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Executive summary

This deliverable presents the initial simulation demonstrator. First, the concept and the goals of the demonstrator are explained. The presented simulation demonstrator visualises the results from the three simulators from work package five and shows the main benefits of the integration of wireless links into a data centre. For this deliverable a simplified data centre model with a four by four rack structure is introduced as well as the fat tree related logical network topology. The demonstrators input is a comma separated value file containing the data and the results from the simulators. The last part of the report discusses the four scenarios developed for the initial demonstrator. This discussion provides a good overview of the operating principle of the demonstrator.

1 Introduction

1.1 Summary

This deliverable presents the initial simulation demonstrator. Its main goal is to present the results of the simulators from work package five in such a way that people are convinced by the new technology. For the initial simulator a small test data centre with 16 racks was created. Racks are equipped with optical fibre links and four antennas, each radiating in an angular range of 90°. Different key performance indicators can be plotted in a line plot as a function of time or a bar chart for a certain time instant. The data centre model visualises the active fibre and wireless links by coloured cables and rays, respectively. The animated video can be played repetitively or easily be fast-forwarded or rewound. The initial simulation demonstrator comprises four events (link failure, boost operation, interference detection, power failure) that illustrate the advantages of wireless connections in a data centre.

1.2 Structure of this document

This document shows the structure and the functionalities of the initial simulation demonstrator. First, the setup and the topology of the demo data centre are described. Then, the visualisation options and the key performance indicators of the three simulation tools that are developed within TERPOD are presented. After that, one simulation example is processed that illustrates the benefits of wireless links in a data centre. Finally, the goals for the final simulation demonstrator are summarised.

1.3 Relationships with other deliverables

The Initial Simulation Demonstrator presented in this document relates on the following deliverables:

- D5.1 – Initial PHY layer model and simulation. The deliverable explains the basic simulation structure of the physical layer simulator. The initial simulation demonstrator uses results from the physical layer simulation and visualises them.
- D5.3 – Initial DLL model and simulation. This deliverable presents first results from the data link layer simulation. The initial simulation demonstrator visualises some of these results.
- D5.5 – Initial NETWORK-layer and management model. The initial simulation demonstrator presents some results from the network layer simulation.
- D2.1 – Initial Requirements and Scenario Specifications. This deliverable defines the use cases for the integration of wireless links into a data centre network. The test scenarios take the use cases into account.

1.4 Contributors

The following partners have contributed to this deliverable:

- Johannes Eckhardt, TUBS
- Sean Ahearne, Dell EMC
- Noureddine Boujnah, WIT

1.5 Acronyms and abbreviations

CSV – Comma Separated Values

DLL – Data Link Layer

KPI – Key Performance Indicator

NET – Network Layer

PHY – Physical Layer

SiMoNe – Simulator for Mobile Networks

VM – Virtual Machine

2 Setup and Topology

The goal of the simulation demonstrator is to show the feasibility of THz links in the data centre and convince stake holders and third parties of the performance and flexibility benefits of this promising technology. Therefore the most important results and outcomes from the work package five simulators are fed into the demonstrator in order to visualise them and make them tangible.

The main objectives of the simulation demonstrator are:

- To achieve at least the same throughput as fibre
- To reduce the latency by adding wireless connections
- To increase network flexibility by using configurable and adaptable links
- To show the benefits of backup and alternate links that can be utilised through autonomous link management

The scenario in the initial simulation demonstrator is a simplified data centre with 16 racks of type "Unity All Flash" from Dell EMC placed in a four by four topology as shown in Figure 1. This 4 x 4 unit represent a manageable size for the demonstrator that would help demonstrate its full capacity while enabling scalability. Each rack has a width of 0.61 m, a height of 1.9 m and a depth of 1.054 m. The racks in each row are placed next to each other in such a way that they are shifted by 0.61 m. The distance between each row corresponds to 1.574 m. All these values are taken from the Dell EMC Research Data Centre, Cork, Ireland.

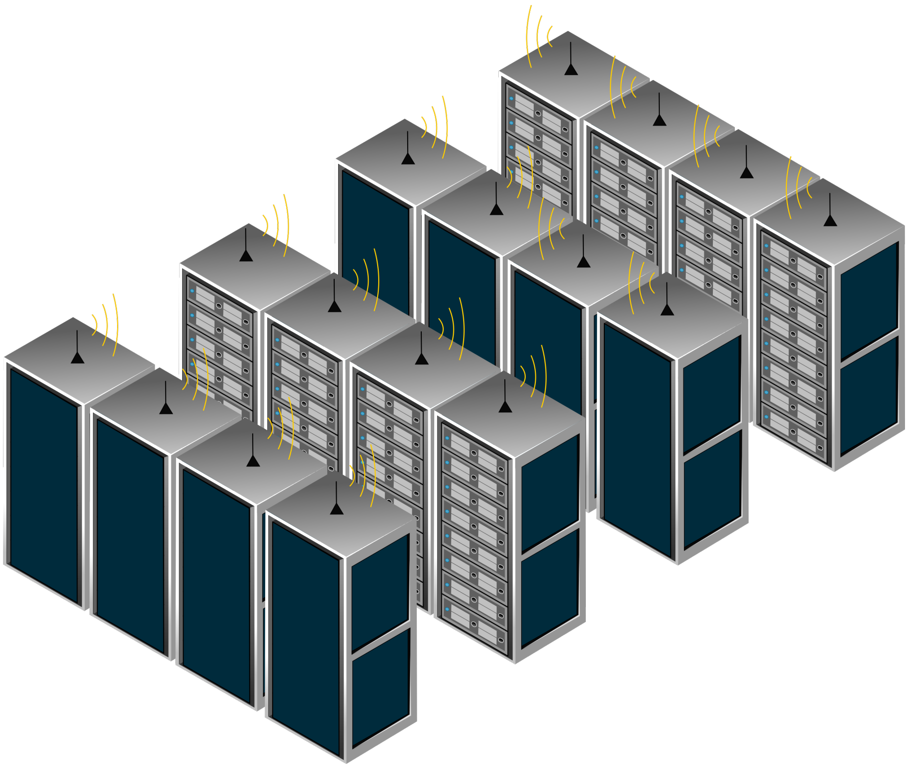

Figure 1: Initial data centre topology

The racks are equipped with a fibre connection and a wireless connection to other racks. All racks of the same row are connected via fibre to an aggregate switch. These aggregates are then connected to each other to enable a data transfer between all racks. For reasons of simplification a core-network switch is omitted. The logical network topology is presented in Figure 2.

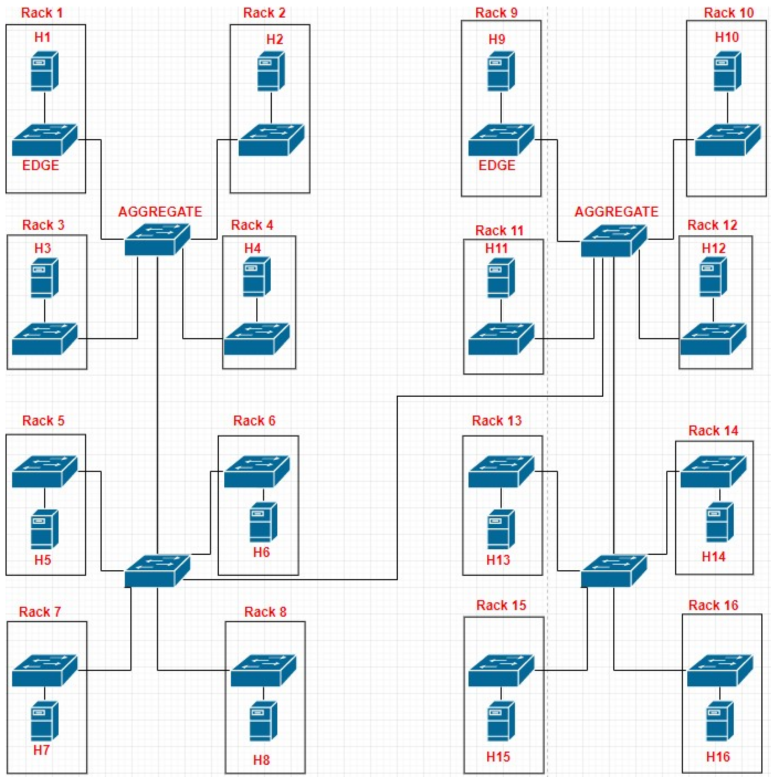

Figure 2: Logical network plan of the data centre

The initial demonstrator focuses on the inter-rack communication. Each rack is equipped with four steerable antennas on its top. It is assumed that each antenna is able to cover an angular scanning range of 90°. This corresponds to the latest results in antenna design from INESC TEC. The antennas of each rack are labelled from 1 to 4 as shown in Figure 3 to avoid any ambiguity.

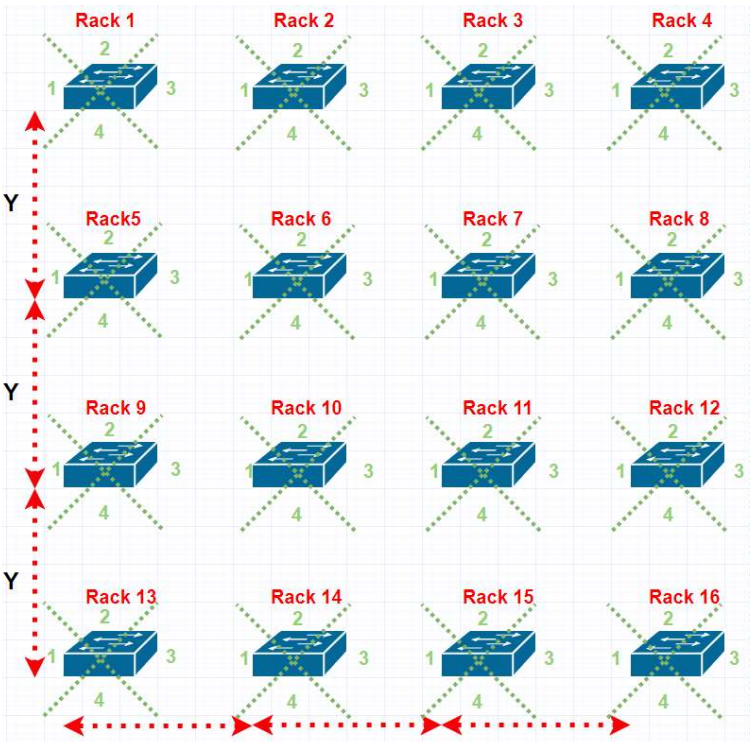

Figure 3: Antennas and assigned sectors

The fact that each rack has more than one antenna reflects on the one hand that directional antennas are needed for THz communication and on the other hand it allows multiple links to one rack e.g. for multi-hop connections.

For demonstration reasons, the demonstrator uses a bandwidth of 12.96 GHz that is chosen accordingly to the IEEE Std 802.15.3d-2017 standard [1] and recent results of the benchtop demonstrator from T6.1. Such a bandwidth will enable us to update the system to a higher data rate up to 100 Gbit/s with higher order modulation schemes. For the initial simulation demonstrator some realistic test data was chosen to prove the correct operating principles and to illustrate the effect of THz link integration into a data centre network. A maximum PHY data rate of 10 Gbit/s is assumed for the shortest path length. It reduces with increasing distance between the transmitter and the receiver and with increasing interference from other links. Higher layer characteristics are linked to the PHY data rate by a functional correlation in this initial demonstrator.

3 Functionalities

The demonstrator is a tool that is able to combine results from different simulators and present them in a comprehensive and global manner. It visualises the data centre in a three dimensional way showing racks, aggregates, fibre cables and wireless links. For the 3D visualisation the helix toolkit [2] was integrated into the Simulator for Mobile Networks *SiMoNe* [3]. The three dimensional view of the test data centre is shown in Figure 4. Each rack has four antennas on its top that are represented by four pink tubes. The racks are connected to the aggregate switches via fibre cables that are visualised with black lines. If the fibre link is active, the line is coloured red. The aggregate switches are also linked to each other with fibre links represented with black lines. They operate in the same way as the fibre connection from the racks to the aggregate switches.

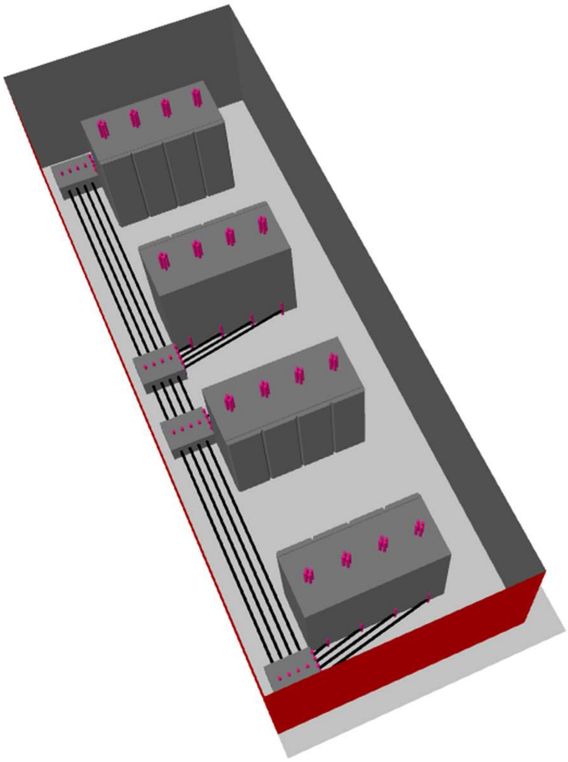

Figure 4: 3D view of the data centre

The data centre demonstrator is embedded in the SiMoNe simulator. The data to be visualised is fed to the demonstrator in a comma separated value spreadsheet file (CSV). For each event the csv-file contains one row giving the timestamp, the transmitting and receiving rack and the key performance indicators (KPI) of interest. The structure of the .csv file is illustrated in Table 1.

Table 1: Schema of the .csv file

Time	TX	RX	KPI1	KPI2	…
0.000	R1	R12	30	0.02	…
0.500	R3	R4	20	0.001	…
…	…	…	…	…	…

The demonstrator animates the links creating a video and shows selected KPIs in a diagram in parallel. The user can freely move forward and backward in the video. To present the whole performance of the data centre, the KPIs from all simulated layers summarised in Table 2 are part of the demonstrator.

Table 2: Demonstrated quantities

Quantity	Unit	Abbreviation	Layer
Bit Error Rate		BER	PHY
Data rate	Gbit/s		PHY
Channel delay	ns		PHY
Frame Error Rate		FER	DLL
Mean number of retransmissions		MNOR	DLL
DLL Throughput	Gbit/s		DLL
Goodput	Gbit/s		DLL
NET Throughput	Gbit/s		NET
Latency	µs		NET
Packet Loss	%		NET

There are two possible ways to display the KPIs. The first option is the line plot shown in Figure 5. The KPI, in this case the bit error rate, is plotted as a function of the simulation time. Different links can be distinguished by different colours.

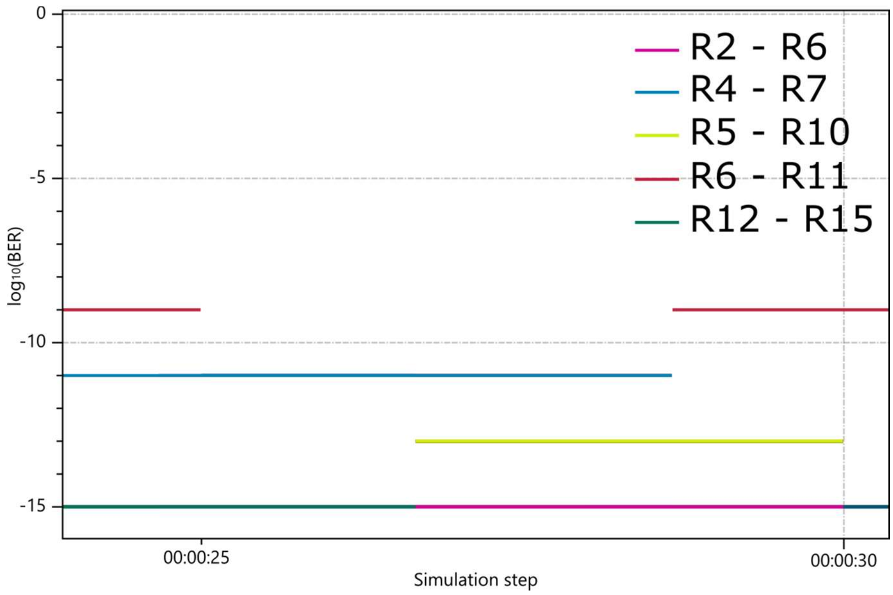

Figure 5: Line plot of the Bit Error Rate

The second option is a bar chart. The bar chart shows the selected KPI for all links for a certain time instant as presented in Figure 6. In this example, the data rate of all links is shown. If the data rate is equal to zero, the link is not active.

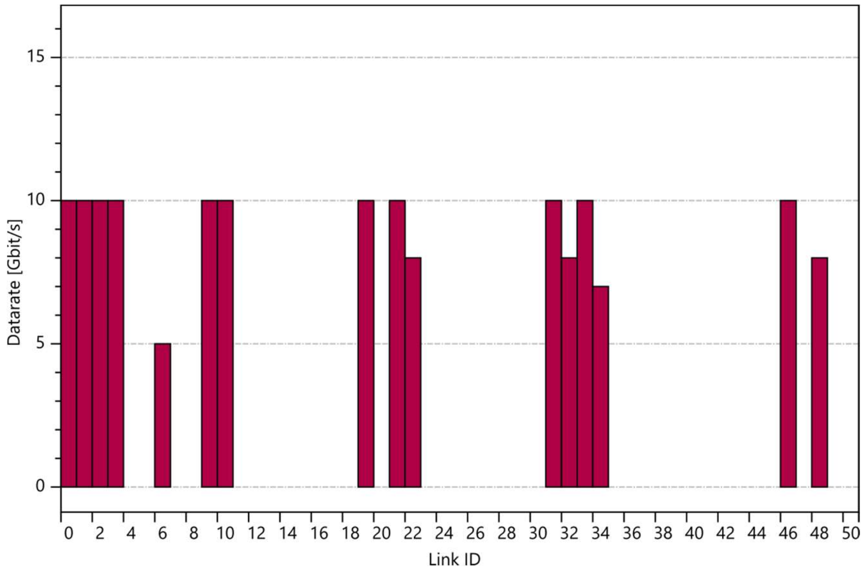

Figure 6: Bar chart of the data rate

4 Demonstration example

The initial simulation demonstrator presents four situations that show the benefits of a wireless data centre. The demonstration lasts 33 seconds. The racks are named number 1 beginning from the top left and continuing row-wise to number 16 at the bottom right.

Link failure

At time instant t = 10 s the fibre link between the two aggregate switches in the middle fails. Without wireless links, a proper fail-over would not be possible and the current data transfer between rack 5 and rack 10 would be interrupted. In the wireless data centre the data transfer can proceed only influenced by the lower throughput without the additional fibre link. At the same time, the fail-over protocol is initiated and a virtual machine (VM) is transferred from rack 5 to rack 11. Because of an existing link from rack 5 to rack 10 that blocks a direct link from rack 5 to rack 11, a multi-hop connection is used for the transfer of the VM.

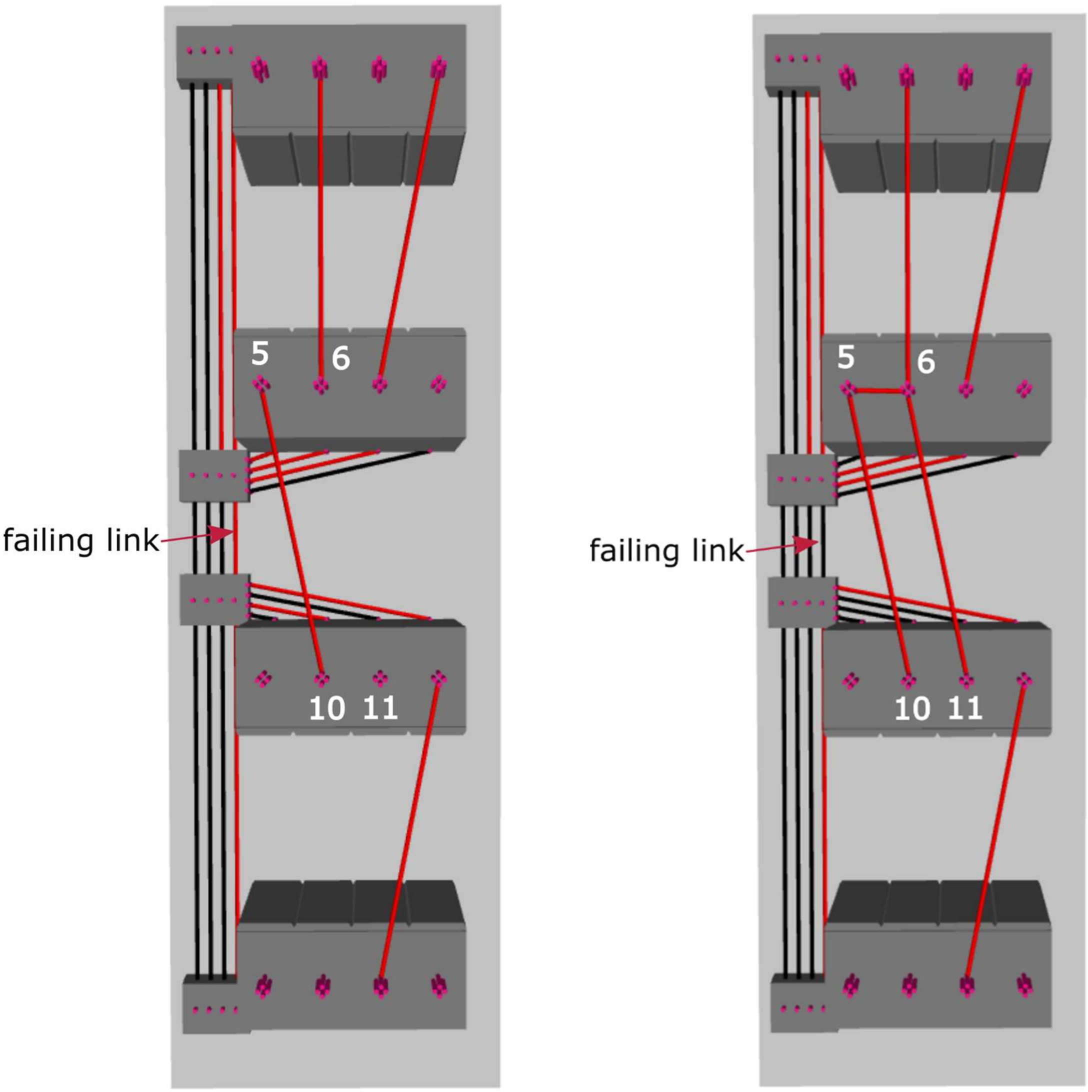

Figure 7: Data centre before (left) and after (right) link failure

Figure 7 shows on the left hand side the configuration of the network before the link failure. On the right hand side of Figure 7 the network configuration after the link failure can be seen. The fibre link between aggregate switches 2 and 3 is offline and the multi-hop connection from rack 5 via rack 6 to rack 11 appeared. Once the connection between rack 5 and 10 is finished, a direct link from rack 5 to rack 11 will replace the multi-hop link.

Boost operation

The second functionality is the boost operation. In this scenario the throughput of the existing link between rack 12 and rack 15 is not sufficient for the running application. In a data centre without wireless links a wired fibre cable would have to be installed. The wireless data centre makes use of the multiple number of possible multi-hop connections between two racks and creates two parallel links. Figure 8 shows the link in normal and boost mode. The throughput is augmented at the expense of a lower latency. Once the throughput requirements normalise, the connections transform to a direct link.

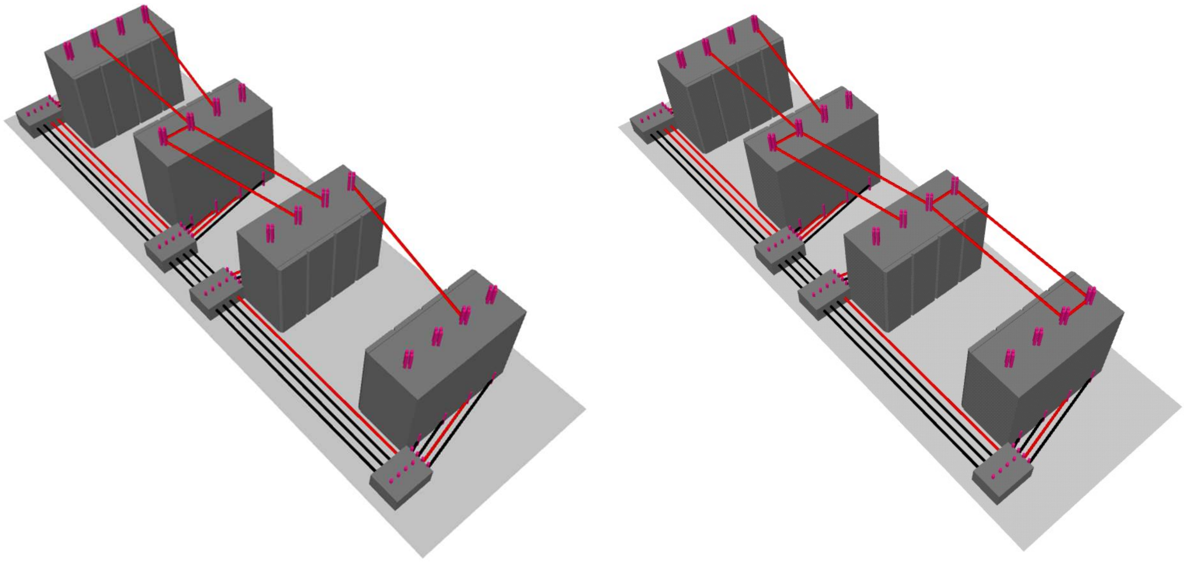

Figure 8: Illustration of the boost operation: normal mode (left) and boost mode (right)

Interference detection

Simultaneously active links may possibly lead to high interference at the receiver and impair the performance of the wireless link. In this scenario the network controller detects a highly interfering link and switches to a multi-hop link with a better global performance. First an existing link from rack 2 to rack 9 operates in a normal mode as shown in Figure 9 on the left-hand side. Then a new link from rack 3 to rack 6 is created. The interference at the antenna of rack 9 from that newly created link is very high. Therefore the controller decides to replace the link from rack 2 to rack 9 by a multi-hop link via rack 5 that has a different angle of arrival at the receiving antenna, thereby reducing interference. This is illustrated in Figure 9 on the right-hand side.

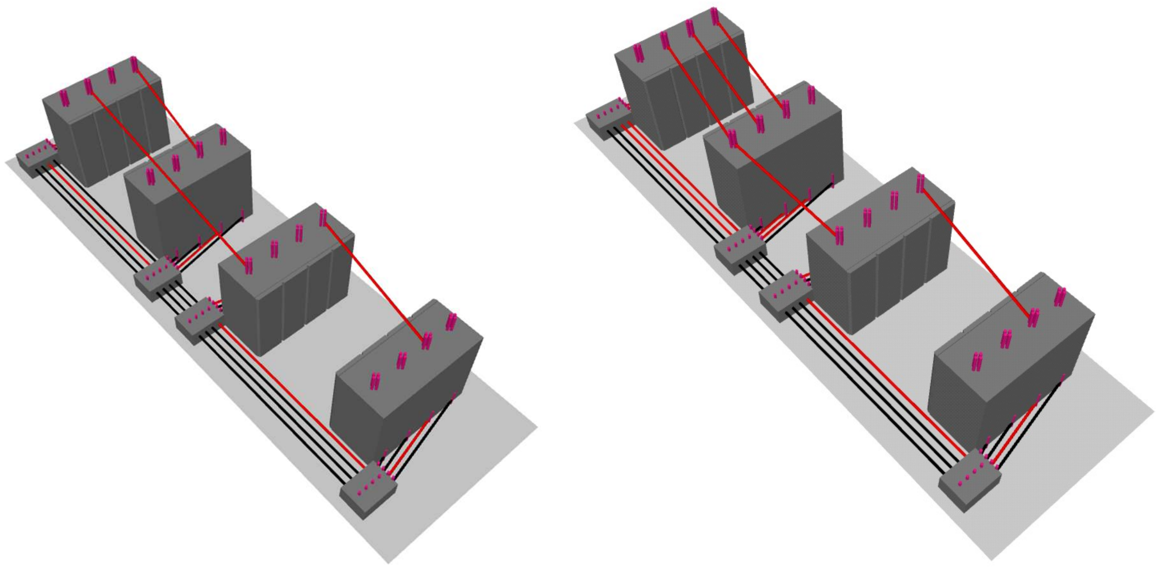

Figure 9: Illustration of the interference detection: normal mode (left) and multi-hop (right)

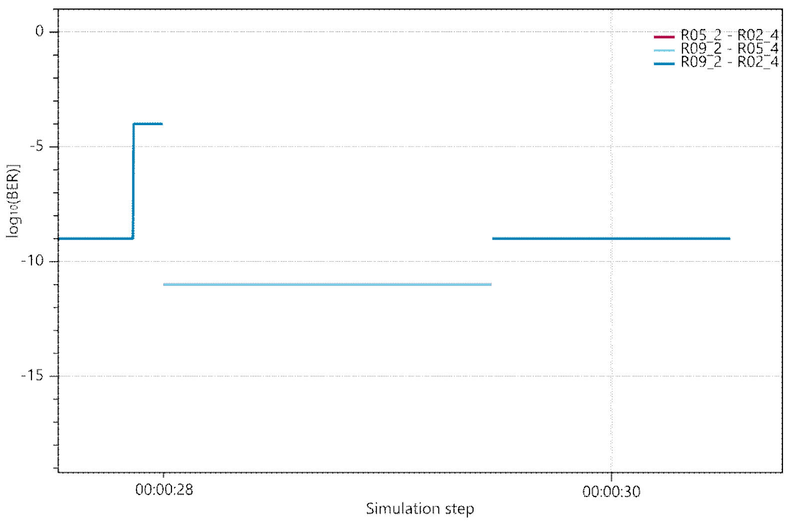

Figure 10: line plot of the interference detection

The line plot in Figure 10 shows the high rise of the BER when the interfering link is introduced. The controller switches to the multi-hop link that has a lower BER, in expense of a higher latency, for in overall performance improvement.

Row power failure

The last application is a power failure event. At t = 25 s row 4 suffers a power failure and battery backups are activated. The emergency response of the fail-over protocol initialises a migration of VMs from row 4 to the opposite row 3. The full throughput combining fibre and wireless links is used to reduce the critical transmission time.

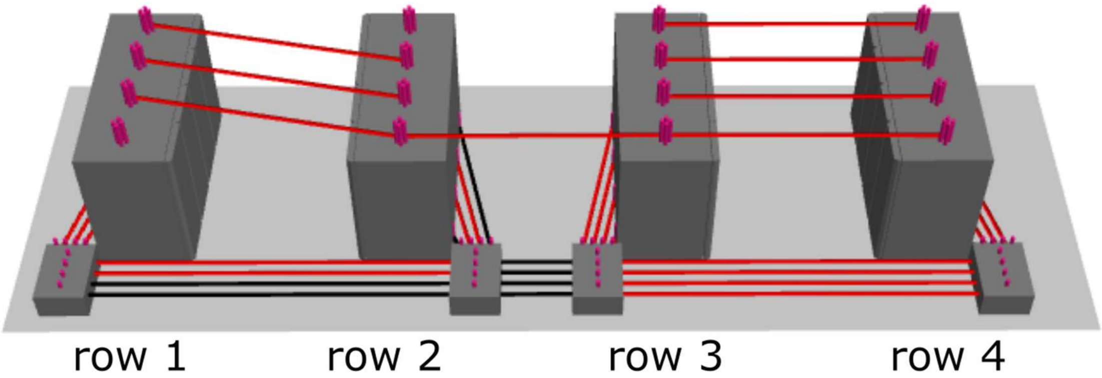

Figure 11: Illustration of the row power failure

5 Conclusion/Further work

This initial simulation demonstrator shows the operating principle of the visualisation of simulation results from work package five simulators. It visualises the wired and wireless connections in a test data centre with a four by four rack topology. The racks are equipped with four top-of-rack antennas that each radiate in an angular range of 90°. The demonstrator offers the possibility to present various key performance indicators from the physical layer, the data link layer and the network layer. They can be plotted in a line plot or a bar chart format. For demonstration purposes the initial simulation demonstrator uses some representative values for the KPIs.

The further work towards the final simulation demonstrator consists of the transfer of the demo environment to the full model layout of the Dell EMC Research Data Centre shown in Figure 12. The representative values will also be replaced by real simulation results from the work package five simulators. Furthermore the intra-rack communication will be integrated in the demonstrator. It is also foreseen that an audience will be involved to make the demonstrator interactive. This will strengthen the impact of the demonstrator, attracting high interest for the integration of THz wireless links into a data centre.

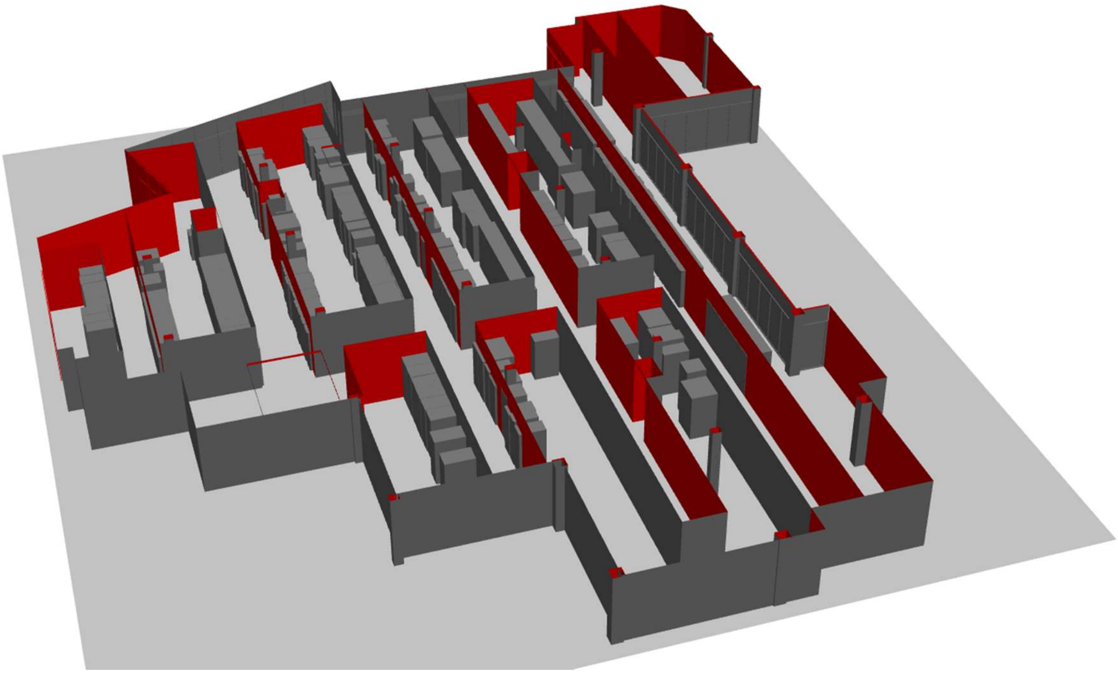

Figure 12: 3D model of the Dell EMC Research Data Centre

References

[1] IEEE 802.15.3d IEEE Standard for High Data Rate, Wireless Multi-Media Networks, Amendment 2: 100 Gb/s Wireless, Switched Point-to-Point Physical Layer

[2] Helix Toolkit 3D for .NET, http://helix-toolkit.github.io/

[3] D. M. Rose, J. Baumgarten, S. Hahn and T. Kurner, "SiMoNe - Simulator for Mobile Networks: System-Level Simulations in the Context of Realistic Scenarios," *2015 IEEE 81st Vehicular Technology Conference (VTC Spring)*, Glasgow, 2015, pp. 1-7.