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On the Comparison of THz X-Haul Links using Generic Rain Cloud Movement

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Abstract

In the future mobile network, the deployment of cell sites is inevitable to support the ever-increasing demand for high data rates and the ubiquitous mobile accessibility of the end-user devices. Connecting wireless X-haul links operating at the 300 GHz instead of cabling with fibres is a promising approach to reduce the overall expenditure for mobile network operators. Rain is one of the most significant factors affecting wave propagation at THz (sub-mm) frequency spectrum. Four different THz X-haul networks are planned using the automatic planning algorithms and the impacts of the spatial and temporal changes of the rain in the given THz X-haul networks are simulated using an in-house developed simulation tool for mobile networks.

1 Introduction

The demand for high data rates from the end-user devices is gradually increasing [1]. For mobile network operators, one of the possible solutions to support this trend is to increase the number of cell sites that cover a relatively shorter range of mobile access to achieve higher spatial spectrum efficiency, known as small cells [2]. Each of the cell sites requires a transmission channel to the core network. The transmission channel encompassing fronthaul, midhaul, and backhaul link is known as X-haul link. Traditionally, the X-haul links are provided by fibre connections. However, it is not cost-effective to connect all newly deployed cell sites with a cable connection and in some cases cabling is not feasible at all. For mobile network operators, one of the promising ways to alleviate the mentioned problems is to provide a wireless connection using THz spectrum instead of fiber, which is a relatively inexpensive and quick method to connect the links supporting high data transmission thanks to the large bandwidths available.

The planning of THz X-haul links is a typical non-deterministic problem. In other words, there is no certain mathematical approach to search for the optimal state. Furthermore, the difficulty of the planning increases gradually as the number of X-haul links (cell sites) increases. This means that planning THz X-haul links of a large number of newly deployed small cells is highly complex thus it may require immense human resources or may not be feasible to complete without any computational aids. Therefore, the authors have developed four automatic planning algorithms [3], [4], [5] and [6] for various network architectures. Each of them efficiently plans the THz X-haul links within a short period of the time in four different network constellations, star LoS (Line-of-Sight), star NLoS (Non-Line-of-Sight), ring LoS, and ring NLoS, respectively.

The wave propagation at the THz (sub-mm) frequency spectrum is susceptible to weather conditions and X-haul links are a typical outdoor application scenario. In particular, rain is one of the factors that has a considerable impact on the wave propagation at THz frequency, thus the quality of the THz X-haul links. In general, rain cloud modelling is based on meteorological monitoring (weather observation). The formation and extinction of rain clouds including size, duration, and intensity are highly sporadic, determined by multi-factorial variables, and vary in time and space. In addition, the size of rain clouds is often greater than a few tens of kilometres, which is excessive compared to the size of affordable simulation scenarios. Consequently, the conventional approach to rain cloud modelling is inappropriate for small-scale simulations to observe the impact of the rain cloud's spatial changes. Therefore, a novel method based on [7] to generate the generic spatial changes of rain clouds is introduced and used to compare the simulation results of the THz X-haul links in different network constellations. This work will provide the fundamental knowledge of the THz X-haul links under the realistic weather condition.

The main focus of this paper is to study the impact of the spatial and temporal variation of the rain cloud on the quality of THz links in different network constellations based on the simulations. The remaining part of the paper is organized as follows: In Section 2, the simulation environment including simulation scenario, the method to generate generic rain cloud movement, and the simulation parameters is discussed. The simulation results including automatic planned THz X-haul network, quality analysis of the THz links under the spatial and temporal variation of the rain cloud are provided in Section 3. A brief conclusion is given in Section 4.

2 Simulation Environment

This section describes the simulation environment including the simulation scenario, generic rain cloud movement, and simulation parameters.

2.1 Simulation Scenario

Figure 1 visualizes the cell deployment scenario in the city center of Berlin modelled in [8], where high data throughput is required due to the high volume of the floating population. In this scenario, 62 macro cell sites (MCSs) are presented in red dots. The position of the MCSs is arbitrarily determined based on the deployment statistics of a mobile network operator. To support the high data throughput of the future mobile network, 176 small cell sites (SCSs) are assumed to be newly installed and arbitrarily positioned in the scenario. Here, it is assumed that 50 % of SCSs are located at the top of the buildings, while the rest of SCSs are positioned at the street level (lamppost site).

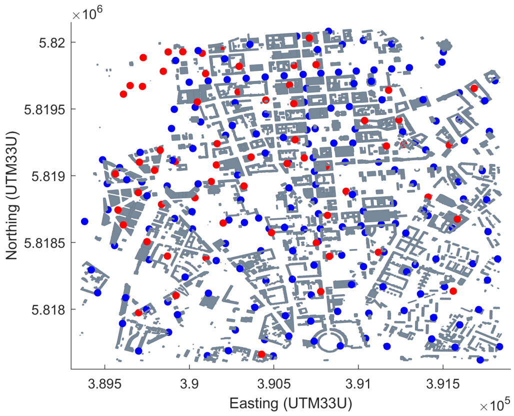

Figure 1. A cell deployment scenario in the city center of Berlin including macro cell sites (red) and small cell sites (blue)

2.2 Generic Rain Cloud Movement

The generation of a generic rain cloud movement starts with calculating the spatial and temporal distribution of the rain cloud exploiting mathematical equations given in [7].

The spatial distribution of the rain rate within the rain cloud shows a negative exponent behavior given in (1).

$$R = R_M \cdot e^{-\frac{\rho}{\rho_0}} \quad (1)$$

where R_M indicates the peak rain rate of the rain cloud in mm/h, ρ is the spatial distance to the rain cloud center in km, and ρ_0 means the equivalent radius of the cell in km.

The temporal change of the peak rain rate within a rain cloud decreases with time modeled in (2).

$$R_M(t) = R_p \cdot e^{-0.024 \cdot R_p^{0.299} \cdot |t|} \quad (2)$$

where $R_M(t)$ temporal change of peak rain rate of the rain cloud and R_p is the maximum value of R_M throughout the rain cloud's life.

One of the findings in [7] is the inverse correlation between the peak rain rate of the rain cloud ($R_M(t)$) and the equivalent radius of the cell (ρ_0) given in (3).

$$k = R_M(t) \cdot \rho_0(t) \quad (3)$$

The change of rain clouds in the spatial and temporal domains can be found considering the mathematical equations above.

Once the generation of the spatial and temporal changes of the rain cloud is completed, the center position of the rain cloud is determined for each timestamp. Based on the information of the center positions and the spatial and temporal changes of the rain cloud, the rain rate of each point in the given scenario can be obtained for each timestamp taking into account random changes to provide the irregular and sporadic change of cloud shape.

The next step is to quantify the values of the rain rates at each point in the scenario obtained in the previous step to assign the integer values that reduce the required effort and time for the simulations. The quantification step can be set to any desired value.

2.3 Simulation Parameters

To study the impact of the rain cloud movement on the THz X-haul links using different networking topologies, three subsequent simulations have been completed in the following order: automatic planning of THz X-haul network, generation of a generic rain cloud model, and ray-tracing simulation of the planned network considering the rain cloud movement.

A total of four automatic planning algorithms have been applied to plan the THz X-Haul links using the parameters given in table 1. Here, the tag S-LoS and S-NLoS are based on the star topology and the difference is that S-LoS considers the LoS condition for the premise of the valid THz links, while S-NLoS allows NLoS links that are reflected by the walls. This is also true for the tag R-LoS and R-NLoS, which are based on the ring topology. All algorithms share the same value of the safety angle (4 degrees) that prevents the high level of interference between two adjacent links caused by the overlapping of the main lobes of the antennas. The maximum link distance for all algorithms is set to 300 m to ensure the sufficient received power of the

Table 1. Parameters for Planning of THz X-haul Network.

Tag	S-LoS	S-NLoS	R-LoS	R-NLoS
Safety angle	4 deg	4 deg	4 deg	4 deg
Link distance	300 m	300 m	300 m	300 m
N of hops	N/A	N/A	6	6
NLoS link	No	Yes	No	Yes

Table 2. Parameters for Generic Rain Cloud Movement.

Parameter	Value
R_p	50 mm/h
t	1 min
ρ_0	1 km
k	20
Cloud step	200 m
Timestamp	30
Quantify value of rain	10 mm/h

signal for wireless communication. For the tag R-LoS and R-NLoS, the number of hops allowed is limited to 6.

To generate the generic rain cloud, the mathematical models given in the previous section are used with the use of the parameters given in table 2. The parameters are adequately chosen for the appropriate size of the generic spatial rain cloud movement within the given simulation scenario to study the effects of its movement on the THz X-Haul links planned in different constellations.

The simulation parameters given in table 3 are used for ray-tracing simulations on the automatically planned THz X-haul links considering the rain cloud movement. Here, a total of 32 transmission channels corresponding to 69,12 GHz (2,16 GHz for one channel) are assumed and an additional 10 dB of the system margin is taken into account.

Table 3. Input Parameters for Ray-tracing Simulations.

Parameter	Value
Tx Power	0 dBm
Tx and Rx antenna gain	48.5 dBi
Carrier frequency	300 GHz
Temperature	290 K
Number of channels	32
System margin	10 dB

3 Simulation Results

The planning of THz X-haul links is carried out in various network constellations using the parameters given in table 1. For the case of S-LoS [3], a total of 97 SCSs can have their X-haul links over wireless connections. Using S-NLoS [4], a total of 105 SCSs can have their X-haul links wirelessly. In the case of R-LoS [5], 110 SCSs are identified for the potential cell sites whose THz X-haul links can be provided over a wireless connection. Using R-NLoS [6], 108 fiber connections can be replaced by THz X-haul connections. One of the THz X-haul networks automatically planned by S-LoS [3] is exemplarily shown in fig 2.

A total of 45 X-haul links were identified as the common links shared by all the planned THz X-haul networks. An example for the temporal variation of the signal-to-interference-plus-noise-ratio (SINR) of a certain link is given in fig 3. Here to see, a clear structural advantage of

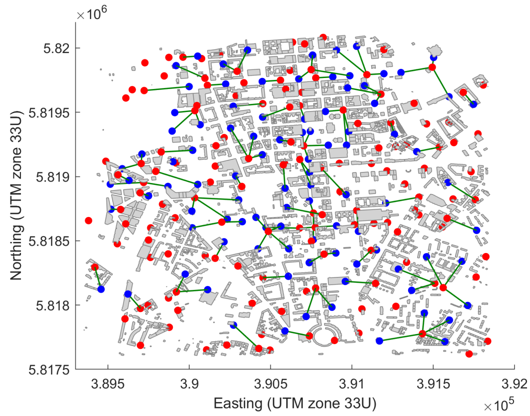

Figure 2. An exemplary result of the automatically planned THz X-haul network using [3].

the THz X-haul network using ring algorithm over the rain cloud movement. As it can be seen at timestamp 16 (red circle), an alternative link of the THz X-haul link using ring topology showed a slightly better SINR than the chosen common link shared by all planned THz X-haul networks. Figure 4 visualizes the THz X-haul links (green lines) and the rain cloud (blue area) demonstrating an apparent explanation for the higher SINR value of the alternative link. The THz X-haul link between cell2 and cell3 is the common link shared by all networks and is partially covered by the rain cloud at the timestamp 16. This results in the degradation of the SINR value of the link and therefore of the data transmission rate. However, in the case of R-LoS and R-NLoS, the THz link between cell1 and cell3 provides an alternative link that is not affected by the rain. Therefore, the alternative link shows the better received power of the signal resulting in a higher SINR value. To extrapolate this result, the structural advantage of the ring network can be more frequently seen when the size of rain cloud is reduced and the size of the cloud step is further decreased. Another clear structural advantage of the THz X-haul network using the ring algorithm is demonstrated in fig 5.

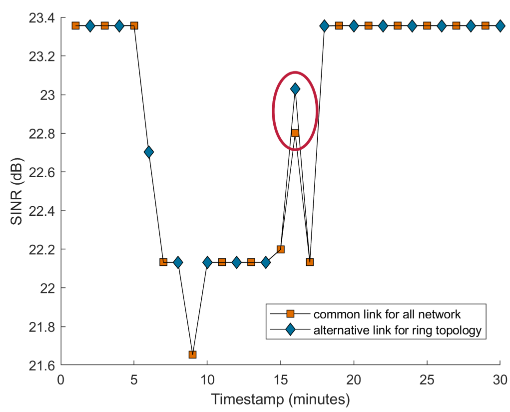

Figure 3. Temporal variation of the SINR value of a THz X-haul link under the generic spatial rain cloud movement.

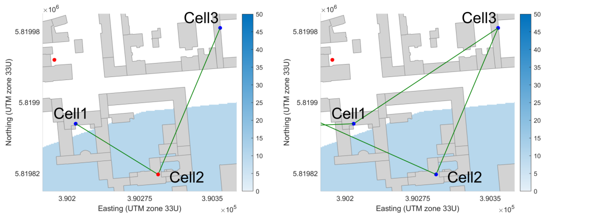

Figure 4. A visualization of the THz X-haul networks planned with S-LoS (left), with R-LoS (right), and rain cloud (blue area) at simulation timestamp 16.

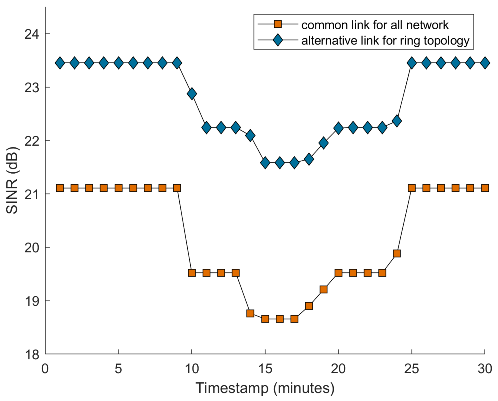

Figure 5. Comparison of the time-varying SINR value of a THz X-Haul link using different planning algorithms.

Here, the alternative link of the ring networks and the common link shared by all networks were covered by the same rain areas at all timestamps, but the alternative link always provides a better SINR than the common link. This is because the link distance of the alternative link is shorter than the common link resulting in a higher received power of the signal and, thus the higher SINR value. The simulation results above show the apparent structural advantages of the THz X-haul links planned in ring topology against the spatial and temporal changes of the rain.

4 Conclusion

In this paper, the performance of the THz X-haul links planned by four different network typologies have been researched considering the generic spatial and temporal rain cloud movement. There were a total of 45 common X-haul links shared by all the planned networks. A clear structural advantage of the THz X-haul links planned by ring algorithm was possible to identify. At one timestamp, a common link shared by all networks showed a slightly worse SINR value than its alternative link provided in the case of ring algorithm. This is because that the common link was partially affected by rain at the given timestamp, while the alternative link was not covered by rain. Besides, in some cases, the alternative links and the common links were covered by the same rain areas. However, the alternative links showed a better SINR value than the corresponding common links due to the fact that the link distance of the alternative links was shorter than the common links. The structural SINR advantages of ring topology based network is more frequently to observe when the temporal resolution of the rain changes is finer and the size of the rain cloud is much smaller. The simulation results apparently grounded in the advantage of the ring topology-based THz X-haul links demonstrating that in certain cases the ring topology based THz X-haul links may be more stable than the star topology based one, as it can provide alternative links that are less affected by the weather conditions.

5 Acknowledgements

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