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Tera**h**ertz end-to-end wireless systems supp**o**rting ultra-high data **R**ate applications

ThoR

Deliverable D2.4
Definition of Scenarios for Demonstration and Simulation

Coordinator (EU): Thomas Kürner
Organisation: Technische Universität Braunschweig

Coordinator (Japan): Tetsuya Kawanishi
Organisation: Waseda University

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Leader in charge of deliverable: Bo Kum Jung
Technische Universität Braunschweig

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Change register

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1. Statement of independence

The work described in this document is genuinely a result of efforts pertaining to the ThoR project. Any external source is properly referenced.

Confirmation by Authors:	Bo Kum Jung	TUBS
	Petr Jurcik	DTAG
	Iulia Dan	UST
	Eisaku Sasaki	NEC
	Thomas Kürner	TUBS

2. Abbreviations

B5G	Beyond 5G
DSLAM	Digital subscriber line access multiplexer
FTTC	Fibre-to-the-cabinet, -curb
FTTB	Fibre-to-the-building, -basement
FFTH	Fibre-to-the-home
FTTP	Fibre-to-the-premises
MFC	Multifunction Cabinets
MCS	Macro-cell site
SCS	Small-cell site
LOS	Line-of-Sight
NLOS	Non-Line-of-Sight
TX	Transmitter
RX	Receiver
HPA	High power solid state amplifier
LO	Local oscillator
PRBS	Pseudo random bits sequences
TWTA	Traveling wave tube amplifier

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3. Executive summary

The Terahertz end-to-end wireless systems supporting ultra-high data Rate applications (ThoR) project offers various pre-defined simulation scenarios for simulation and demonstration in order to unify input environments at each consortium. Furthermore, we provide also other party a reference of scenarios for the purpose of testing different simulation tools respectively approaches.

In this document, six artificial scenarios are defined to cover various network deployments assuming different locations, density of exist base station, density of planed base station, deployed types and population flows. Further, this document concludes on data format for exchange essential data for simulation and demonstration. In addition, the requirements for scenarios at the points of simulation-based, demonstration-based and specific components are also presented in this document.

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4. Purpose of the Scenario Definition

Simulations and experimental demonstrations are a significant part of the ThoR project. In order to carry out these simulations and demonstrations in a well-defined way and to have a reference for the comparison of different approaches both inside and outside the consortium, ThoR has made an effort to define a set-up of basic scenarios for simulation and demonstration.

For the simulation-based studies we are following similar approaches as in other EU projects like IST- MOMENTUM [1], ICT-SEMAFOUR [2] and COST IC1004 [3], where consortium partner Technische Universität Braunschweig (TUBS) has participated and contributed to the dedicated deliverables on scenario definition [4], [5], [6]. The ThoR-Scenarios will be used in the following way:

- Using a well-defined set of networks and environmental data throughout the project. This will avoids lengthy scenario descriptions and explanations in the core deliverables. Since this deliverable is a public one the same holds also for publications, which are based on the ThoR scenarios.
- Algorithms implemented by different ThoR partners can be tested on the same set of data yielding a high degree of comparability. This is especially the case for propagation studies carried out in WP 5
- Some parts of the scenario data[1] will be made publicly available and therefore wills serve as a reference data for other groups outside the ThoR project. This will contribute to the sustainability of the ThoR results.
- Although scenario data including site locations are defined in this deliverable, this does not mean, that during the life-time of the ThoR project these data will not be modified. Since Thor will also work on planning guidelines for 300 GHz backhaul/fronthaul links it is very likely, that slight modification of the data may become necessary. Still the scenarios defined in this deliverable will be the starting point and anchor for these modifications.

For the experimental demonstration-based studies (Required Set-up for the experimental demonstrations), three activities will take place during ThoR project including laboratory stage experiments, operational outdoor testing in live network and software-based demonstration.

- In the laboratory demonstration, an arbitrary waveform generator and offline signal processing (DSP) will be used for generation and transmission of pseudo-data with data rate of at least 100 Gbps over short distance around tens of meters.
- ThoR will show the very first operational demonstration of a THz wireless link of actual user data in a mobile communication network testbed with real-time modems. All technological building blocks developed by ThoR partners will be integrated to demonstrate 300 GHz high performance, outdoor deployable wireless links.
- The software-based demonstration will show the scalability of the ThoR approach targeting full data rate up to 315 Gbps and taking into account the measured characteristics of the hardware developed and used in the project.

[1] Subject to the terms and conditions for the use of the data

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5. Requirements for Scenarios

5.1. Requirements for simulation

The requirements for *the simulation-based studies* are as follows:

1. For the planning and situation of backhaul/fronthaul links the availability of line-of-sight connections or at least “obstructed” line-of-sight connections, where a connection can be established via one reflection in case of non-line-of-sight, is essential. These conditions can be checked by using of ray-based methods. Hence, the simulated scenarios shall contain **3D building data**, which enable the application of ray-based methods including the check for line-of-sight conditions between the antennas.
2. To evaluate algorithms in broad applications a **variety of different scenarios** should be provided. The variety shall be w.r.t. building density, building heights, homogeneity of build-up structures as well as network densities.
3. Since ThoR is an EU-Japan project, at least one scenario shall be set-up in an EU city and one in a city in Japan.
4. ThoR intends to make the results of at least one **scenario publicly available**. The data is needed from at least one city, which enables this by its terms and conditions for the usage of data.

The three following cities have been selected to set-up the scenarios for simulation-based studies there:

- **Hannover**: The selected scenario has already been part of the scenarios defined in FP7-SEMAFOUR and IC 1004 projects [5] [6]. This data has already been available at partner TUBS from the beginning and could be used immediately for the first simulations carried out in ThoR. The results presented in [7] have been generated using this scenario data. However, the terms and conditions of using the 3D building data does not allow to publish the 3D building data outside TUBS.
- **Shinjuku**: This is a Japanese scenario. There are restrictions due to the licensing of 3D building data allowing the usage by partners CIT and TUBS only.
- **Berlin**: The 3D building data is freely available [8] and has the potential to generate publicly available scenario data.

5.1.1. Specific requirements for Berlin scenarios

In order to increase experienced data rates for end customers and satisfy growth volume of data traffic consumed by the 5G and beyond 5G (B5G) use-cases and applications [9], the network operators can move optical fibre network closer and closer to the end customers. The fibre-optic service delivery scenarios can be categorized according to where the fibre terminates as follows.

- Fibre-to-the-cabinet, -curb (FTTC) is scenario where optical fibre cable is terminated inside a street-cabinet within hundreds of meters from the customer premises. The connection over these last hundreds of meter from street-cabinet to the customer promises is delivered via traditional metallic cables (phone lines) or wireless links (e.g. using ThoR radio equipment).
- Fibre-to-the-building, -basement (FTTB) is scenario where optical cable is terminated at the boundary of (multi-dwelling) building. Delivery of the service to the individual customer premise (household) is via non-optical means such as indoor coaxial, power line or twisted-pair cabling, or wireless links (e.g. WiFi).
- Fibre-to-the-home (FTTH) or Fibre-to-the-premises (FTTP) are scenarios where optical cable is terminated in the customer premise. This full end-to-end optical fibre connection can deliver the fastest data rates.
- Fibre-to-the-room (FTTR) is scenario where optical cable is terminated at each room in a building. This is dedicated for hotels or conference centres, however, it could be applied to rooms in houses, as well.

The termination of optical fibres in the buildings (i.e. FTTB) or customer premises (i.e. FTTH or FTTR) provide the fastest data rates for end customers, but these scenarios are often prohibitively expensive, technically difficult or even unfeasible, and too time consuming in EU cities where aerial wiring is not available. The FTTC scenario would achieve the best compromise between the fibre-

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optic deployment cost and achieved data rates, and this scenario is further analysed within simulation study in the city of Berlin. In Japan, the penetration of FTTH is much wider than in EU by using aerial cables, however, the termination of fibres in the rooms (FTTR) would be expensive or unfeasible. The FTTH with Thor THz links would be the best scenario for future high-speed access services.

In the city of Berlin, there the optical fibres are assumed to be presented (terminated) at roof-top macro-cell sites and additionally at so-called Multifunction Cabinets (MFC). The MFC is a street cabinet (see Fig. 1) containing remote/outdoor DSLAM equipment. The MFC can be extended by an additional on-top box, which can contain radio equipment for wireless connection between MFC and end customer premises (Fixed Wireless Access use case) or small-cell sites (Mobile broadband use case). The height of typical MFC is approx. 1.4 meters, so the radio equipment (antenna), which is installed inside on-top box, can be considered at 1.6 meters.

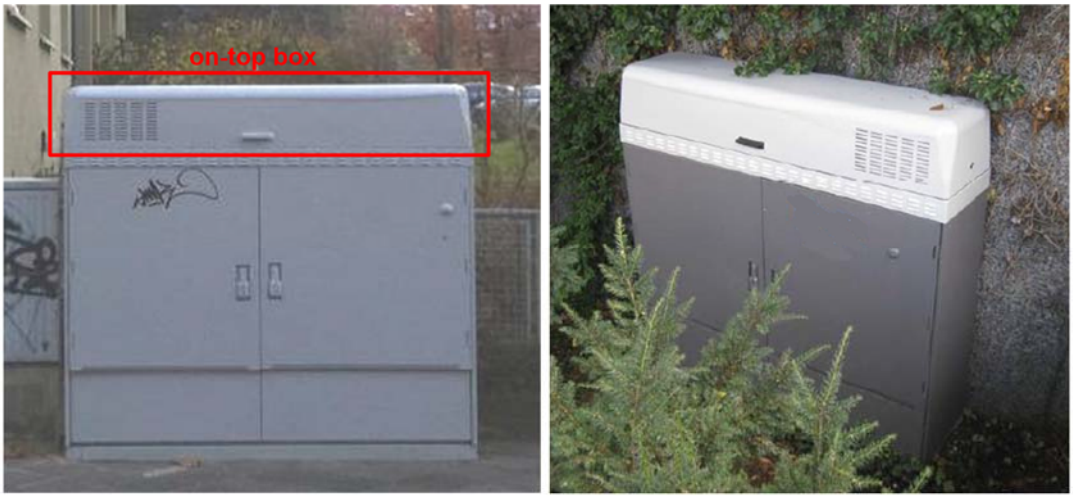

Fig. 1: Examples of typical Multifunction Cabinet with on-top box deployed in Germany

The density of optical fibre termination points (at macro-cell sites and MFCs) significantly varies from country to country and from network operator to network operator, e.g. the deployment of MFC is very dense and the share of fibre-connected macro-cell sites/MFCs is very high in Germany.

The fibre-connected macro-cell sites and MFCs can be used as an (aggregation) end-point for the wireless links towards customer premises (Fixed Wireless Access use case) and small-cell sites (Mobile broadband use case). The radio equipment at the second end-point is considered to be mounted on walls or lamp/utility poles at height ranging from 2.5 meters to 5 meters. Note that the height above 2.5 meters ensures a protection against vandalism; while the height below 5 meters allows the installation and maintenance be done by only one technician using a ladder without any

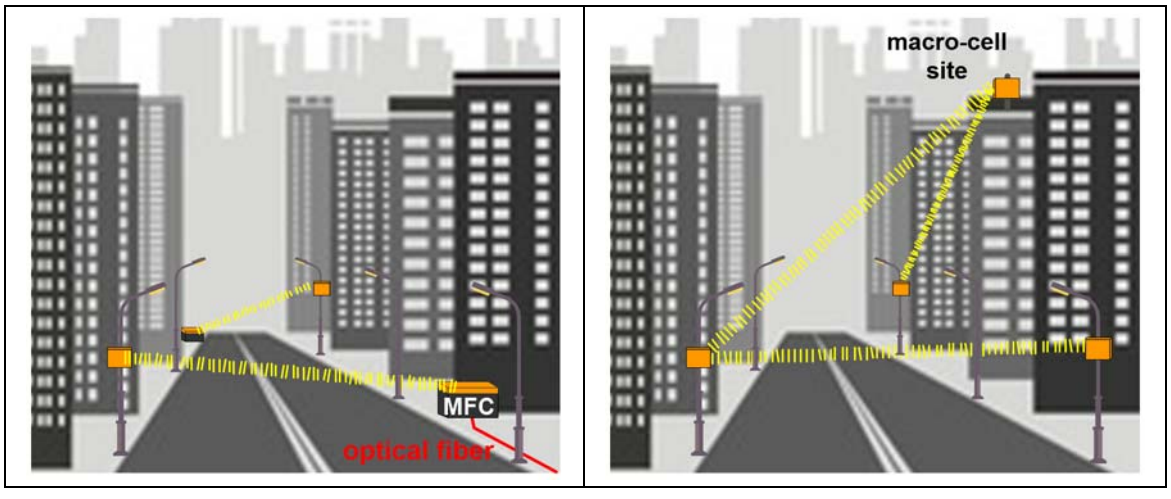

Fig. 2: Street-level (left) and roof-top (right) deployment scenarios of optical fibre termination points, assuming mobile broadband use case.

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climbing gear and training. The height of 4 meters is considered for the simulation study. Note that one or more wireless links (multi-hop) between end-points can exist.

The outdoor installation of radio equipment is usually complex process requiring an approval (license) from the telecommunications regulatory office (e.g. Bundesnetzagentur (BNetzA) in Germany). If the radiated power is below a threshold (e.g. 10 W in Germany), the acquisition of license is not needed, and an announcement to regulatory office is usually sufficient. Note that the threshold as well as whole process is country dependent. All the requirements considered in the simulation study are summarized in **Fehler! Verweisquelle konnte nicht gefunden werden.**.

Table 1: The requirements on installation of radio equipment

Radio equipment mounted	Height above the ground	Maximum TX power (EIRP)
on the wall	4 meters	10 W (= 40dBm)
on lamp/utility pole	4 meters	10 W
inside MFC on-top box	1.6 meters	10 W
at macro-cell site	equal to height of macro-cell site	

5.2. Requirements for lab and experimental demonstrations

The requirements for the lab and experimental *demonstration-based studies* are as follows:

1. The final target of ThoR project is to achieve stable data rate of 100 Gbps, over 1km distance, at 300 GHz band.
2. Considering large propagation loss in the 300 GHz band, high Transmit (TX) power is necessary.
3. ThoR has decided to use a Traveling wave tube amplifier (TWTA) as a High power solid state amplifier (HPA) of 300 GHz TX for the transmission over long distance.
4. The design target or specifications which have been acquired from the prototype evaluation are described in Required Set-up for the experimental demonstrations.

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6. Scenarios for Simulation and Software-base Demonstration

Using of various realistic simulation environments is essential for achieving comparable results at simulation stage. Therefore, total of six scenarios are provided by ThoR-project respectively one scenario in Hannover, four scenarios in Berlin and one scenario in Shinjuku. Five of them are defined for traditional cellular network. These scenarios are designed according to different locations, category of usage-based construction, population and typical density of Macro-cell sites (MCS) and Small-cell sites (SCS). The fifth scenario is designed for demonstrating a relay use-case requiring transmission of high volume of data over long distance. This scenario emulates an international attractive event like Olympic games or Football World Cup, in which the broadcast center may be placed far from the event site.

In the following sub-sections, details of each scenario will be described and a simple overview of all six scenarios is summarized in Table 2. Each scenario represents beyond 5G small-cell deployment use-case. The scenarios are served as an outline to simulate and demonstrate wireless front-backhaul links.

Table 2: Overview of all scenarios

	Location	Category	Dimension	MCS density	SCS density
Hannover Scenario	Hannover	High population density[2]	1 km x 1 km	Low	Ultrahigh
Berlin Scenario 1	Berlin Mitte	High population density	2.5 km x 2.5 km	High	Relative high
Berlin Scenario 2	Berlin Kurfürstendamm	Middle population density[3]	2.5 km x 2.5 km	Middle	Middle
Berlin Scenario 3	Berlin Dahlem	Low population density[4]	5 km x 5 km	Low	Low
Berlin Scenario 4	Berlin Olympic Stadium	Relay case[5]	3.2 km x 2 km	N/A	N/A
Shinjuku Scenario	Shinjuku	High population density	2.1 km x 2.1 km	High	High

6.1. Hannover Scenario

Hannover scenario is designed in the region of 1 km x 1 km in the city centre of Hannover that contains throughput hungry area such as main train station, commercial promenade, business and residential areas. Where the population density is very high during the day and night, as well as the demand of high data rate. Therefore, high SCS density is expected to support high accumulated data flow of user devices.

This scenario is a fully artificial case that the MCS is not based on real data from network operator, but pre-defined data with reliable density and location in the data base at partner TUBS. It delivers an ultra-dense SCS deployment case with density of $300\ \mathrm{SCSs/km^2}$, while the density of MCS is about $3\ \mathrm{MCSs/km^2}$.

[2] High population density represents that this region contains additionally sightseeing attractions or Skyscraper or public transportation centre including middle population flow

[3] Middle population density represents that this region contains working space, commercial street and residential area.

[4] Low population density means that this region is used as residential area.

[5] Relay case is a special data transmission case

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In this scenario, every SCS is positioned $1\ \mathrm{m}$ above the rooftop of the surrounding building. This means, street level deployment of SCS is not assumed in this scenario. The average building height in this region is measured $17.2\ \mathrm{m}$, and the standard deviation of building height is $8.64\mathrm{m}$. The average height of deployed SCS is $22.1\ \mathrm{m}$ with standard deviation of SCS height equals to $7.21\ \mathrm{m}$. Table 3 shows measured parameters of designed scenario. Additionally, MFC is not considered as a part of the scenario.

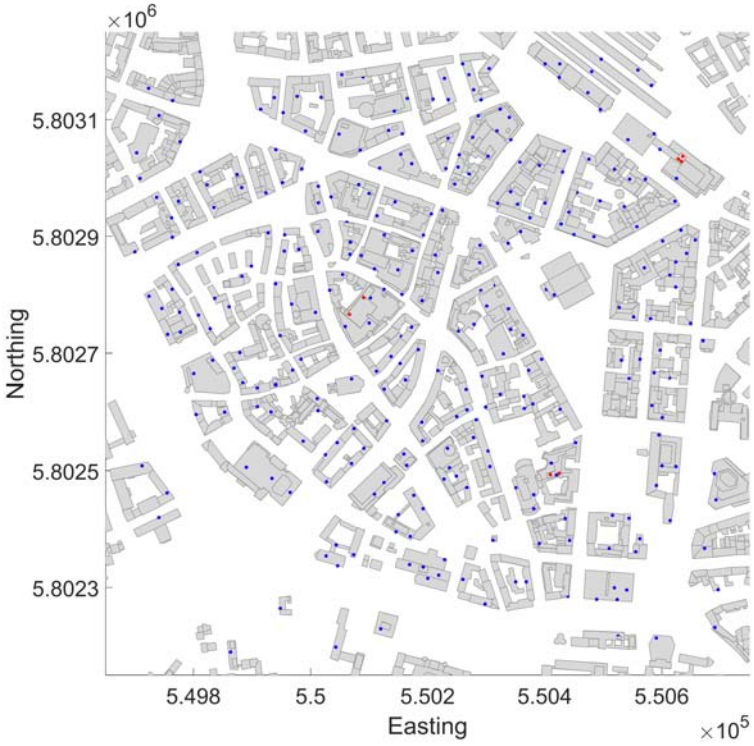

Fig. 3: 2D map of Hannover scenario with marked MCS (red dot) and SCS (blue dot)

An overview of resulted scenario can be seen in Fig. 3, where grey blocks represent building data, red dots represent sector antenna of MCS and blue dots represent SCS locations. Additionally, a part of scenario showing the surroundings of main train station is presented as 3D map in Fig. 4.

Table 3: Parameters of Hannover Scenario

Parameter	Value
$Ø_{\text{building height}}$	~17.2 m
$\sigma_{\text{building height}}$	~8.64 m
$Ø_{\text{SCS height}}$	~22.1 m
$\sigma_{\text{SCS height}}$	~7.21 m
$Ø_{\text{MCS height}}$	34 m
$\sigma_{\text{MCS height}}$	~1.4 m
SCS Density	$300\ \text{SCSs/km}^2$
MCS Density	$3\ \text{MCSs/km}^2$

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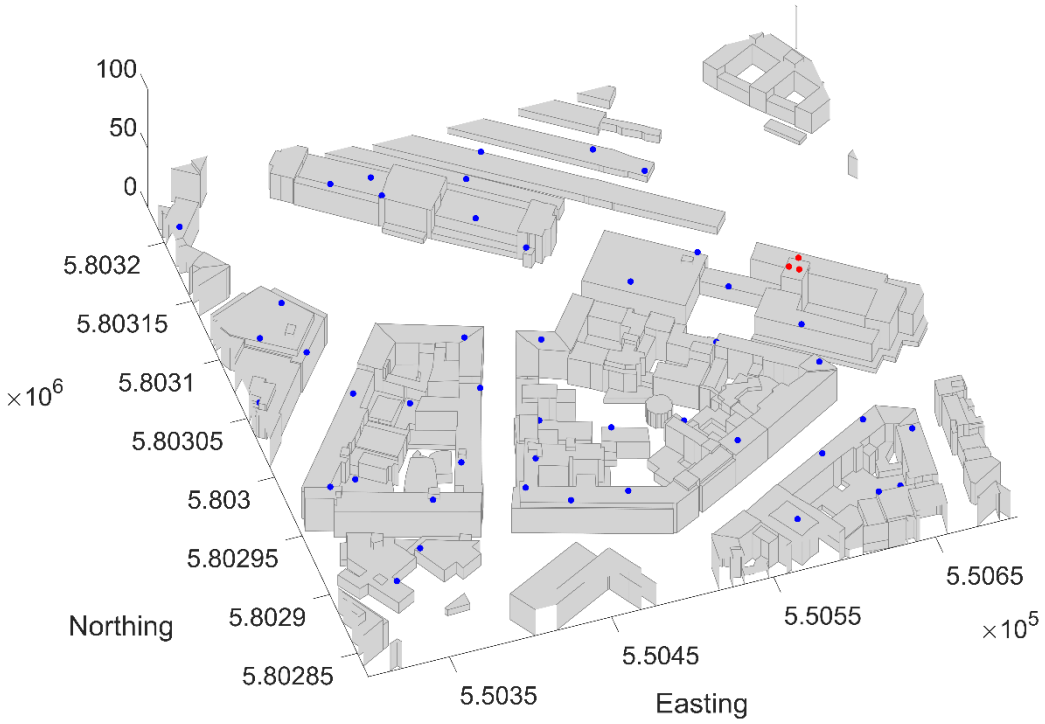

Fig. 4: 3D map of surroundings of main train station in Hannover scenario

By using this scenario, it is expected the characteristics of wireless front/backhaul links in the case of ultra-dense SCS deployment with any MFC and any street level positioned SCS are investigated and served as a reference for real application, where similar parameters can be detected.

6.2. Berlin Scenarios

Four scenarios in the city of Berlin were identified and are shown in Fig. 5. Three of them are typical cellular network cases in Berlin region representing various MCS density and geographical land use case.

The real data of MCS and MFC locations was provided by Deutsche Telecom AG. Since this data is confidential and cannot be published, artificial locations for MCS and MFC are generated based on this real data following the same distribution and density. According to region use cases, SCS density is assumed chronologically around 30, 20 and 10 $\mathrm{SCSs/km^2}$. The 50% of deployed SCS are assumed to be located 1m above the rooftop, while the rest of SCS are located at a height of 4m above the ground either mounted on the external wall of the building or lamp/utility poles, as described in section 5.1.1.

The fourth scenario is additionally offered as a special relay scenario for transporting high volume of data traffic over long distance in order to broadcast popular events such as World cup tournament and Olympic game. Assuming that the broadcasting centre is set up in different location like between Olympic stadium and Berlin-Messe.

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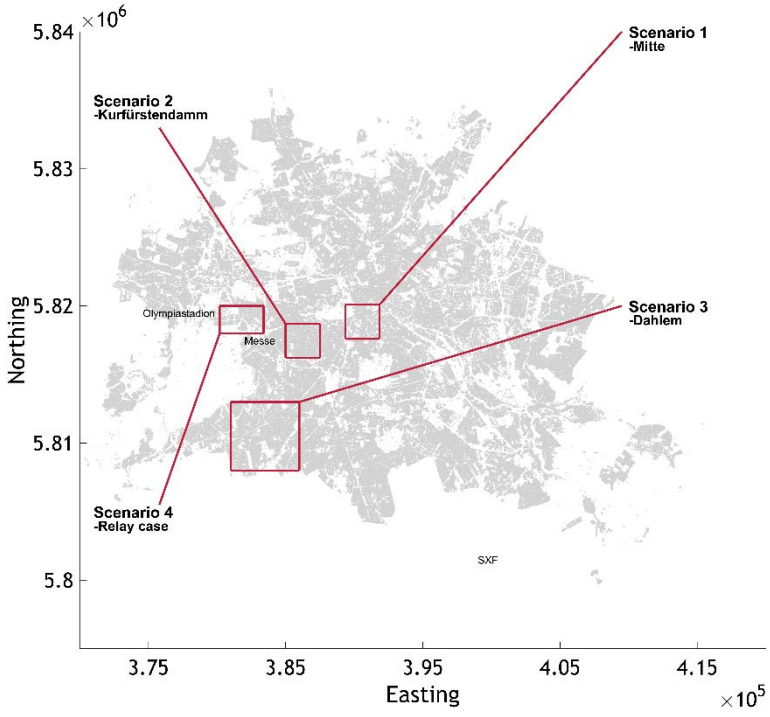

Fig. 5: Overview of all Berlin scenarios

6.2.1. Scenario 1

Scenario 1 includes throughput intensive area like business area, shopping street and sightseeing attractions within 2.5 km x 2.5 km region in the middle of Berlin. Naturally, it is possible to observe the highest density of MCS among Berlin scenarios, namely ~10 $\mathrm{MCSs/km^2}$ with average height of 28 m with standard deviation of 16.7 m. The artificial MCS locations are assumed 3 m above the rooftop at each positioned building. Therefore, also relative high density of SCS is necessary to be realized in 6.2.1Scenario 1 in order to meet the high demand of data traffic.

Fig. 6 shows exact locations of MCS, MFC and SCS in detail. In this scenario, 176 SCSs are considered to be deployed with ~30 $\mathrm{SCSs/km^2}$ density. As it mentioned in section 6.2, half of SCSs (i.e. 88 locations) are selected at street level 4m above the ground in order to provide mobile network coverage at sightseeing locations and streets, where the tourist would be passing by with high probability - for example, a street from Brandenburger Tor to Berliner Dom, which can be observed as blue line in upper side of Fig. 6. The rest 88 SCs are positioned 1 m above the roof top of the building. As a result, average SCS height is 15.5 m in this scenario with standard deviation of 12.7 m. Additionally, MFCs are located in this scenario with desnity of 14.24 $\mathrm{Locations/km^2}$. As an example, 3D overview of a part of Berlin scenario 1 is also presented in Fig. 7 including Brandenburger Tor and Deutscher Bundestag.

This scenario provides realistic simulation results in the centre of megacity in which many pedestrians can be presented due to commercial promenade, business area combined with sightseeing attractions. Especially, it is possible to observe various deployed type of SCS in this scenario, namely above the rooftop, on the wall and lamp/utility pole.

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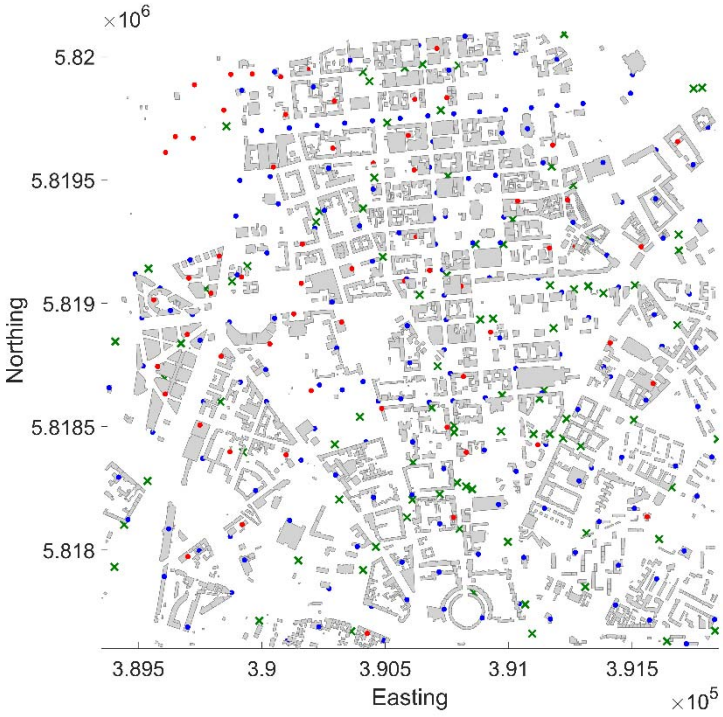

Fig. 6: 2D map of Scenario 1 with marked MCS (red dot), MFC (green cross) and SCS (blue dot)

In the map, the grey blocks represent buildings, red dots represent MCS, blue dots represent SCS and green crosses represent MFC.

Table 4: Parameters of Berlin Scenario 1

Parameter	Value
$Ø_{\text{building height}}$	~26.6 m
$\sigma_{\text{building height}}$	~10.2 m
$Ø_{\text{SCS height}}$	~15.5 m
$\sigma_{\text{SCS height}}$	~12.7 m
$Ø_{\text{MCS height}}$	~28 m
$\sigma_{\text{MCS height}}$	~16.7 m
SCS Density	28.1 SCSs/km^2
MCS Density	9.9 MCSs/km^2
MFC Density	14.24 MFCs/km^2

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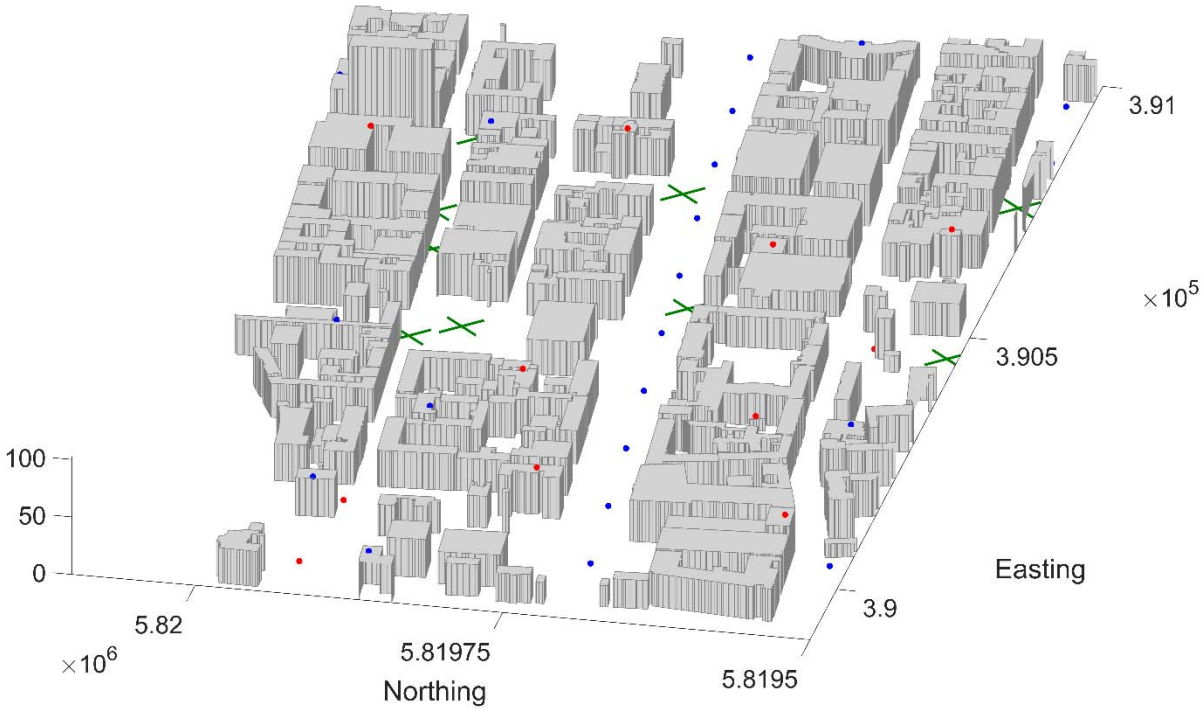

Fig. 7: 3D map of a part of Berlin Scenario 1

6.2.2. Scenario 2

Scenario 2 describes 2.5 km x 2.5 km region of Kurfürstendamm in Berlin which is typical area around city centre where business area, shopping street and residential area are equally combined. Thus, the high volume of data traffic is estimated in this region. The density of MCS in this region refers the middle of Berlin scenarios, namely ~4.16 $\mathrm{MCSs/km^2}$. Accordingly, 120 SCSs are considered to be deployed in this scenario resulting in relative high density of ~20 $\mathrm{SCSs/km^2}$.

Locations of MCS, MFC and SCS are shown in Fig. 8. In addition, a part of this scenario is shown as 3D in Fig. 9. The grey blocks represent buildings, red points represent MCS, blue points represent SCS and green crosses represent MFC. The designed MCS are positioned at around 32 m high in average with ~8 m standard deviation.

As mentioned in section 6.2, 50 % of SCSs (i.e. 60 SCSs in this case) are positioned at a height of 4m (street level deployment), while the rest are positioned 1m above the rooftop of the buildings. In summary, SCs are positioned at average height of 14.6 m with 11.3 m deviation.

This scenario provides realistic simulation environments for surrounding area of centrum in megacity where traffic demands and population density are relative high.

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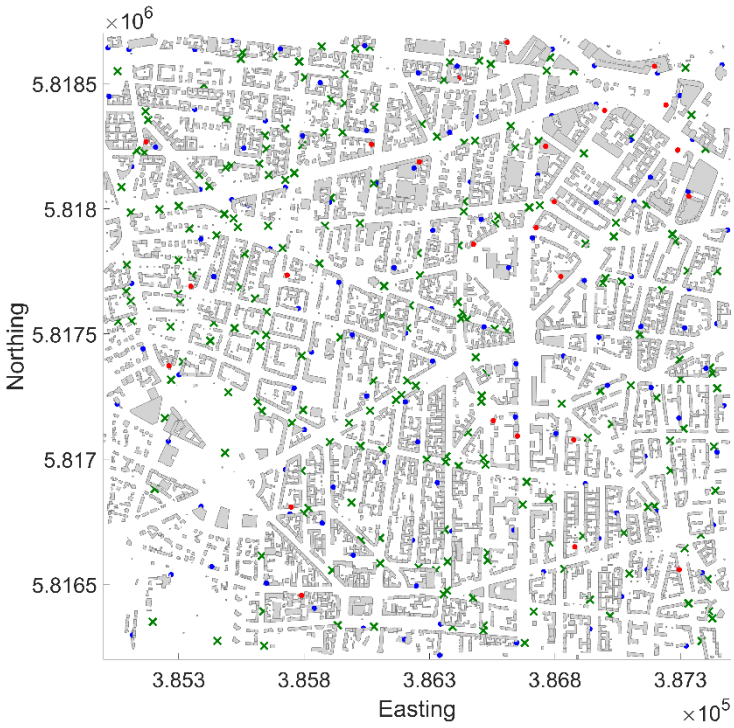

Fig. 8: 2D map of Berlin Scenario 2 with marked MCS (red dot), MFC (green cross) and SCS (blue dot)

Table 5: Parameters of Berlin Scenario 2

Parameter	Value
$Ø_{\text{building height}}$	~23.3 m
$\sigma_{\text{building height}}$	~7.3 m
$Ø_{\text{SCS height}}$	~14.6 m
$\sigma_{\text{SCS height}}$	~11.3 m
$Ø_{\text{MCS height}}$	~31.9 m
$\sigma_{\text{MCS height}}$	~8.2 m
SCS Density	19.2 SCSs/km^2
MCS Density	4.16 MCSs/km^2
MFC Density	34.88 MFCs/km^2

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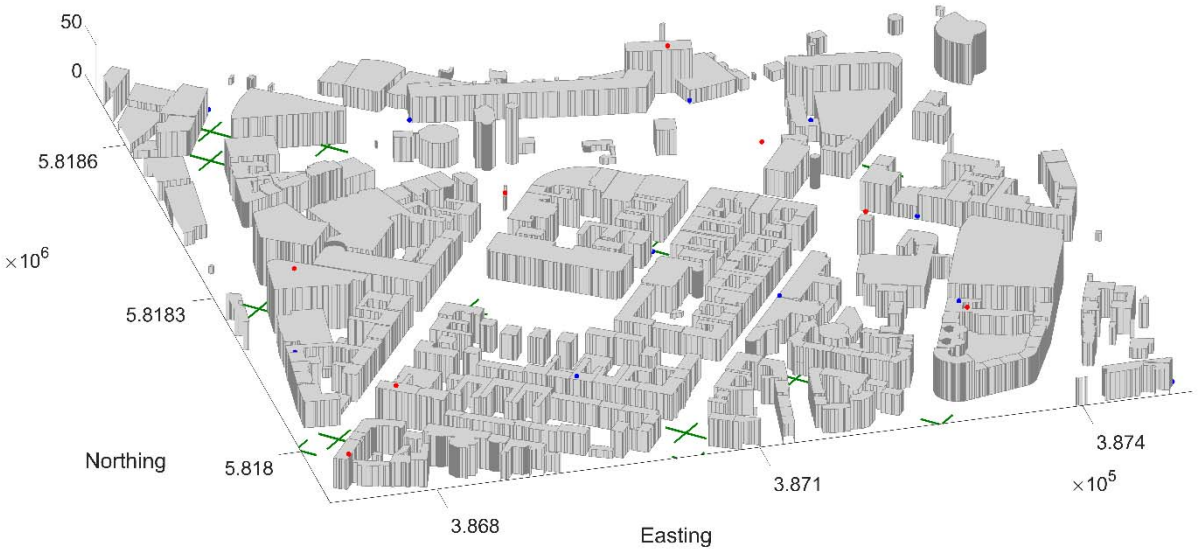

Fig. 9: 3D map of a part of Berlin Scenario 2

6.2.3. Scenario 3

Scenario 3 describes 5 km x 5 km region of Dahlem in Berlin which is typical residential area. The expected volume of data traffic in this region is estimated relative low compared with other scenarios. Therefore, MCS density refers the lowest value respectively ~0.56 $\mathrm{MCSs/km^2}$. Accordingly, 260 SCSs are considered to be deployed in this scenario resulting in low density of ~10 $\mathrm{SCSs/km^2}$.

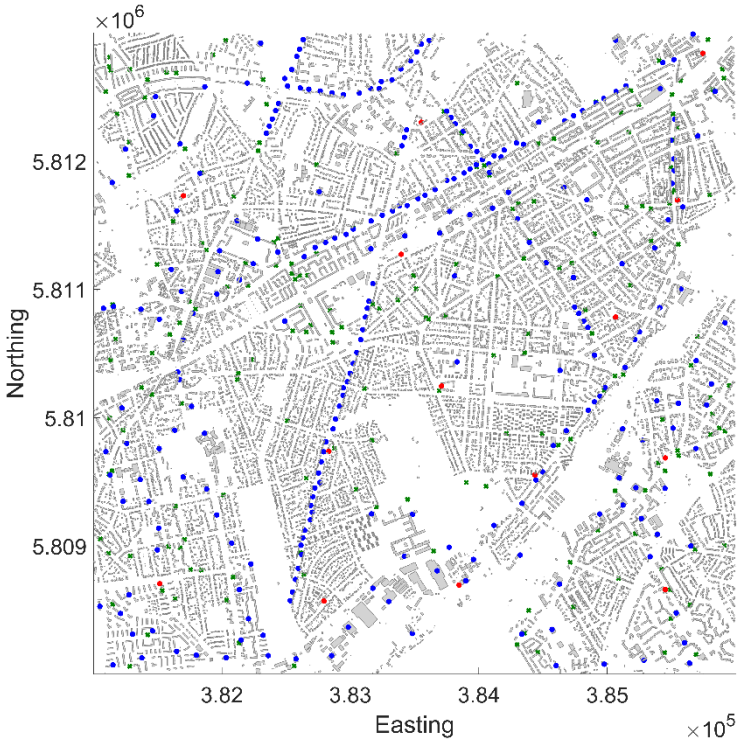

Fig. 10: 2D map of Berlin Scenario 3 with marked MCS (red dot), MFC (green cross) and SCS (blue dot)

The 50 % of SCs are positioned 1 m above the rooftop, while the rest are located at the lamp or utility poles along the streets. Which results, around 12.5 m average SCSs height with 9.1 m deviation. The MCSs are deployed at average height of 27.8 m with 4.4 m deviation. Locations of MCS, MFC and SCS are shown in Fig. 10. The grey blocks represent buildings, red points represent

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MCS, blue points represent SCS and green crosses represent MFC. Additional 3D map of detailed sector of Berlin Scenario 3 is shown in Fig. 11 and Fig. 12.

Table 6: Parameters of Berlin Scenario 3

Parameter	Value
$Ø_{\text{building height}}$	~ 19.6m
$\sigma_{\text{building height}}$	~ 5.4m
$Ø_{\text{SCS height}}$	~ 12.5 m
$\sigma_{\text{SCS height}}$	~ 9.1m
$Ø_{\text{MCS height}}$	~ 27.8m
$\sigma_{\text{MCS height}}$	~ 4.4m
SCS Density	$\sim 10\ \text{SCSs/km}^2$
MCS Density	$0.56\ \text{MCSs/km}^2$
MFC Density	$7.88\ \text{MFCs/km}^2$

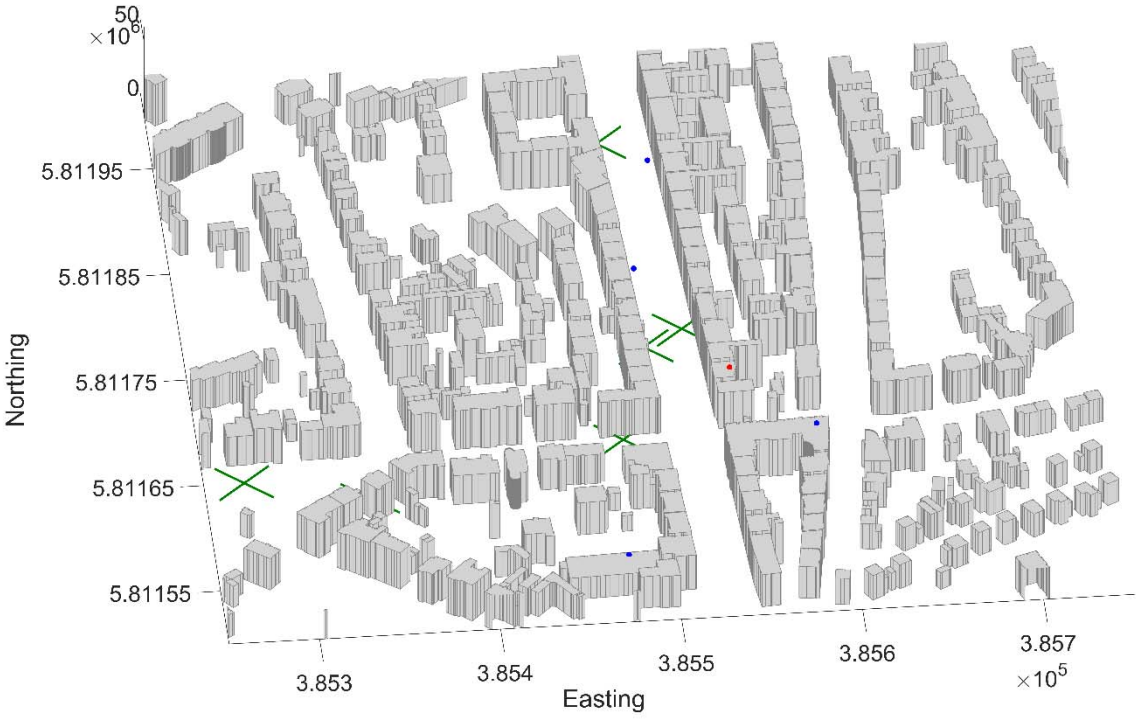

Fig. 11: 3D map of Berlin Scenario 3

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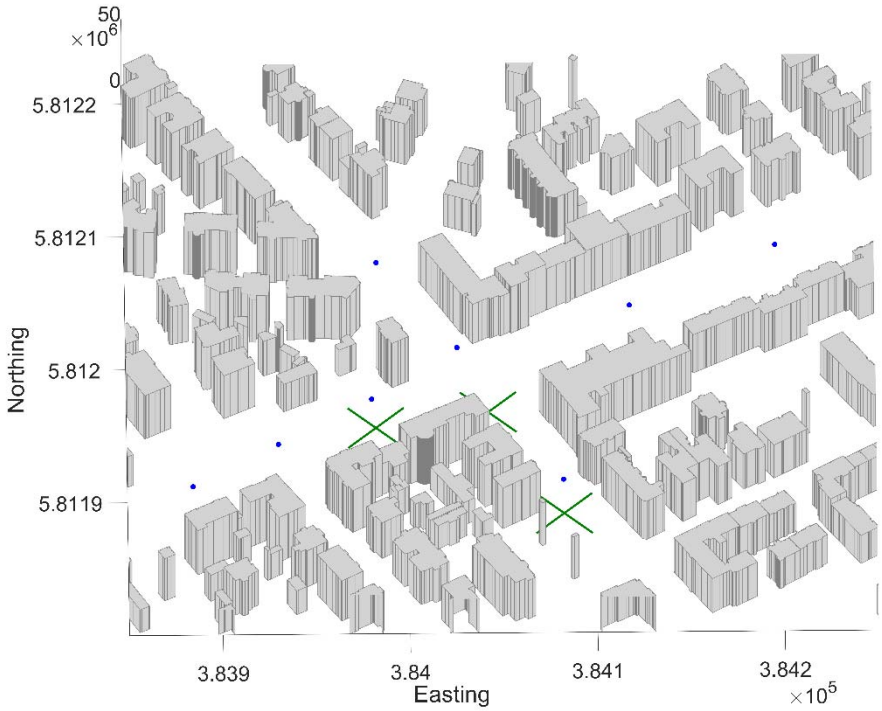

Fig. 12: 3D map of a part of Berlin Scenario 3

6.2.4. Scenario 4

In general, this scenario is a special scenario for demonstration high data traffic wireless channel for broadcasting with separating broadcasting hub and event location can be facilitated using either direct connection or multi-hops depending on required data rate.

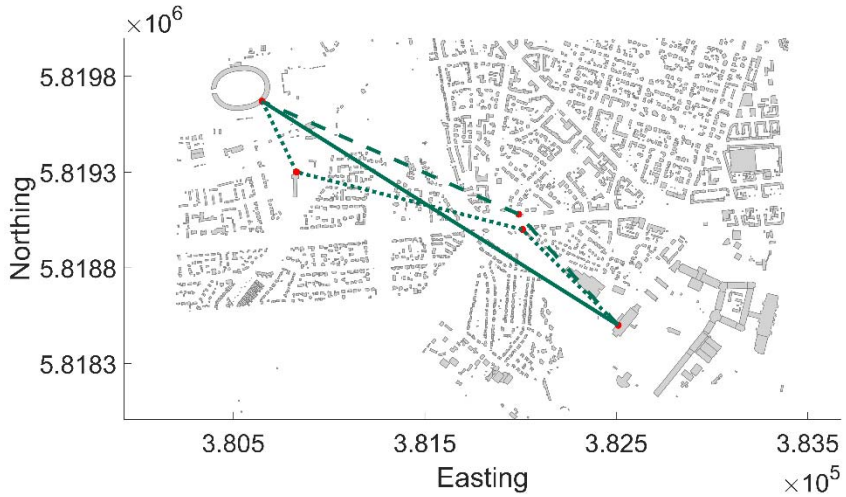

Fig. 13: 2D map of Berlin Scenario 4- special use case

The Scenario 4 is designed for the case of high data transportation between Olympic stadium and Berlin-Messe, where broadcasting centre is arranged in Berlin-Messe using exist glass fibre. In the meantime any cables are available at Olympic stadium even though events are held on the spot. Fig. 13 shows possible rays for connecting wireless channel between two sites, where red points are relay locations and green lines represent designed path for wireless channel, namely direct transmission with solid line, one hop with dashed line and two hops with dotted line. 3D map of Berlin Scenario 4 is also shown in Fig. 14.

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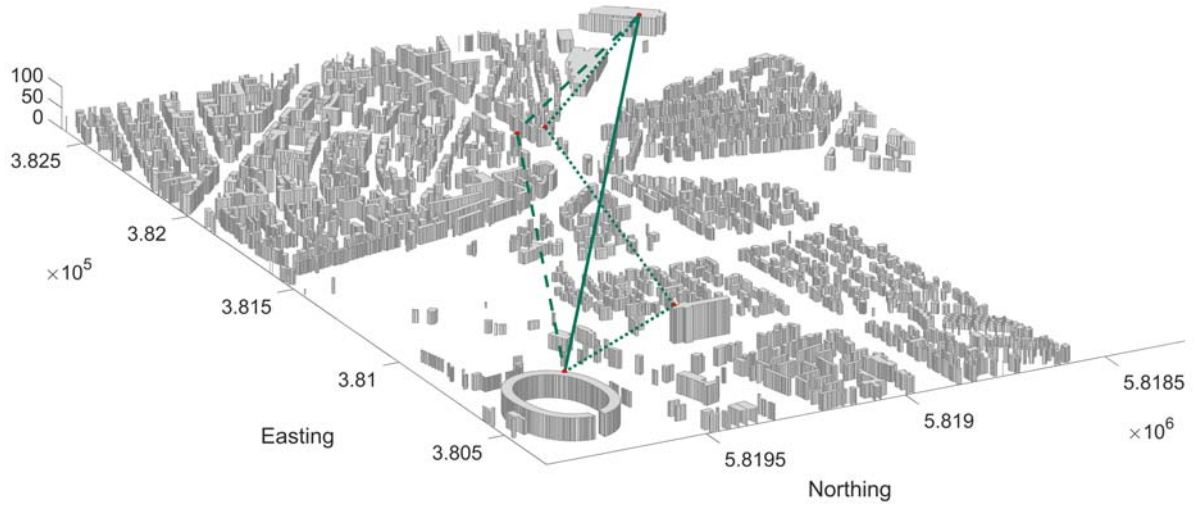

Fig. 14: 3D map of a part of Berlin Scenario 4

6.3. Shinjuku Scenario

As a part of EU-Japan project, we provide also one scenario in Shinjuku, Japan. This scenario contains areas with skyscrapers which can be commonly encountered in megacities such as New York and Shanghai. This scenario is classified as a complete street-level deployment. It means, all SCSs are mounted only at the existing lamp poles at the height of 4 m.

This scenario describes ~2.1 km x 2.1 km centre of Shinjuku in Tokyo where typical skyscrapers are observed in the middle of this region. Nonetheless, due to the majority of low-rise buildings surrounding skyscrapers, relative low level of building height is observed as it notated in Table 7 The MCS density is designed based on real data from Berlin Scenario 1, namely 40 MCSs. In this scenario, 400 SCSs are additionally mounted at lamp or utility poles along the streets. The whole scenario is shown in Fig. 15, and a part of this scenario is shown as 3D map in Fig. 16 where the skyscrapers can be found.

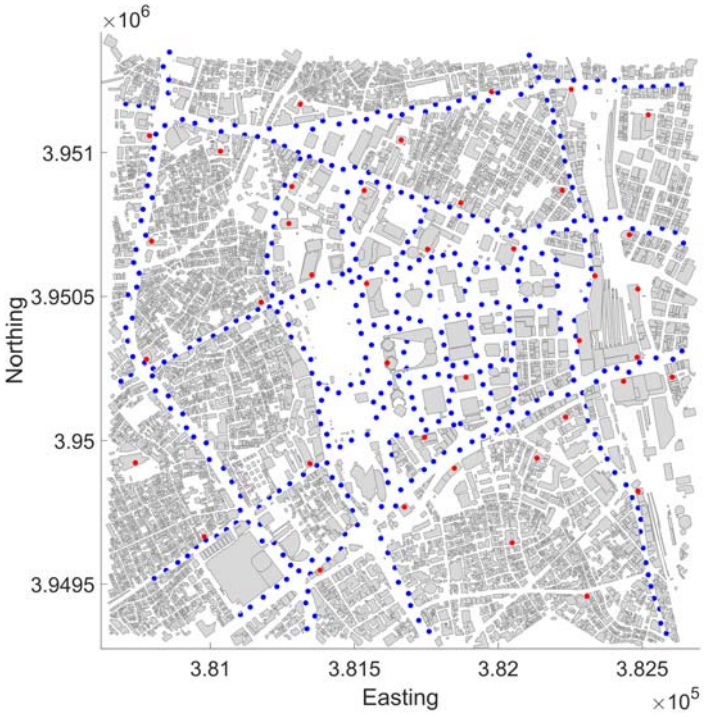

Fig. 15: 2D map of Shinjuku Scenario

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Since SCSs are positioned at a height of 4m at lamp poles, the probability of Line-of-Sight (LOS) between SCS and MCS is relative low due to the blockage by surrounding buildings. Thus, impact of Non-Line-of-Sight (NLOS) rays in particular reflected by external wall are desired to be researched in this scenario.

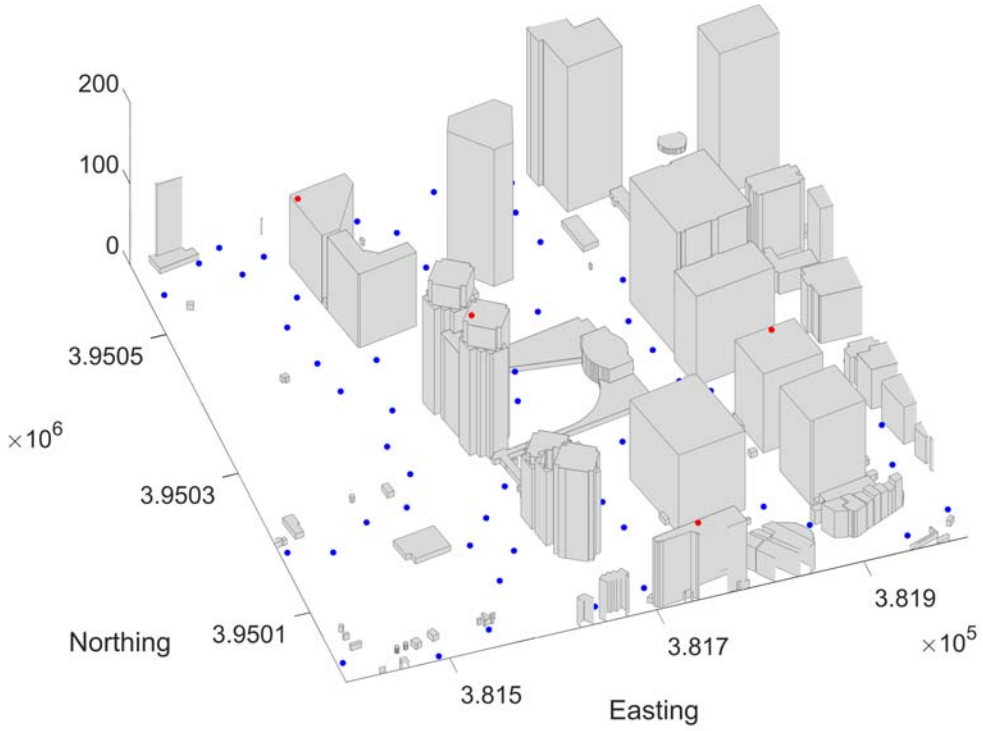

Fig. 16: 3D map of a part of Shinjuku Scenario

Table 7: Parameters of Shinjuku Scenario

Parameter	Value
$Ø_{\text{building height}}$	~12.5 m
$\sigma_{\text{building height}}$	~12.2 m
$Ø_{\text{SCS height}}$	~4 m
$\sigma_{\text{SCS height}}$	~0 m
$Ø_{\text{MCS height}}$	~61.2 m
$\sigma_{\text{MCS height}}$	~37.3 m
SCS Density	$\sim 90\ \text{SCSs/km}^2$
MCS Density	$\sim 9\ \text{MCSs/km}^2$

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7. Definition of Formats for Data Exchange

Sharing the aformentioned six scenarios as a reference is meaningful to crosscheck various simulation methods from different vendors. Therefore, the exchange data formats are defined in this section.

The building data will be distributed in shapefile format (.shp). At least the following three mandatory parameters must be provided: x-coordinates, y-coordinates and height. Out of the mandatory parameters, four additional parameters (such as geometry, bounding box, usage, material of external wall) can be further delivered in order to describe more details. Each single line of Shapefile format represent single building. As a result, an example of delivered Shapefile format can be seen in Table 8.

Table 8: Example of Shapefile format

Geometry	Bounding Box	X-coordinate	Y-coordinate	Material	Usage	Height
'Polygon'	$[x_{\alpha 1}, y_{\beta 1}; x_{\gamma 1}, y_{\delta 1}]$	$[x_1,\ldots, x_n]$	$[y_1,\ldots, y_n]$	'Concrete'	'Hotel'	z_1
'Polygon'	$[x_{\alpha 2}, y_{\beta 2}; x_{\gamma 2}, y_{\delta 2}]$	$[x_1,\ldots, x_m]$	$[y_1,\ldots, y_m]$	'Concrete'	'House'	z_2
'Polygon'	$[x_{\alpha 1}, y_{\beta 1}; x_{\gamma 1}, y_{\delta 1}]$	$[x_1,\ldots, x_j]$	$[y_1,\ldots, y_j]$	'Unknown'	' '	z_2

In the case that additional information are uncertain, field should not be filled with an arbitrary value but rather with 'Unknown' or empty value.

Locations of MCS, SCS and MFC are stored in Matlab data file (.mat). Matlab-file should have to contain fundamental information about x, y-coordinates, height and deployed type. An example of this format is shown in Table 9.

Table 9: Exemplary data format of locations

Type	X-coordinate	Y-coordinate	Height
'Lamp post'	x_1	y_1	z_1
'On the wall'	x_2	y_2	z_2
'Macro'	x_3	y_3	z_3
'MFC'	x_4	y_4	z_4

The data can be exchanged without any limitation. Nevertheless, in order to avoid potential conflict and to compare under the same condition, the aforementioned formats of data should be strictly followed, and original data are not allowed to be modified.

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8. Required Set-up for the experimental demonstrations

ThoR demonstration activities include laboratory stage experiments (refer to as Demo 2) for versatile data rate and modulation format testing, providing valuable scientific insights into the PHY limitations of THz links. In addition, ThoR will show the very first operational demonstration of a THz wireless link of actual user data in a mobile communication network testbed with real-time modems (refer to as Demo 3). The ThoR system concept is scalable to support the full data rate of up to 315 Gbps compliant with the IEEE 802.15.3d standard, which will be shown by software simulation (referred to as Demo 4) taking into account the measured characteristics of the hardware developed and used in the project. The overall concept of demonstrations in ThoR-project is shown in Fig. 17.

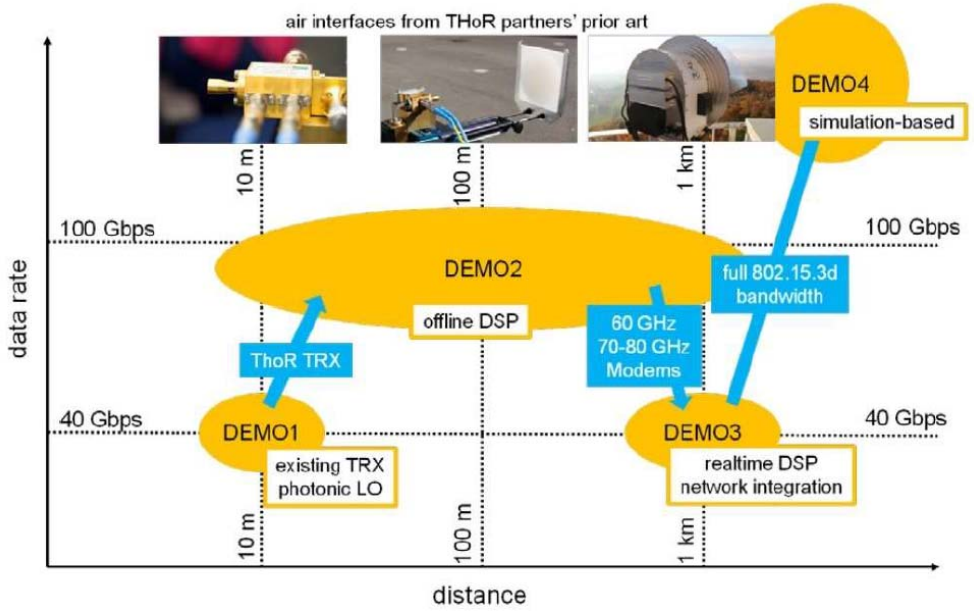

Fig. 17: Demonstration concept of ThoR project

8.1. Laboratory demonstration - Demo 2

The aim of the second demonstration in ThoR is to show the high data rate capability of the proposed terahertz system. For this purpose, the 300 GHz transmitter (TX) and receiver (RX) designed in WP4 will be combined with an existing in-house developed 70 GHz TRX.**Fehler! Verweisquelle konnte nicht gefunden werden.**Fig. 18 shows the schematic of this measurement setup.

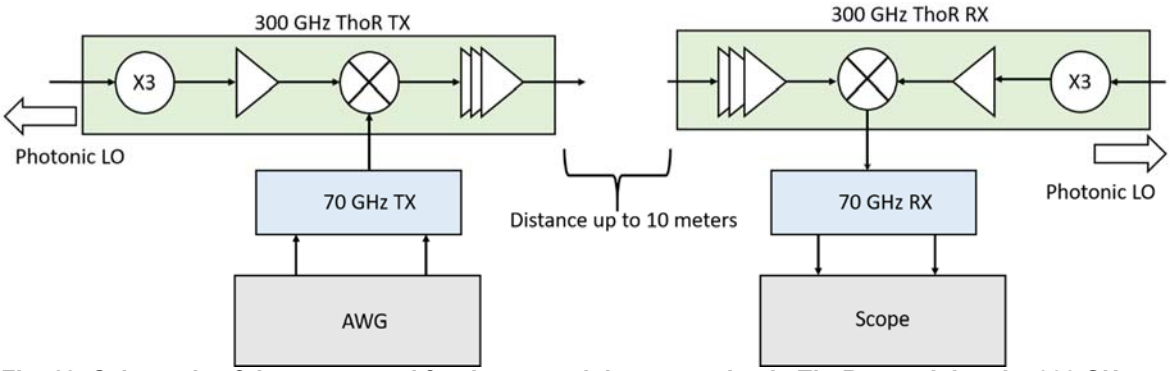

Fig. 18: Schematic of the setup used for the second demonstration in ThoR containing the 300 GHz TX and RX, a 70 GHz system and baseband electronics: an arbitrary waveform generator and oscilloscope

The 300 GHz TX is composed of a frequency multiplier by three, a buffer amplifier, a passive fundamental up-converter mixer and an amplifier stage. All these components are integrated in one chip and packaged in a waveguide based module. A high power solid state amplifier (HPA), packaged in another module can be used for higher transmitting distances. The signal is amplified and concentrated using horn antennas and transmitted over the air in an indoor environment. Therefore, distances up to 10 meters are an appropriate goal. On the receiver side, after a similar

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horn antenna, a low-noise amplifier receives the signal, which will be down-converted in the E-Band, 70-90 GHz. The local oscillator (LO) path is the same as in the transmitter. The LO is provided for both TX and RX photonically and will be developed in WP4. The mechanical interface between the LO and the 300 GHz module is waveguide WR-10. The signals will be generated in an arbitrary waveform generator, using pseudo random bits sequences (PRBS) modulated with different modulation formats, up to 64QAM. The 70 GHz system will up-convert these broadband signals and supply them to the 300 GHz TX. On the receiver side a very fast oscilloscope will demodulate the signals and the post-processing will occur offline using a special software. With these setup high bandwidths, up to 40 GHz, can be used and high data rates can be achieved.

8.2. Operational demonstration - Demo 3

The target of this operation demo is to demonstrate propagation of the 300 GHz signal over a real world propagation path and demonstrate the feasibility of the link installation procedure at these frequencies. A bi-directional end-to-end link at 300 GHz will be integrated into Deutsche Telekom live network targeting up to 40 Gbps over 1 km link distance. The demonstration will be performed over the air in a point-to-point link setup. Bi-directionality is achieved through two parallel ThoR links. Available 60 GHz (V-Band) modems (expecting data rate of 13 Gbps) provided by consortium partner HRCP and 70-80 GHz (E-Band) modems (expecting data rate of 40 Gbps) provided by partner SIKLU will be used for this operational demonstration. Note that real-time data transmission within Demo 3 is limited to 40 Gbps due to the modems and chip-sets currently available to consortium members. Chip-set or modem development is out of ThoR scope, but higher data rates may be tested during the project if chip-set or modem capabilities evolve.

Since Deutsche Telekom as network provider operates in many European countries, the location and detailed setup for Demo 3 have not been decided yet. The location depends on the availability and suitability of macro-cell sites and street lamp/utility poles (emulated by a tripod) for installation of developed hardware prototypes. The other location restriction will result from the acquisition of experimental broadcasting license for transmission over the 300 GHz band. Note that the restrictions (e.g. on transmit power) given by the acquired license would not allow us to reach intended data rate or link distance. The network in Germany or Czech Republic is currently under consideration.

The experimental setup will consist of a 300 GHz band transmitter, receiver, and signal generator and analyzer. The analysis of link coverage and interference scenarios will be evaluated in focus on street-level installation (small-cell) thus being impacted by buildings, vegetation and spatially and temporally dynamic traffic. Since the beam width of the THz high gain antenna is very narrow, the analysis will also include evaluation of the effects of the fluctuation of the beam axis caused by strong wind on the communication quality. The influence of various weather conditions (such as rain, wind and fog) on the stability and performance of the wireless link shall be also studied within this task. Further, the entire system shall be evaluated in order to demonstrate the applicability as fibre-like wireless fronthaul/backhaul links.

8.2.1. Traveling Wave Tube Amplifier

In the 300 GHz band, propagation loss is larger than the microwave bands up to 40GHz (see Fig.19). Especially, rain attenuation (see Fig.20) cannot be ignored when the link distance is long such as 1 km [9]. It is necessary to increase the Tx power against the propagation loss to keep enough received signal level (RSL) at the receiver. A traveling wave tube amplifier (TWTA) is useful for increasing the Tx power.

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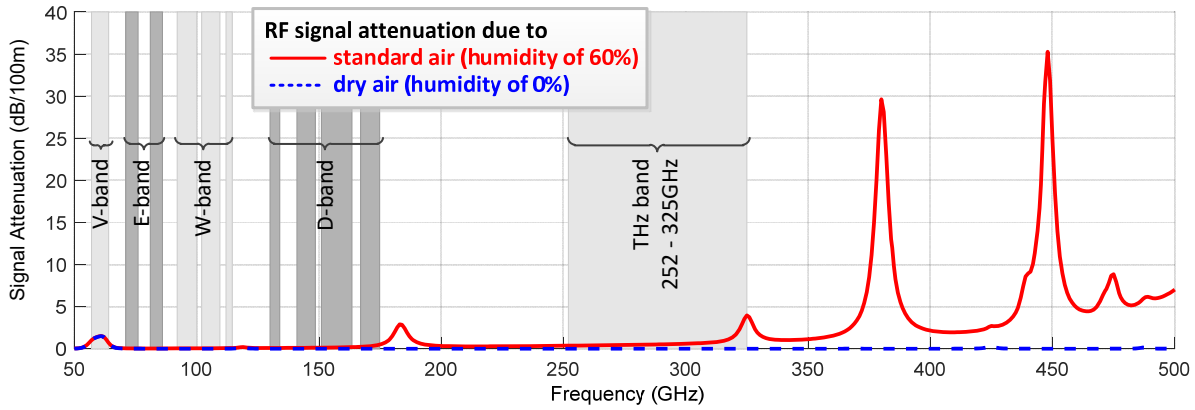

Fig. 19: Frequency-dependent RF signal attenuation due to atmospheric gases (ITU-R Rec. P.676)

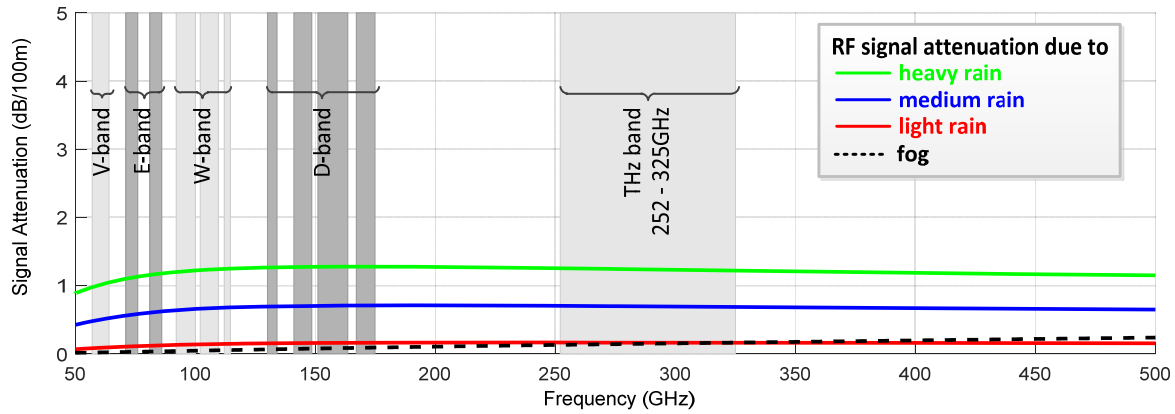

Fig. 20: Frequency-dependent RF signal attenuation due to rain (ITU-R Rec. P.838)

The TWTA will be allocated after the solid state amplifier when the long distance transmission demo (Demo 3) will be conducted. The interface conditions are shown in Table 10: Design Target of TWTA

Table 10: Design Target of TWTA

Item	Target / spec
Input Level	10 mW
Gain	20 dB (at 290 GHz)
Output Level（Saturation）	1W
Effective Bandwidth	5 GHz
I/O Interface (Wave-guide)	WR-3 (same as WR-3.4) : 220 to 330 GHz Inside Dimension : 0.864 mm × 0.432 mm
Expected VSWR for I/O object	< 1.2

The gain will be expected more than 15 dB against the target gain 20 dB. However, the bandwidth is limited. All of the modulated signals which are output of V-band and E-band modems cannot be input into the TWTA. Moreover, the number of TWTA will be one due to yield issue. In this case, only single direction transmission will be available. Special consideration will be required for the Demo 3.

9. Summary and Conclusion

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This deliverable D2.4 outlines the six simulation scenarios. Although they are artificial, the four scenarios in Berlin have been derived based on a statistical analysis of the real network data provided by the mobile network operators Deutsche Telekom. The scenarios in Hannover and Shinjuku are completely artificial. These well-defined scenarios provides reliable simulation and demonstration environments allowing comparison of various - simulation approaches by the consortium members as well as by external parties. With respect to the designed scenarios, the planned and ongoing ThoR tasks for the simulation and demonstration of 300 GHz wireless front/backhaul links will be conducted. Furthermore, this deliverable provides also the overview of foreseen experimental demonstrations.

10. References

[1] [Online]. Available: http://www.zib.de/momentum/data.php.

[2] [Online]. Available: http://www.fp7-semafour.de/.

[3] [Online]. Available: http://www.ic1004.org/.

[4] „IST-MOMENTUM; Deliverable D5.2: Reference Scenarios,“ 2003. [Online]. Available: http://www.zib.de/momentum/paper/momentum-d52.pdf.

[5] „FP7-SEMAFOUR D3.4 - Demonstration scenarios(updated version),“ 2015. [Online]. Available: http://www.fp7-

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semafour.eu/media/cms_page_media/10/SEMAFOUR_(316384)_D3.4_Demonstration_Scenarios_Update_v1.0.pdf.

[6] [Online]. Available: http://www.ifn.ing.tu-bs.de/sim-scenario.

[7] B. K. Jung, N. Dreyer, J. Eckhardt und T. Kürner, „Simulation and Automatic Planning and of 300 GHz Backhaul Links," *IRmmWTHz in Paris,* September 2019.

[8] [Online]. Available: http://daten.berlin.de/tags/3d-stadtmodell.

[9] P. Jurcik, Y. Leiba und R.-P. Braun, „Deliverable 2.1 Requirements for B5G backhaul/fronthaul," 2018.

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