Simulation and Automatic Planning of 300 GHz Backhaul Links

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Abstract— The IEEE Standard 802.15.3d defines a communication systems allowing wireless solutions for backhaul links operating at 300 GHz with data rates of 100 Gbit/s and beyond. The European Horizon 2020 ThoR project works towards the demonstration of such a solution. One of the goals of ThoR is to develop algorithms for automatic planning of 300 GHz backhaul links and the derivation of planning guidelines. In this paper, an automatic algorithm for the planning of 300 GHz backhaul links using 3D ray tracing taking into account atmospheric effects is presented. The influence of both the applied antennas and the weather conditions are evaluated for an automatically planned network by using a realistic scenario of an ultra-dense network in the city of Hannover.

I. INTRODUCTION

WITH ultra-densification in 5G and beyond 5G networks, mobile base stations with inter-site distances of 350 m and less have to be connected to the core network via backhaul links. At the same time access links at millimetre waves will enable data rates of several Gbit/s per user. Both conditions set high requirements on the backhaul links, which have to provide aggregated data rates for an enormous number of base stations. For base stations without fibre access, wireless backhaul links could be an alternative. Based on the IEEE Standard 802.15.3d [1], wireless solutions for backhaul links operating at 300 GHz enable data rates of 100 Gbit/s and beyond. The Horizon 2020 ThoR project [2] works towards the demonstration of such a solution. One of the goals of this project is to develop algorithms for automatic planning of 300 GHz backhaul links and the derivation of planning guidelines by simulating algorithms in various scenarios.

II. APPROACH

Our approach assumes a group of fibre linked base stations (set A) surrounded by base stations without any backhaul (set B). In order to provide backhauling to the base stations in set B we try to connect these base stations with the base stations on set A via 300 GHz wireless links wherever possible. Our automatic planning algorithm tries to determine the minimum number of additionally required fibre links, connecting all base stations to the core network. This is done by evaluating possible 300 GHz backhaul links, considering the line-of-sight connections between base stations from set A and set B as well as the possible interference between the 300 GHz backhaul links. Radio links are evaluated by using 3D ray optical path loss predictions considering atmospheric weather conditions (rain rate, humidity, air pressure and temperature) according to the models in [3, 4, 5 and 6].

III. AUTOMATIC PLANNING BACKHAUL LINKS

The automatic planning tool considers two factors for determining wireless backhaul links: line-of-sight between two antennas and a minimum safety angle between two adjacent links: In case two base stations are wirelessly linked

to the same fibred base stations, a minimum angle between these links must be fulfilled. This so-called safety angle ensures an interference free radio link. A simple flow diagram of the algorithm is shown in Fig. 1. A star topology is used for interconnecting wireless links since it is simplest topology providing reliable performance [7]. First of all, the automatic planning algorithm for 300 GHz backhaul links tries to reduce the number of backhaul requiring base stations in set B by providing wireless backhaul links between set A and B considering the shortest wireless links. It is further assumed, that each base station, which is backhauled with a wireless link has a one-hop-connection to a base station with a fibre backhaul.

Fig. 1. Simplified flow diagram of the automatic planning algorithm of 300 GHz backhaul links

Once every possible wireless link between set A and B has been checked in the 1st stage providing temporary wireless backhaul links, in the following 2nd stage the algorithm attempts to find out the minimum number of required additional fibre backhauls link (set C). This is done by a heuristic search algorithm, which selects base stations for a fibre link backhaul, which have the largest number of potential

wireless links In case of more than one base station having the same number of possible wireless links, one is selected randomly. In the 3rd stage, the safety angle of wireless backhaul links is checked. If base stations cannot be backhauled wirelessly due to the safety angle constraint, an iteration of the 2nd and 3rd stage is done. Once every base station has at least one valid wireless backhaul link or one fibre backhaul link the ultimate wireless links are established between selected fibre backhaul and wireless backhaul required base stations in the 4th stage. Here the shortest wireless link distance is considered. Since the algorithm includes a random selection, 2nd to 4th stages are iterated for providing a variety set of fibre required base stations. Finally, the optimum solution is selected in the 5th stage.

IV. RESULTS

In a first simulation set-up, the algorithm has been applied on the Hannover scenario [8], which includes 3D building data around the central station, commercial promenade, business and residential area. A 50 dBi parabolic reflector antenna is used in order to compensate high path loss at 300 GHz. The simplified applied antenna diagram derived from measured values in [9, 10] is shown in Fig 2.

Fig. 2. Radiation pattern of drafted 50 dBi parabolic reflector antenna used for simulation

For set A we assumed three base stations holding in total seven geographically separated sector antennas. Set B comprises 300 base stations that are part of an ultra-dense network. An exemplary result of automatically planned backhaul links is shown in Fig 3. The resulting signal-to-interference-plus-noise ratio (SINR) for various gain antenna diagrams with clear weather condition is presented in Fig. 4. The radiation patterns of 30 and 40 dBi antenna diagram are formulated from the mathematical model in [11, 12]. In the case of 5 GHz bandwidth, 90.1 % of the backhaul links do not exceeded an SINR of 22 dB using 30 dBi antenna diagram, required to serve the highest modulation and coding scheme defined in [1]. Likewise 5.8 % of the backhaul links with 40 dBi and 0.4 % of the backhaul links with 50 dBi. In case of 50 GHz bandwidth using 40 dBi antenna diagram, 33.4 % of the backhaul links have an SINR less than 22 dB. As it described above, 30 and 40 dBi antennas can limited support the highest modulation and coding scheme. Furthermore, this limitation taking into account the weather condition and the safety reserve is foreseeable to be further severe. Thus, 50 dBi

gain antenna is recommended for further simulation and demonstration of wireless backhaul links given the use cases defined in Thor.

Fig. 3. Automatically planned 300 GHz backhaul links in the Hannover scenario including Base stations with wireless (blue) and fibre (red) backhaul links

Fig. 4. SINR for used 30, 40 and 50 dBi antenna diagram assuming a transmit power of 0 dBm and clear weather condition.

Fig. 5: SINR for clear, bad and extreme weather conditions assuming a transmit power of 0 dBm and an antenna gain of 50 dBi at both ends of the links.

In Fig. 5, the impact of various weather conditions on the resulting SINR in this scenario is presented. The air pressure for each weather condition is set to a standard value of 1013.25 hPa [13]. For the clear weather condition case neither

rain nor cloud and fog are assumed with 15 °C temperature and 7.5 g/m³ standard ground-level surface water vapour density [14]. A rain rate of 50 mm/h together with a cloud and fog water-vapour density of 0.5 g/m³ is defined as bad weather condition resulting in a total attenuation of 31.8 dB/km, which typically leads to a visibility less than 50 m. Likewise, the extreme weather condition case is defined as 50 mm/h rain rate and 37.5 g/m³ water-vapour density (high humidity) with 35 °C temperature resulting in a total attenuation of 51.1 dB/km. As shown in Fig. 5, weather condition has a noticeable impact of SINR of the entire system. In case of a 5 GHz bandwidth, less than 0.6 % of the backhaul links do not exceed an SINR of 22 dB. In case of a bandwidth of 50 GHz this number increases to 1.4 % of the backhaul links.

Table 1: Relationship between pre-defined maximum allowed link distance and resulted mean link distance

allowed link distance [m]	100	150	200	250	300	350
mean link distance [m]	54.1	74.5	78.3	93.8	89.2	105.5

Fig. 6: Algorithm efficiency with the perspective of replacement fibre backhaul links into wireless backhaul

Fig. 6 shows the number of fibred backhaul links as a function of the mean link distance that can be replaced by wireless links using the proposed automatic planning algorithm. Note, that in Fig. 6 the resulting mean wireless links distance is displayed, which is a function of the maximum allowed distance and usually significantly smaller (see Table 1). In this scenario, from 80 to 89 % of all base stations can use wireless backhaul links. The ratio of the wireless backhauls shows a linear relationship on the resulting mean value of wireless links distance.

V. CONCLUSION

An automatic planning algorithm for 300GHz backhaul links and simulation results are presented. The automatic planning algorithm can determine, which newly deployed base stations can use a 300 GHz wireless backhaul and which minimum set of base stations require fibre backhaul links with the automatic planning algorithm, SINR under various circumstances in terms of antenna gains and weather conditions is analysed. It is shown, that a 50 dBi antenna is a

pre-requisite for wireless backhaul links to enable the highest modulation and coding scheme technically supported in IEEE Std. 802.15.3d. Furthermore, the impact of various weather conditions on the SINR is investigated. This revealed, that in the investigated scenario even under extreme weather conditions more than 98% of all links achieve the required SINR for a bandwidth of 50 GHz. By using automatic planning algorithm with given circumstances, it is possible to replace 80 to 89 % of the fibre backhaul links by wireless backhaul links.

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