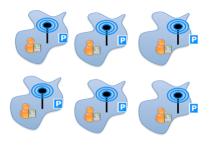

Figure 3. High-rate hot-spots scenario

Mm-wave small-cells can be used to provide coverage in locations where the coverage of the traditional cellular network is not available by providing a point of presence or they can be used to provide very high capacity in localized spaces within the coverage of the traditional cellular network. Since very short distance is required as well as no obstacles are permitted between the hot-spot and mobile users, a smart positioning of the mm-waves hot-spots in optimal places which can be easily reached by the majority of users passing over there. No mobility issues in the Mm-wave hot-spot are expected to occur. The separated control plane and the rich context-information can guide mobile user to find these hot-spots and reducing channel acquisition time.

2) High-rate areas: This scenario consists in a new generation mixed mobile network in an urban environment including traditional LTE/LTE-A base stations and a small number of mm-waves small-cells which provide almost full coverage in the area, as depicted

in Figure 4. Since each mm-wave small-cell covers small portions of area, a set of mm-waves small-cells is placed in order to cover a broader area. The mm-waves small-cells can perfectly work with the traditional set of LTE/LTE-A base stations without interfering each others, as different carrier frequencies are involved.
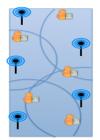

Figure 4. High-rate areas scenario

This scenario requires larger areas to be covered. We expect a lower small-cell density than in indoor scenarios, therefore a limited number of mm-waves small-cells may interfere each other. A limited cooperation amongst mm-waves small-cells is required for mitigating interference, such as basic algorithms for interference alignment. LOS and NLOS transmissions are expected to occur, full use of advanced antenna and cooperation techniques to provide high capacity, however large scale antenna systems cannot be used due to the small number of involved small-cells. The mobility management through the separated control plane is another issue to be addressed, however users are expected to have limited mobility. The context management decreases data channel acquisition time and can be used for mobility prediction in order to facilitate the handover management.

3) Larger areas: This scenario consists in a new generation mixed mobile network in an urban environment including traditional LTE/LTE-A base stations and a huge number of mm-waves small-cells which provide almost full coverage in the area. The considered area is large. Since each mm-waves small-cell covers small portions of area, a large set of mm-waves small-cells is involved. As shown in Figure 5, different mm-waves small-cells work together in order to cover the same area and improve the efficiency. The mm-waves small-cells can perfectly work with the traditional set of LTE/LTE-A base stations without interfering each others, as different carrier frequencies are involved.

The scenario is characterized by many and densely deployed small-cells that interfere each other. Therefore, the highest cooperation amongst mm-waves small-cells is required, such as CoMP techniques by performing a coordinated scheduling. Moreover, in some case different small-cells may provide the same traffic to the same user using large-scale antenna systems. In that case, Joint Transmission (CoMP-JT) techniques are required in order to exploiting the cooperation between different small-cells. Small-cell
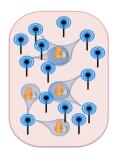

Figure 5. Larger areas scenario

placement optimization is required to provide high-capacity to the whole area, cooperative beamforming and interference coordination optimization must be used as well. The mobility management through the separated control plane is another issue to be addressed; users are expected to have very high and differentiated mobility. The separated control plane together with native mm-wave techniques should be used to design a sophisticated mobility management. The context management decreases data channel acquisition time and can be used for mobility prediction in order to facilitate the handover management. The traditional definition of static cell may be no longer adequate, the dynamic cell structuring can be implemented to match the characteristics of the scenario. Virtual cells can be created (and released) on-demand to serve specific users by means of the cooperation among different small-cells.

IV. Conclusions

In this paper we gave an overview over the fundamentals of mm-wave propagation for 5G access channels. Based on this investigation a set of reference scenarios with their individual specific challenges and properties was presented.

Acknowlegment

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