△ **Altair**

MIMO System Simulation in WinProp

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Introduction

This white paper presents and discusses practical examples of communication simulations involving Multiple Input Multiple Output (MIMO) technology. Two workflows exist for MIMO simulations in WinProp; this note discusses the workflows, and presents an example with relevant results for each.

Challenges

Multiple Input Multiple Output (MIMO) systems, which deploy spatially separated multiple antenna elements at both ends of the transmission link, can achieve higher data rates and more reliable wireless connections than Single Input Single Output (SISO) systems with one antenna on each end of the link. In theory, the MIMO channel capacity can increase linearly with the number of antenna pairs, provided the environment is rich in multipath (Fig. 1, Fig. 2). Ideally, the multipath is so rich that the propagation channels between each pair of transmit and receive antennas are statistically independent. This allows antennas to transmit different data streams on the same carrier and together achieve a higher total data rate. (This of course requires advanced coding and signal-processing techniques.) The capacity gain ultimately depends on the propagation channel in which the system is operating. Obtaining accurate results for the complicated wireless environment with multiple transmit and receive antennas in an efficient manner can be challenging.
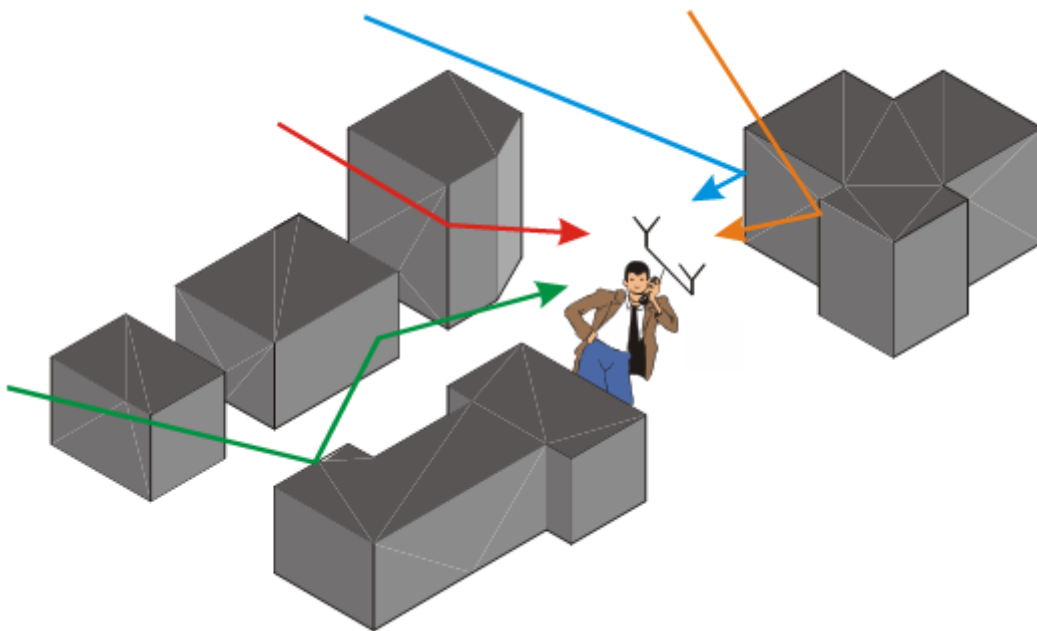

Fig. 1   MIMO is most effective in a rich multipath environment

WinProp and MIMO

WinProp offers accurate simulation methods to characterize the propagation channel and perform network planning.

WinProp's propagation models process 3D vector data of buildings (Fig. 2, Fig. 3) to determine the mobile radio channel within various environments (rural, urban, and indoor). The ray-optical models consider polarization in the antenna patterns and in the transmission, reflection and diffraction coefficients (Fresnel coefficients and Geometrical/Uniform Theory of Diffraction). The options for how WinProp sums the ray contributions, deterministic or statistical, are explained in Appendix A. WinProp computes many result quantities, such as received power, channel capacity, maximum throughput, and more. Beyond this, Appendix B explains how the complete and detailed ray information can be accessed for further signal processing in external tools, if desired.
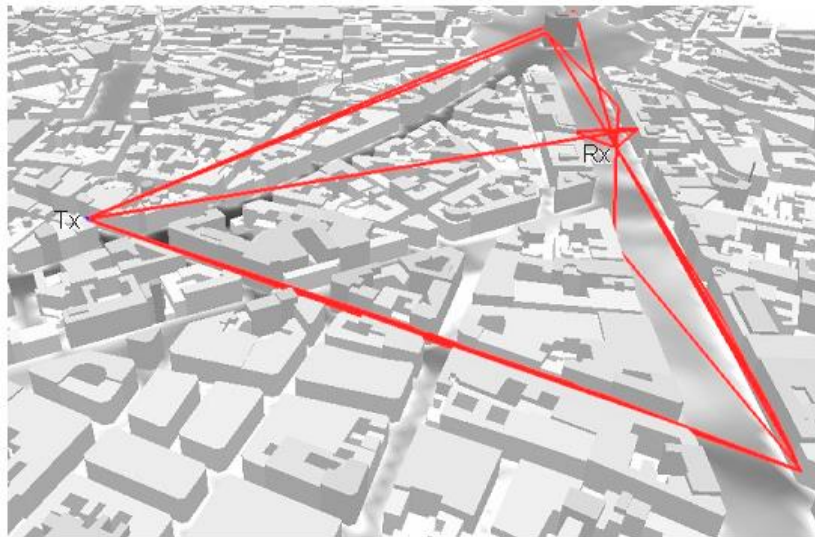

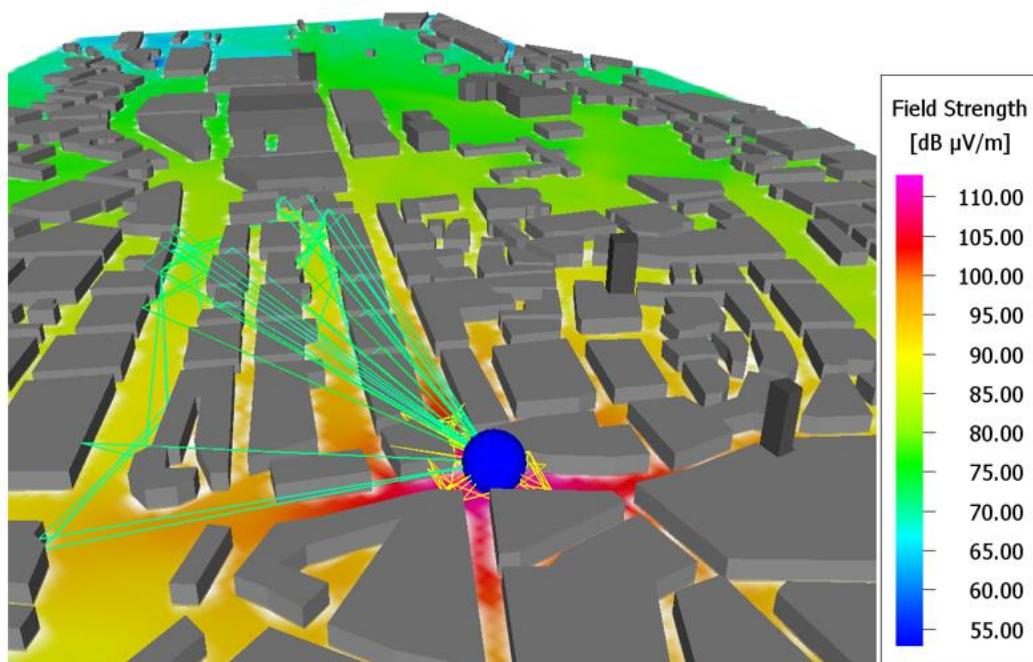*Fig. 2   Ray tracing in an urban scenario*

Fig. 3   Ray tracing is fully 3D, combining propagation through street canyons and over rooftops

For the consideration of MIMO antenna arrays, WinProp offers two work flows:

- MIMO in Radio Links by means antenna post processing;

- MIMO in Network Planning.

For MIMO in Radio Links by means of antenna post processing, one propagation analysis is done for one isotropic antenna at the base station location. Antenna arrays and antenna element patterns are specified as a post-processing step. This is the recommended workflow to evaluate and compare multiple antenna patterns and array configurations without repeating potentially time-consuming simulations, and when results of interest include quantities like Channel Capacity in bit/s/Hz, Channel Impulse Response, Delay Spread and Angular Spread.

For MIMO in network planning, each antenna element on the base-station side is explicitly defined, and one ray-tracing simulation is performed per base-station antenna. This is the recommended workflow when actual network planning is performed, with a defined air interface (e.g. LTE) and specified transmission modes, and when results of interest include quantities like Maximum Throughput in Mb/s.

In all simulations, we have used WinProp's Intelligent Ray tracing (IRT) method, with a fully polarimetric analysis for optimum accuracy, and the use of Fresnel/UTD coefficients for reflection and diffraction.

MIMO in Radio Links by means of Antenna Post Processing

To investigate MIMO Antenna Performance, WinProp offers the capability to compare antennas and antenna configurations by means of post processing. Only one propagation simulation needs to be performed; this has to be done with one isotropic transmitter per site. As an example, consider the urban scenario below, with only one site for convenience.
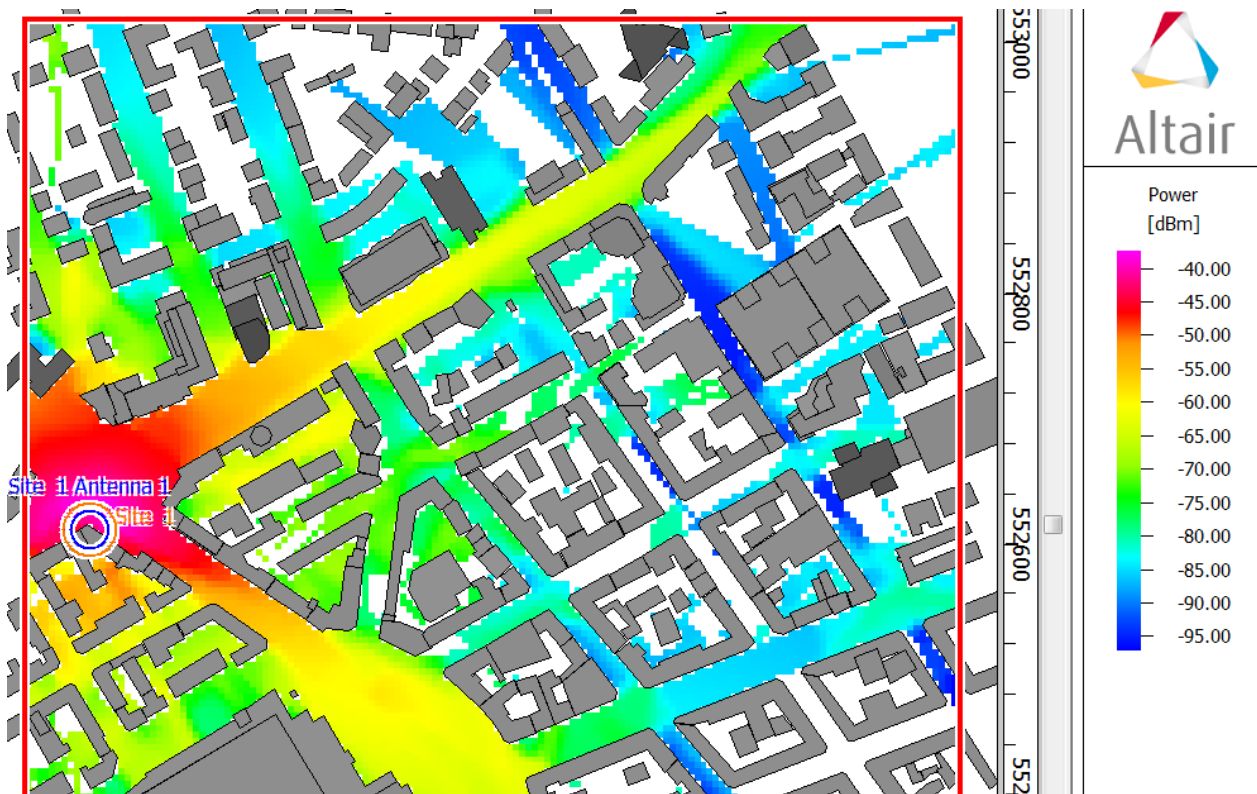

Fig. 4   Propagation result for urban scenario with one isotropic transmitter

For the white pixels no results have been computed, due to user-defined high accuracy settings in the selected method. This one propagation result can be used to evaluate MIMO antenna performance by means of post processing.

Fig. 5 shows the base station antenna. It is a small array that produces the typical sectoral radiation pattern. The antenna elements are oriented 45 degrees off vertical. An accompanying second base-station antenna, in the case of MIMO, has its antenna elements rotated 45 degrees off vertical in the opposite direction.
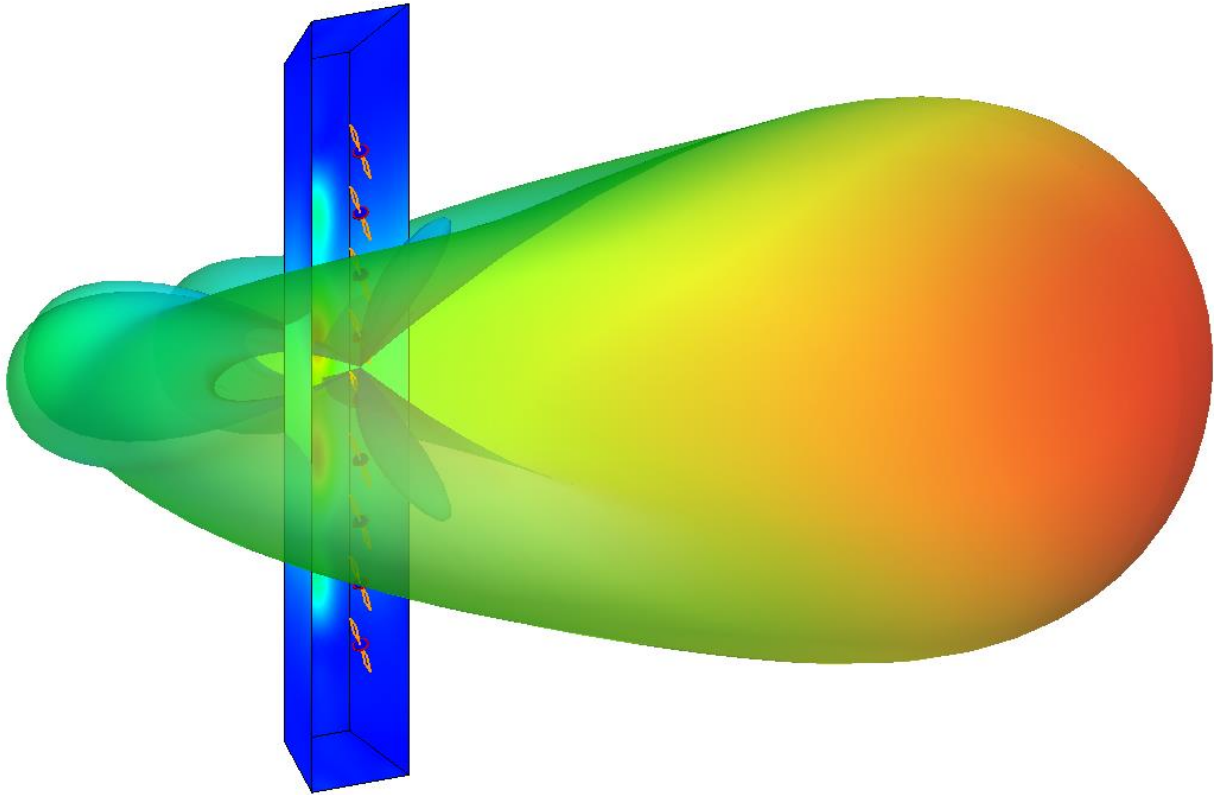

Fig. 5   Base station antenna. This small array is treated as one antenna in the simulation. In the case of 2×2 MIMO, a second base station antenna, with rotated antenna elements but pointing to the same sector, is added.

Fig. 6 shows the mobile antennas. Two dual-band antennas, designed for MIMO in an LTE network, have been integrated in a "shark fin" on the roof of a car for Vehicle-to-Network (V2N) communication. The blue part in the lower left is the top of the rear windshield. The car is included in the antenna simulation because it has a major impact on the radiation patterns. The street surface is not included in the FEKO antenna simulation because it will be included in the WinProp propagation analysis.
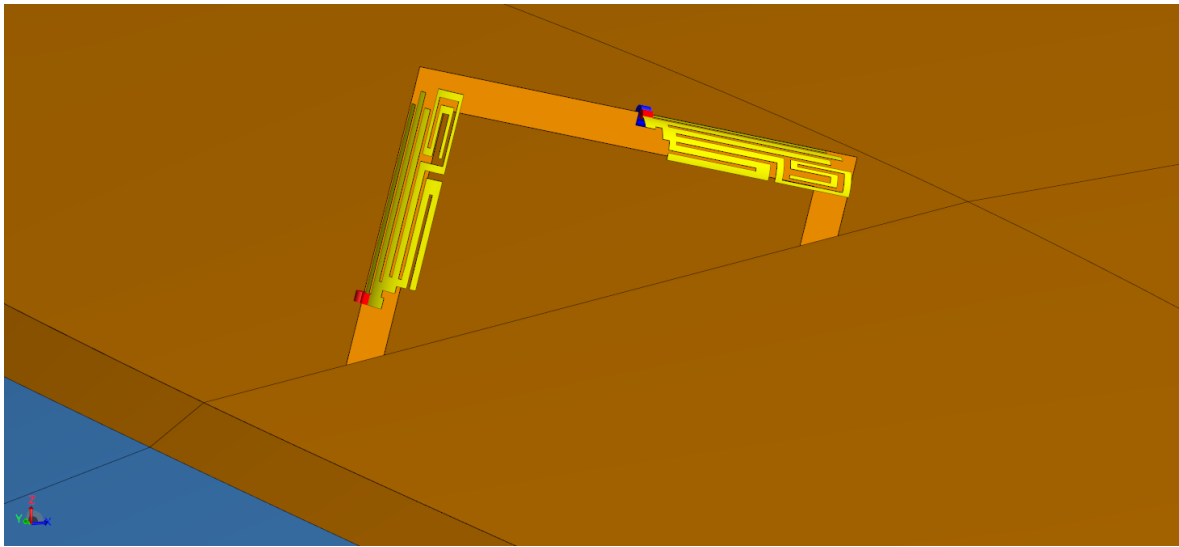
Fig. 6   Mobile-station antennas mounted on the roof of a car. Each antenna is an individual antenna that can handle one MIMO stream in the case of 2×2 MIMO.

Results for MIMO by means of Antenna Post Processing

Results include Channel Impulse Response, Delay Spread, Angular Spread and Channel Capacity. Appendix C explains the details of the Channel Matrix and Channel Capacity. Channel Capacity depends, among other variables, on the Signal-to-Noise-and-Interference Ratio (SNIR). Several SNIR options exist in WinProp in the calculation of Channel Capacity. The Channel Capacity in Fig. 7 is based on an area-wide interference level of -80 dBm.
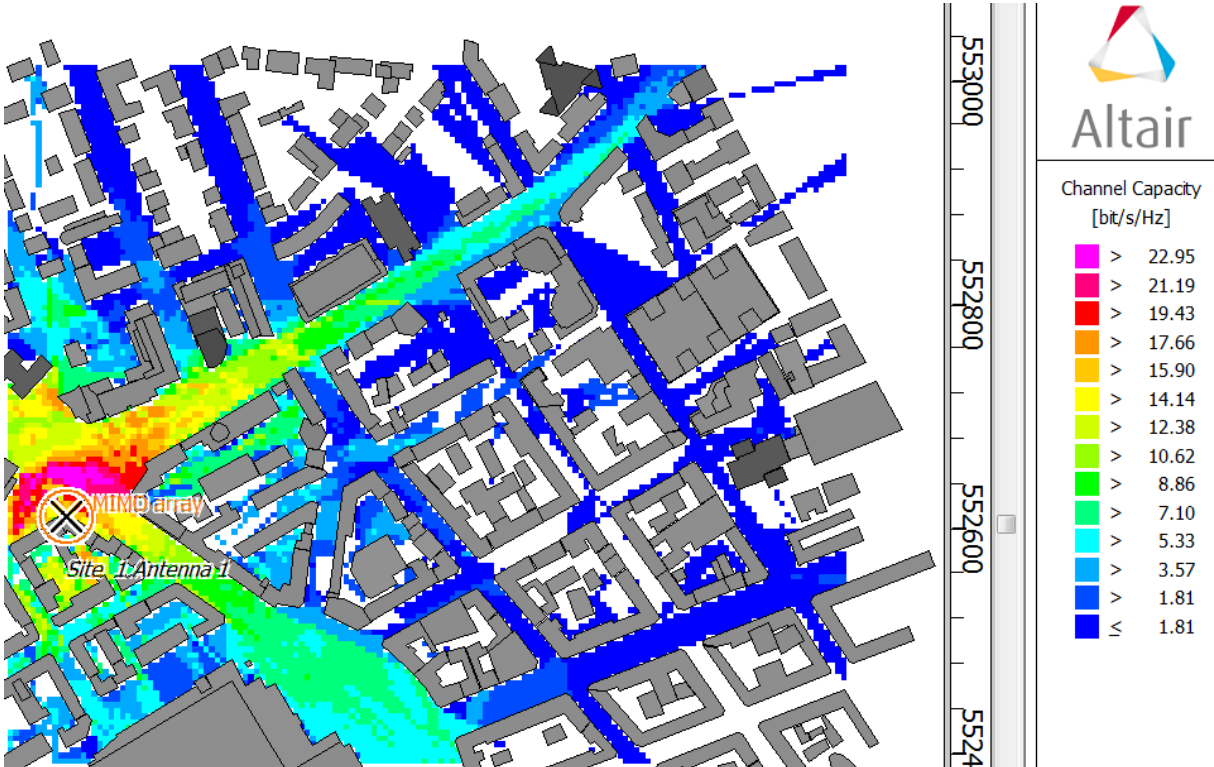

Fig. 7   MIMO Channel Capacity. Two base station antennas, 1 m apart, serve the same sector. The two antennas of Fig. 6 are used on the mobile station.

With the same project, it is easy to evaluate a Single Input Single Output (SISO) configuration next, simply by modifying the antennas in the post-processing step. Fig. 8 shows the SISO Channel Capacity.
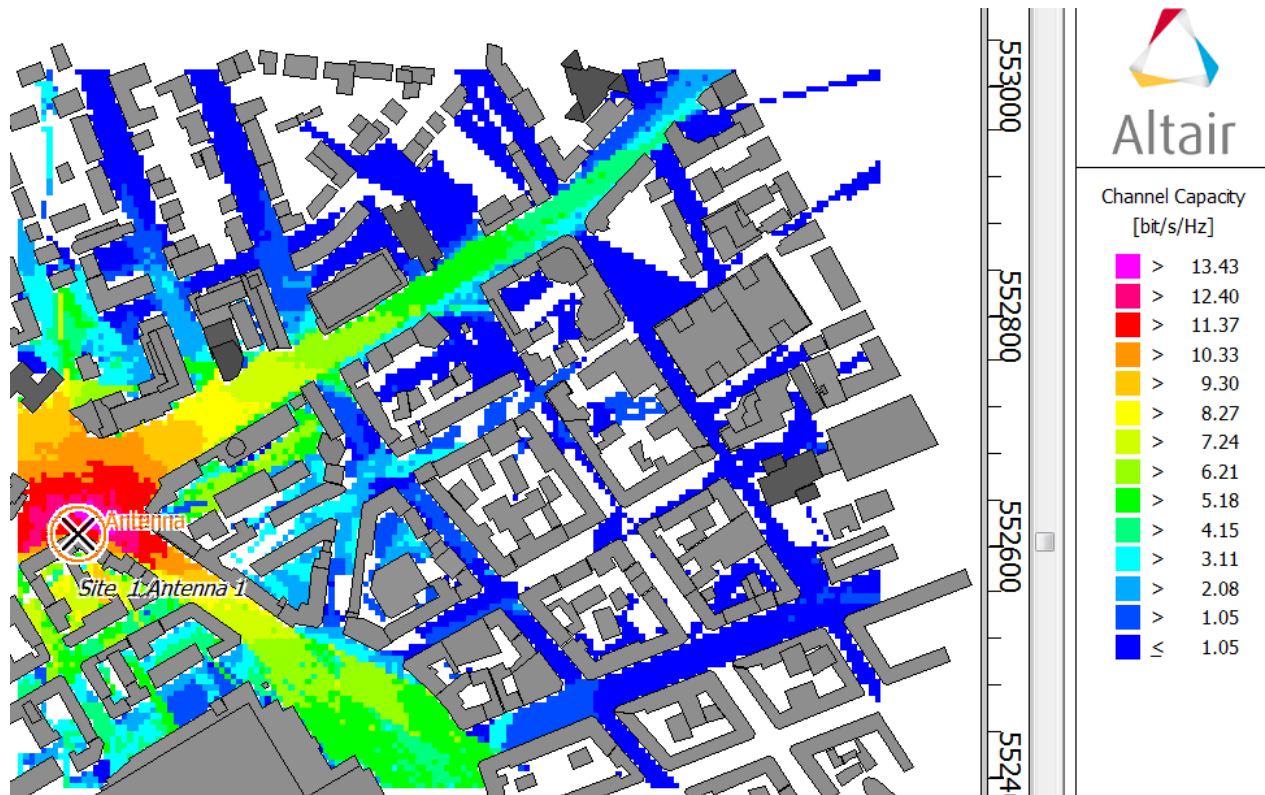

Fig. 8   SISO Channel Capacity. One base station antenna as shown in Fig. 5 is active, and only one of the two mobile antennas of Fig. 6 is used.

By comparing Figs. 7 and 8 we can evaluate the benefit of MIMO over SISO for the antennas of interest in this urban environment. Note that 2x2 MIMO improves the Channel Capacity typically by a factor slightly over 1.5. The theoretical maximum is a factor two, but this can only be achieved in an ideal rich multipath environment. We therefore conclude that the selected antennas are suited for 2×2 MIMO.

MIMO in Network Planning

Having decided on the MIMO antenna configuration, we wish to determine the maximum data rate that can be achieved as the car drives along a trajectory. To this aim, we have defined in WinProp a Network Analysis project based on an LTE air interface. In such a project, every base-station antenna is explicitly present in the project. For every base-station antenna, the user has to specify which carrier it will use, which signal group it will transmit, and, in case of MIMO, which MIMO stream it will transmit. Appendix D provides more detail.

For the mobile-station antennas, one can work in "area mode" to obtain received power in the entire area, but also in "trajectory mode." In trajectory mode, a route is defined for the car, and the mobile-station antenna orientation changes along with the car as it moves along the trajectory and takes turns. Two base-station sites, with for each site the antennas for two sectors, have been defined. For each sector, two antennas are available to handle MIMO. The latter are not visible separately in Figures 9 and 10 due to the scale. Fig. 9 shows an example of the maximum MIMO data throughput along a trajectory, while Fig. 10, for comparison, shows the maximum SISO throughput.

Fig. 9   *Maximum throughput along the trajectory (MIMO)*

Fig. 10   *Maximum throughput along the trajectory (SISO)*

Note that the MIMO throughput is almost twice as high as the SISO throughput.

Conclusion

WinProp offers two work flows for MIMO analysis. One, intended for antenna performance in radio links, starts with one simulation of an isotropic transmitter and evaluates antenna performance through post processing. The other, intended for network analysis, requires simulations of every transmitting antenna. Examples of both have been presented and explained.

Appendix A   Contribution and Superposition of Rays

There are different computation modes for the contribution and the superposition of the individual rays determined with the ray tracing algorithm. These modes can be set on the Computation tab of the Edit Project Parameters menu in ProMan.
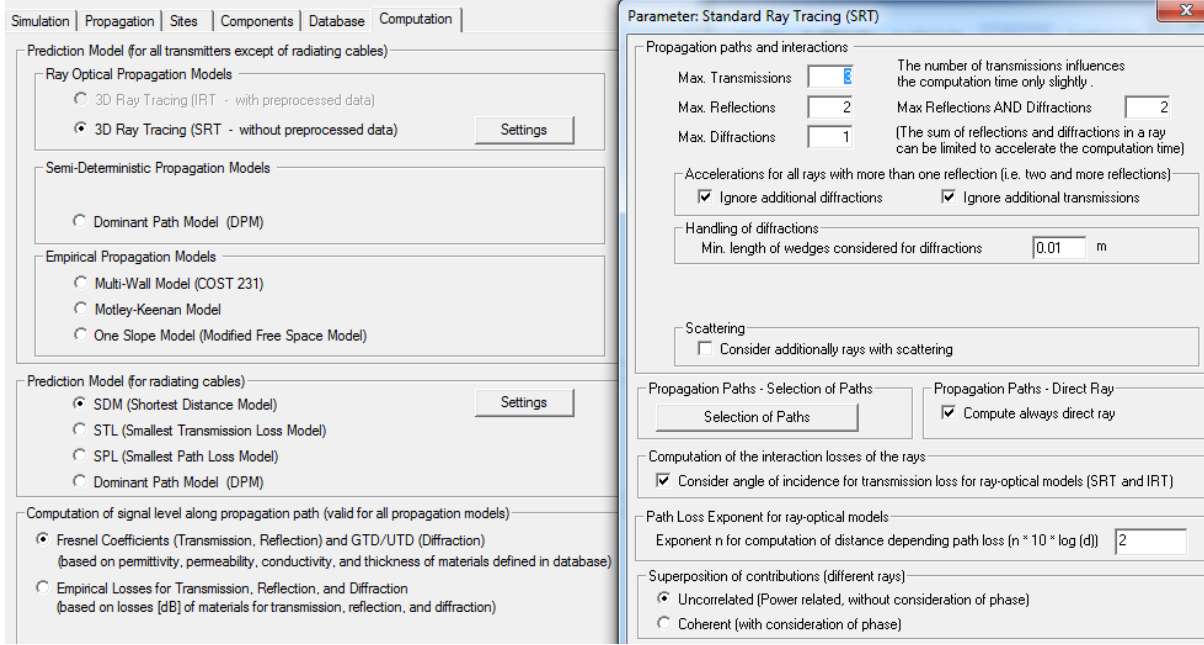

Fig. A1   Settings for the computation and superposition of rays

For the Fresnel and GTD/UTD mode, as well as for the empirical mode (concerning the interaction modeling) combined with the uncorrelated superposition of the rays, the overall field strength of a predicted pixel is computed by summing up the contributions of the individual rays which contribute to the total field strength of this pixel, according to the following formula

$$E_{total} = \sqrt{E_1^{\,2} + E_2^{\,2} + ... + E_n^{\,2}} \qquad\qquad (A1)$$

For the computation with Fresnel coefficients and GTD/UTD in combination with the coherent superposition of the rays, both the polarizations and the phases of the individual contributions are taken into account. Therefore, the contributions of the individual rays are summed up separately for each polarization (real and imaginary part) first:

$$E_{x,real} = E_{1,x,real} + E_{2,x,real} + ... + E_{n,x,real} \qquad\qquad (A2)$$

$$E_{y,real} = E_{1,y,real} + E_{2,y,real} + ... + E_{n,y,real} \qquad\qquad (A3)$$

$$E_{z,real} = E_{1,z,real} + E_{2,z,real} + ... + E_{n,z,real} \qquad\qquad (A4)$$

$$E_{x,imag} = E_{1,x,imag} + E_{2,x,imag} + ... + E_{n,x,imag} \qquad\qquad (A5)$$

$$E_{y,imag} = E_{1,y,imag} + E_{2,y,imag} + ... + E_{n,y,imag} \tag{A6}$$

$$E_{z,imag} = E_{1,z,imag} + E_{2,z,imag} + ... + E_{n,z,imag} \tag{A7}$$

After that, the overall real part and the overall imaginary part are calculated by summing up the corresponding parts of the vector components:

$$E_{real} = \sqrt{E_{x,real}^2 + E_{y,real}^2 + E_{z,real}^2} \tag{A8}$$

$$E_{imag} = \sqrt{E_{x,imag}^2 + E_{y,imag}^2 + E_{z,imag}^2} \tag{A9}$$

Finally, the total field strength of the pixel is determined according to the following formula:

$$E_{total} = \sqrt{E_{real}^2 + E_{imag}^2} \tag{A10}$$

The computation with the empirical mode combined with the coherent superposition of the rays is done as follows. First the field strength components of the contributing rays are summed up for real and imaginary part separately.

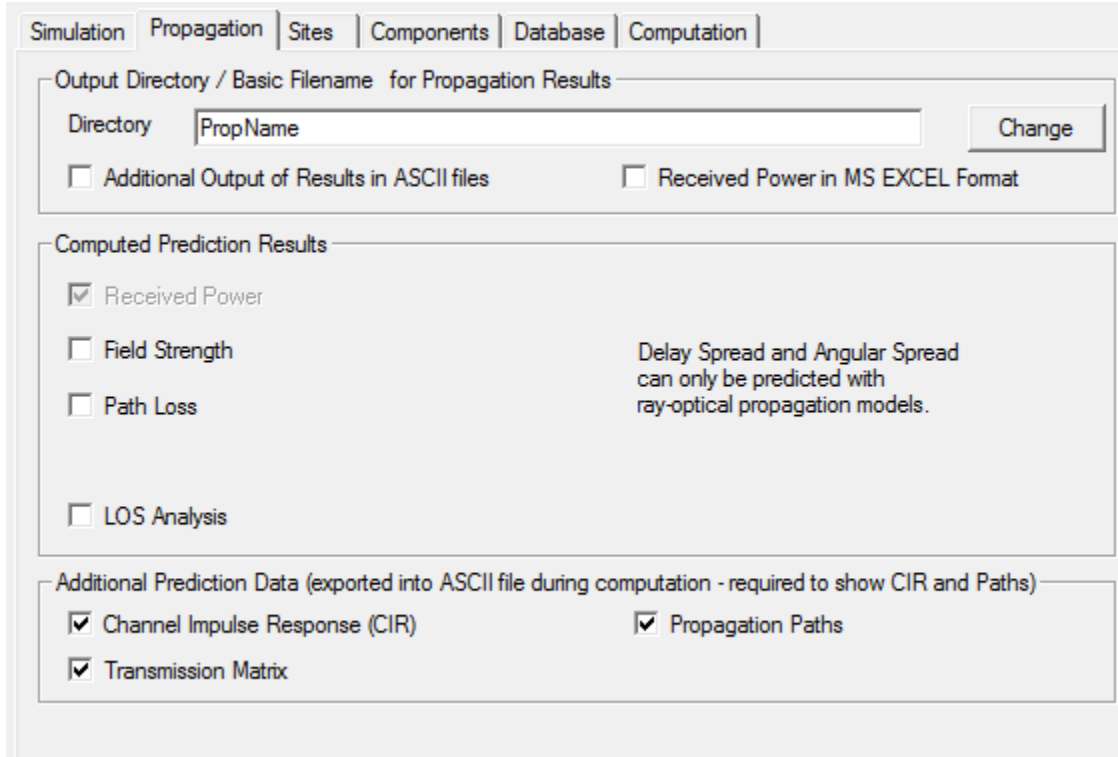$$E_{real} = E_{1,real} + E_{2,real} + ... + E_{n,real} \tag{A11}$$

$$E_{imag} = E_{1,imag} + E_{2,imag} + ... + E_{n,imag} \tag{A12}$$

After that, the overall field strength is calculated according to the following formula:

$$E_{total} = \sqrt{E_{real}^2 + E_{imag}^2} \tag{A13}$$

Appendix B   Ray Data Files

For the purpose of post processing, WinProp's propagation tool ProMan offers the possibility to write the data corresponding to the calculated propagation paths into an ASCII (*.str) or a binary (*.ray) file. This optional output can be selected on the propagation page of the settings menu in ProMan (Fig. B1):

Fig. B1   Options to write output to .str ASCII file

There are different output alternatives within this file, depending on the selected propagation model, the computation mode, the environment under investigation and the enabled outputs on the propagation tab. The ProMan manual describes the format of the file in detail.

Appendix C   Channel Matrix and Channel Capacity

C1   MIMO Channel Matrix

Besides the channel characteristics like delay spread and angular spread, MIMO systems can be evaluated in more detail by calculating the MIMO channel matrix, which describes the radio channel between each transmit and each receive antenna of the system.

There is a complex single-input-single-output (SISO) channel impulse response of length $L+1$ between every transmit antenna m and every receive antenna n of a MIMO system.

$$h_{n,m}(t) = \sum_{l=0}^{L} h_{n,m,l}(t) \tag{C1}$$

The linear time-variant MIMO channel is represented by the channel matrix with dimension $N_R \times N_T$:

$$H(t) = \begin{pmatrix} h_{1,1}(t) & \dots & h_{1,N_T}(t) \\ \dots & \dots & \dots \\ h_{N_R,1}(t) & \dots & h_{N_R,N_T}(t) \end{pmatrix} \tag{C2}$$

with complex elements

$$h_{n,m}(t) = \mathrm{Re}\{h_{n,m}(t)\} + j\,\mathrm{Im}\{h_{n,m}(t)\} \tag{C3}$$

The MIMO channel matrix can be determined by post-processing the ray data simulation output (see Appendix B) of the WinProp prediction tool ProMan by just calculating the phase differences between the single antenna elements of the MIMO antenna arrays at the base station and at the mobile station.

The ray data give a description of all considered propagation paths between the position of the transmitter and each predicted receiver pixel. Field strength, delay and all interaction points (reflections, diffractions, transmissions, scatterings and turns) are listed for the single propagation paths, which contribute to the signal level at a specified location. Based on these data and the dimensions of the MIMO antenna arrays, the phase shifts between the single elements can be computed in the following way. The transmitter location given in the ray file is assumed to be the center of the transmitting MIMO antenna array. At the receiver side, the same assumption is made. Each pixel of the prediction area can be assumed to be the center point of a receiving MIMO antenna array. In order to determine the MIMO channel matrix now, only the phase shifts between the single array elements have to be computed, based on the ray data given in the ray file and on the array settings.

First of all, the angles of departure and arrival have to be computed, using the coordinates of transmitter and the first interaction point of each path and the coordinates of the last interaction point of each path and the receiver, respectively. After that, the phase shifts between the antenna elements of both arrays (see Fig. C1 for example), can be easily computed.
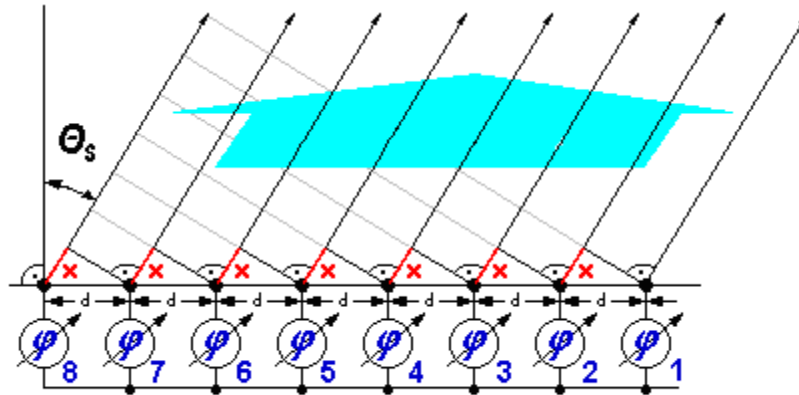
Fig. C1   Uniform linear MIMO antenna array

Phase differences for a linear array are given by

$$\varphi = \frac{360°}{\lambda} \cdot d \cdot \sin\left(\Theta_S\right),\qquad\text{(C4)}$$

where λ is the wavelength.

The equation above holds for arbitrary adjusted uniform linear MIMO antenna arrays with antenna elements located in one horizontal plane. Based on the uniform linear array it is also possible to determine the phase shifts between the elements of a circular antenna array, by adjusting the angle of incidence in the equation above according to the location of the antenna element on the circle.
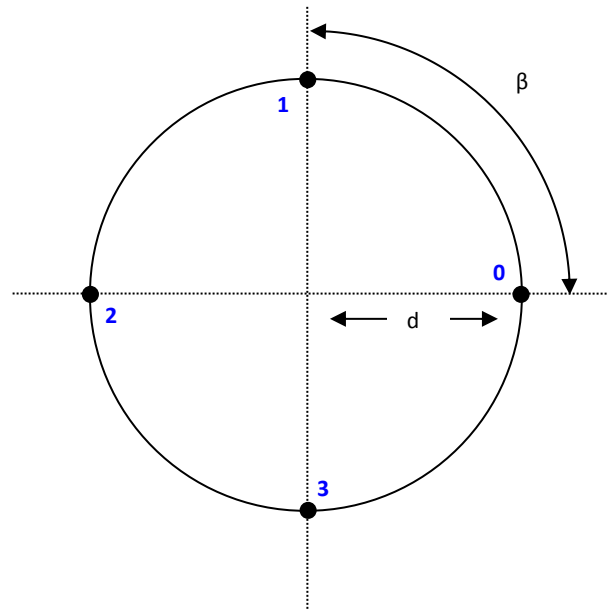

Fig. C2   Circular MIMO antenna array

Phase differences for a circular array are given by

$$\varphi = \frac{360°}{\lambda} \cdot d \cdot \sin(\Theta_S - k \cdot \beta) \qquad \text{(C5)}$$

Here λ denotes the wavelength and k the index of the antenna element ([0,...,3] in this case).

C2   MIMO Channel Capacity

As multiple-input multiple-output (MIMO) systems have emerged as one of the most promising approaches for high data rates, the channel capacity is another interesting parameter of a MIMO system.

The channel capacity of a non-frequency selective MIMO channel can be written as

$$C = \log_2\left(\det\left[I_{N_R} + \frac{P}{N_T \cdot \sigma_n^2} \cdot H_F \cdot H_F^{\ H}\right]\right) \ \left[\text{bit/s/Hz}\right], \qquad \text{(C6)}$$

with the unity matrix I, the overall transmit power P and the noise power σ_n^2. The channel matrices H_F have to be determined by N_F point Fast Fourier Transformation.

For frequency selective MIMO channels, the channel capacity can be obtained by integrating over the non-frequency selective sub channels. The mean signal-to-noise-ratio (SNR) can be expressed by $\rho = P/\sigma_n^2$. The resulting MIMO channel capacity for the frequency selective case can be written as follows:

$$C = \frac{1}{N_F} \sum_{l=0}^{N_F-1} \log_2\left(\det\left[I_{N_R} + \frac{\rho}{N_T} \cdot H_F(l) \cdot H_F(l)^H\right]\right) \left[\text{bit/s/Hz}\right] \qquad \text{(C7)}$$

For comparison of different MIMO channels based on the same SNR, the system has to be normalized to fulfill the following condition:

$$\sum_{m=1}^{N_T} \sum_{n=1}^{N_R} \sum_{l=0}^{N_F-1} \left|H_{n,m}(l)\right|^2 = N_T \cdot N_R \cdot N_F \qquad \text{(C8)}$$

In order to compare different MIMO channels based on the same path loss, the system has to be normalized to fulfill the following condition:

$$\sum_{i=1}^{N_M} \sum_{m=1}^{N_T} \sum_{n=1}^{N_R} \sum_{l=0}^{N_F-1} \left|H_{n,m}(l,i)\right|^2 = N_M \cdot N_T \cdot N_R \cdot N_F \qquad \text{(C9)}$$

It can be shown that the MIMO channel capacity grows with antenna pairs and increasing signal-to-noise-and-interference ratio (SNIR). In Fig. C3, the left two graphs are for a SNIR of 9 dB while the right two are for a SNIR of 18 dB. For each SNIR value, one graph belongs to 2x2 MIMO while the other belongs to 4x4 MIMO. The vertical axis shows the cumulative distribution for the area or trajectory of interest.
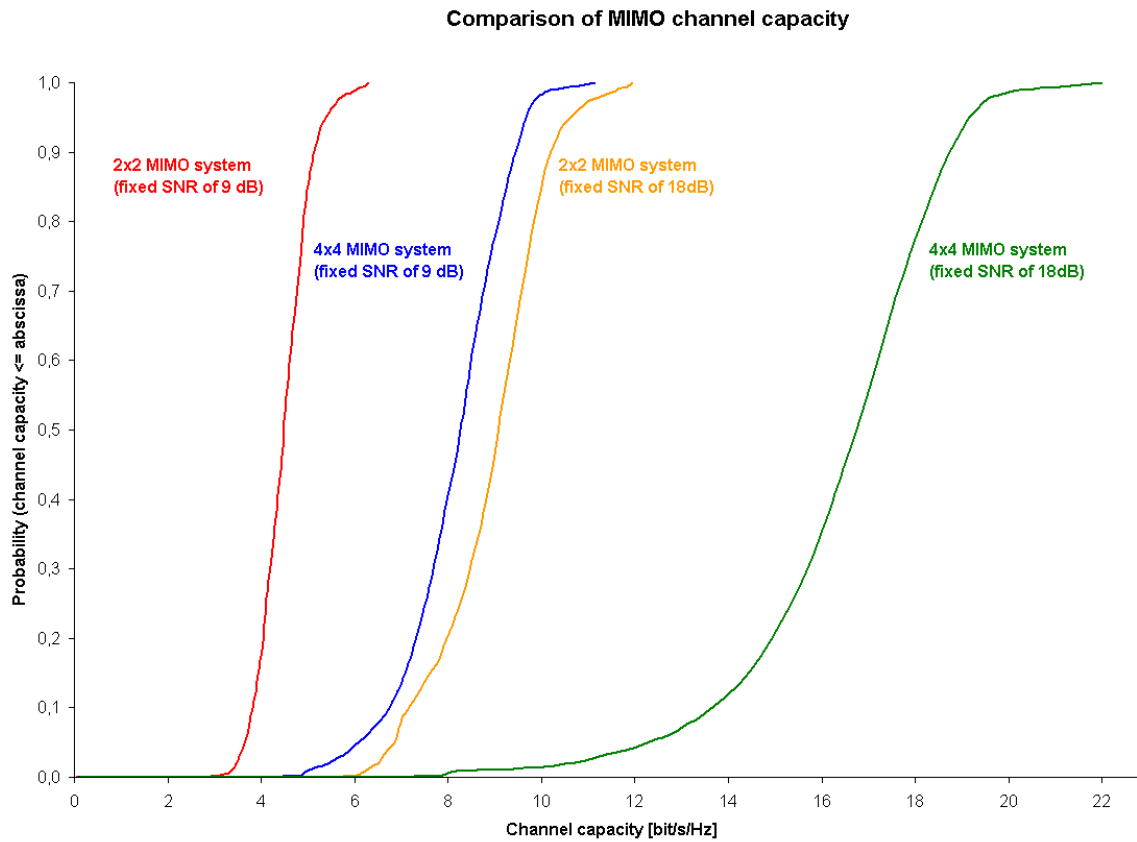
Comparison of MIMO channel capacity

2x2 MIMO system
(fixed SNR of 9 dB)

4x4 MIMO system
(fixed SNR of 9 dB)

2x2 MIMO system
(fixed SNR of 18dB)

4x4 MIMO system
(fixed SNR of 18dB)

Probability (channel capacity <= abscissa)

Channel capacity [bit/s/Hz]

Fig. C3 Channel capacity grows with increasing number of antenna pairs and increasing Signal-to-Noise-and-Interference Ratio

Appendix D   How to set up MIMO Systems and Distributed Antenna Systems in Network Planning

D1   Background

Multiple-input and multiple-output (MIMO) technology is the use of multiple antennas at both the transmitter and receiver (Fig. 1) to improve communication performance. It offers increases in data throughput and link range without additional bandwidth or transmit power. It achieves this by higher spectral efficiency (more bits per second per hertz of bandwidth) and link reliability or diversity (reduced fading). Because of these properties, MIMO is an important part of modern wireless communication standards such as WiMAX, HSPA+, 3GPP Long Term Evolution, 4G, and IEEE 802.11n (Wi-Fi).
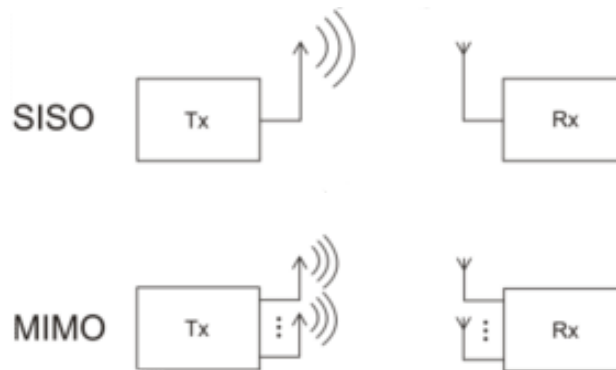

Fig. D1   Conventional SISO system (top) and MIMO system (bottom)

The MIMO antenna configuration can be used for spatial multiplexing. In this case a high rate signal is split into multiple lower rate streams and each stream is transmitted from a different transmit antenna in the same frequency channel (Fig. 1). If these signals arrive at the receiver antenna array with sufficiently different spatial signatures, the receiver can separate these streams into (almost) parallel channels.

Accordingly, the spatial multiplexing by using MIMO antennas is a very powerful technique for increasing channel capacity at higher signal-to-noise-and-interference ratios (SNIR). The maximum number of spatial streams is limited by the lesser of the number of antennas at the transmitter and the number of antennas at the receiver.

Typical MIMO schemes are MIMO 2x2 (i.e. two antennas each at both transmitter and receiver), and MIMO 4x4. In case of spatial multiplexing each MIMO antenna element transmits a separate MIMO data stream. The MIMO scheme 4x2 transmits the MIMO stream 1 from two antenna elements and the MIMO stream 2 from two other antenna elements, thus combining MIMO with a distributed antenna system (DAS). The receiver includes also two antenna elements (for separating the two different MIMO streams).

D2   Modelling in WinProp Network Planning

For considering MIMO antennas in the WinProp radio network planning project first the corresponding MIMO scheme has to be selected on the Air Interface tab of the menu Project / Edit Project Parameter (see Fig. D2). Options for MIMO technology include MIMO 2 Streams, MIMO 4 Streams, but also "No MIMO supported." The latter gives you the flexibility to define a Distributed Antenna System (DAS) instead of a MIMO system. Depending on the selected MIMO scheme a corresponding number of separate MIMO data streams is considered (e.g. MIMO 2x2 with two parallel streams or MIMO 4x4 with four parallel streams). Note that we only specify properties at the transmitter. At the receiver side, the assumption is:

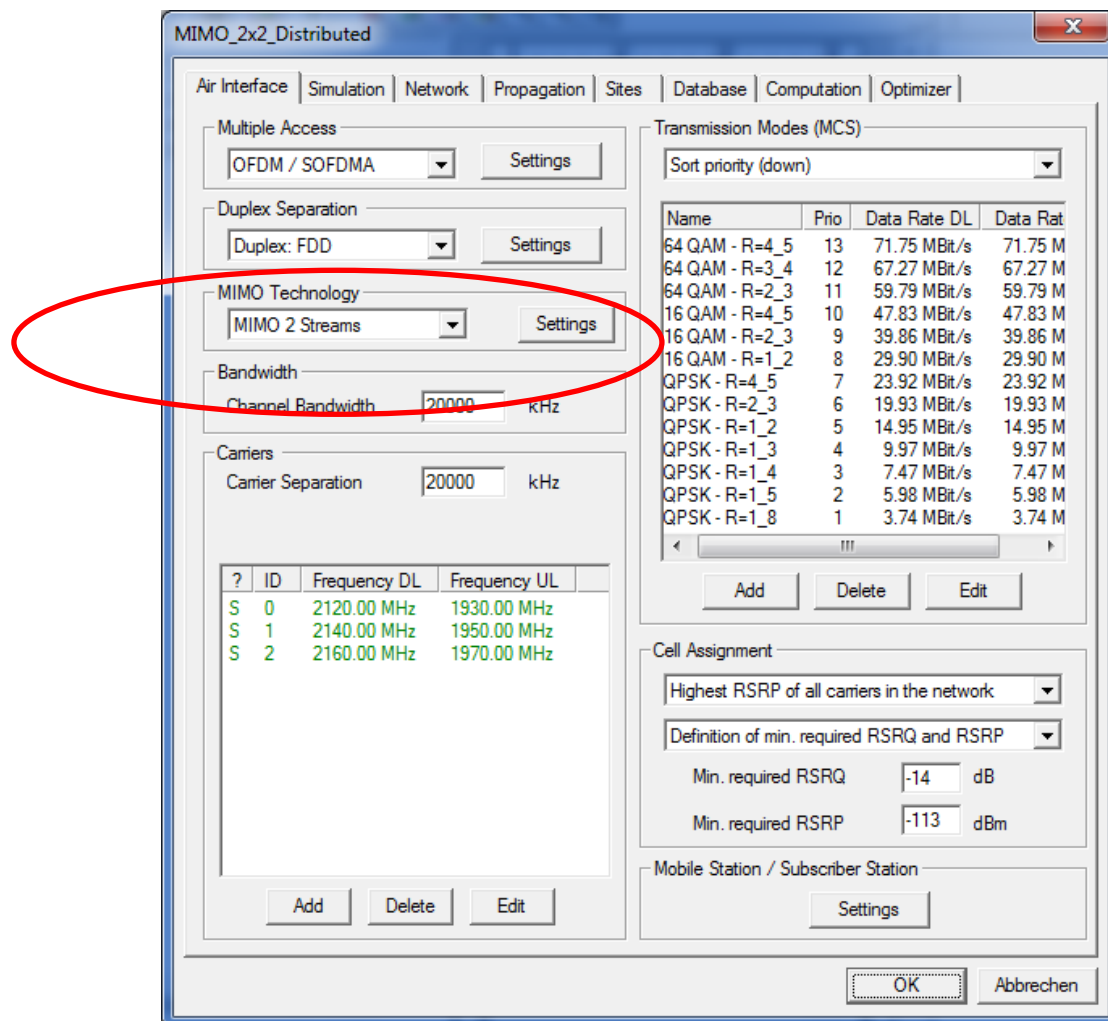(number of Rx antenna elements) = (number of MIMO streams)

Fig. D2 Air interface definition including MIMO technology

Under the Settings button further properties of the MIMO antenna system can be specified (see Figs. D3 and D4).

D2.1 Signaling Overhead

When transmitting multiple data streams in parallel due to spatial multiplexing there is an additional signaling overhead required which reduces the effective achievable data rate. The defined value is considered once for MIMO 2x2 and twice for MIMO 4x4.
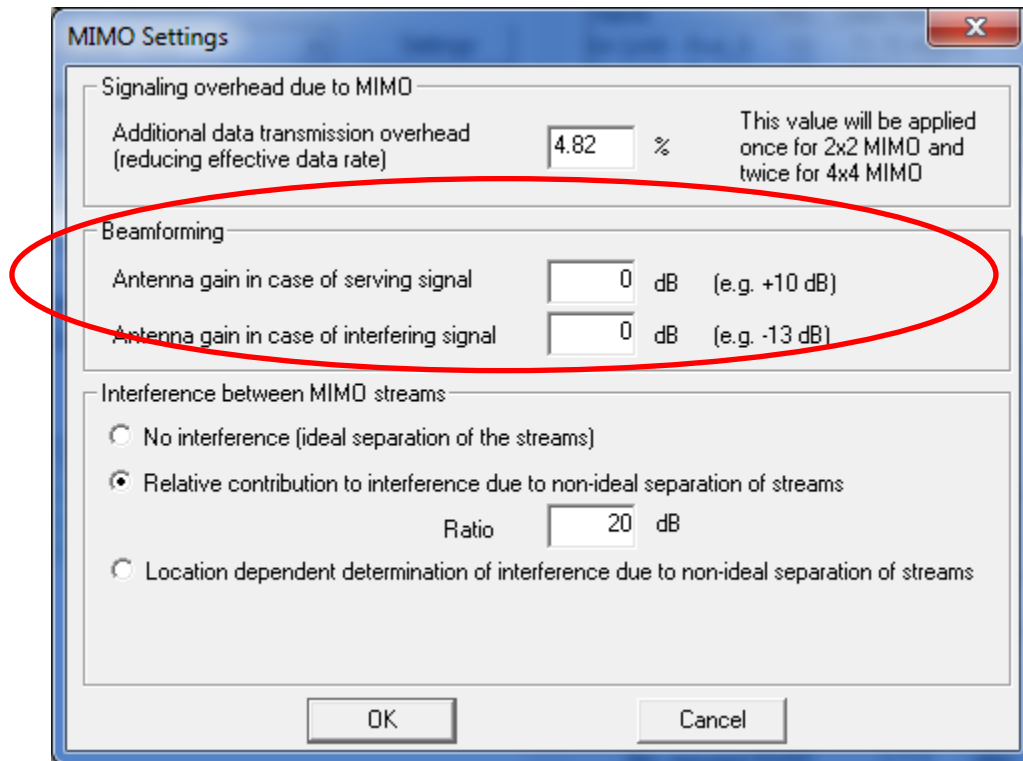

Fig. 3   MIMO settings regarding beamforming

D2.2 Beamforming

Beamforming at the transmitter can be achieved by spatial processing. In this case the same signal is emitted from each of the transmit antennas with appropriate phase weighting such that the signal power is maximized at the receiver input.

The benefits of beamforming are to increase the received signal gain, by making signals emitted from different antennas add up constructively, and to reduce the multipath fading effect. Spatial multiplexing can also be combined with beamforming when the channel is known at the transmitter.

In the absence of scattering, beamforming results in a well-defined directional pattern, thus increasing the antenna gain for the desired signal and reducing the antenna gain for the interfering signal. Consequently,

the antenna gains for the serving and interfering signals can be defined in the MIMO settings (see Figure 3) if beamforming is utilized. These values shall be kept to 0 dB if no beamforming is applied.

D2.3 Interference between MIMO streams

Spatial multiplexing by using MIMO antennas enables to increase the throughput depending on the signal-to-noise-and-interference ratio (SNIR). The SNIR is also influenced by the interference between the different MIMO streams.

The MIMO settings page provides three different options for this purpose (see Fig. 4):

o   *No interference (ideal separation of different streams)*

If different polarizations are used (e.g. vertical polarization for MIMO stream 1 and horizontal polarization for MIMO stream 2) the streams are well separated, especially in Line-of-Sight areas (this is one case where MIMO works well without a rich multipath environment). Thus, a simple assumption consists in neglecting the interference between the different MIMO streams.

o   *Relative contribution to interference due to non-ideal separation of streams*

In this case an overall ratio for the interference between the different streams is specified. If the Envelope Correlation Coefficient equals 0.01 (this can be determined by means of a post-processing script in FEKO, and is a typical value for some systems), then 20 dB is specified at this option. This means that for a MIMO 2x2 system the received power for MIMO stream 1 will increase the interference level for MIMO stream 2 (i.e. received power minus 20 dB) and vice versa. This option considers a constant relative interference impact over the whole simulation area (considering the individual received power values for each stream at each location).

o   *Location dependent determination of interference due to non-ideal separation of streams*

This option considers the individual receiver location and the properties of the corresponding radio link (LOS/NLOS) for the interference impact. To ensure high accuracy, further options for consideration of polarization are available.
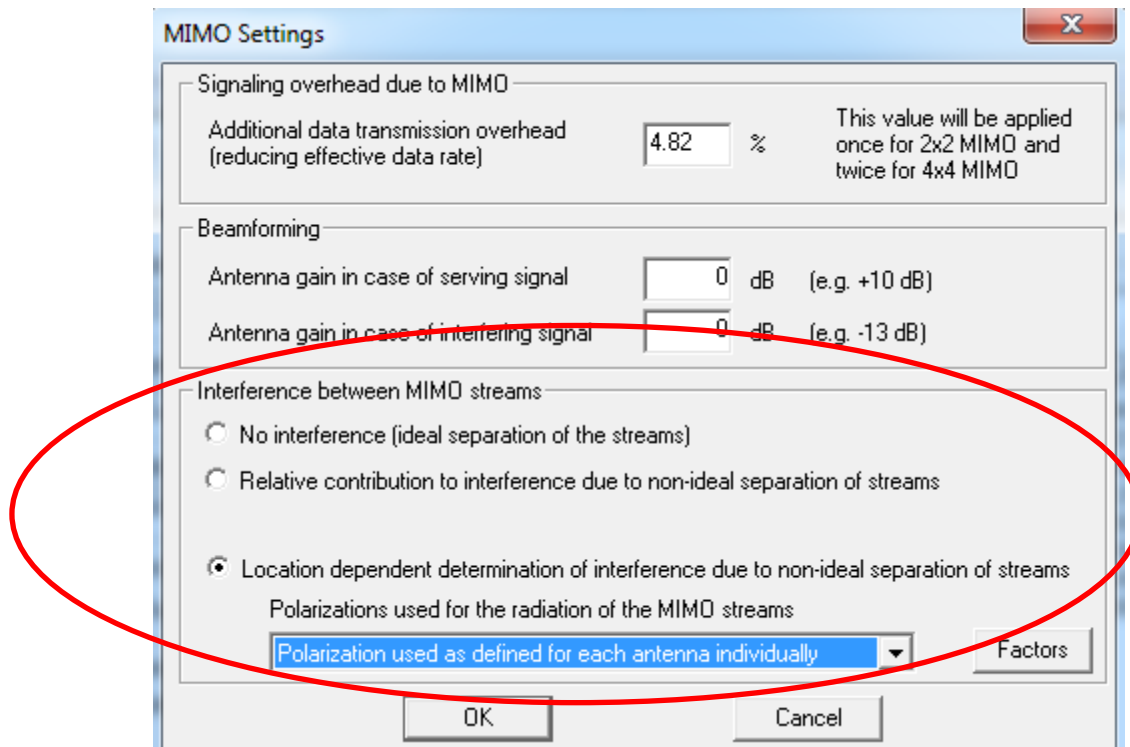
Fig. D4: MIMO settings regarding the interference between different MIMO streams

D2.4 Antenna Definition

At this point, you have defined how many MIMO streams are available. The next important step is part of the antenna definition. Generally, the antennas belonging to MIMO systems are defined in the same way as conventional antennas, i.e. location, carrier frequency, and transmit power of the antennas are defined as usual. **For each MIMO antenna element in network planning, a separate antenna has to be defined in ProMan.**

As part of the selection of the Carrier (the frequency) for every individual antenna in network planning, you are asked to specify certain properties of the transmitted signal: which Signal Group it transmits, and, if applicable, which MIMO Stream within the Signal Group.

For conventional (non-MIMO) antennas the Signal Group ID is set to **individual** (thus no MIMO stream can be selected).

The so-called **Signal Group** has to be set to the **same ID** for all antennas belonging to a MIMO system. Furthermore, the transmitted MIMO stream has to be selected.

Generally, all antennas belonging to a MIMO system must have the same carrier. Depending on the assigned Signal Group ID and the assigned MIMO stream the signals from different antennas are combined constructively or interfere each other.

Defining the system in the Carrier window

Antenna Type	Signal Group	MIMO Stream
Conventional antenna	Individual	Not available
Antenna belonging to DAS	A / B / C / ...	No MIMO
Antenna belonging to MIMO	A / B / C / ...	MIMO stream 1 / stream 2

The Signal Group and MIMO stream selection can be found in the Carrier settings (see Fig. D5) of a transmitter.
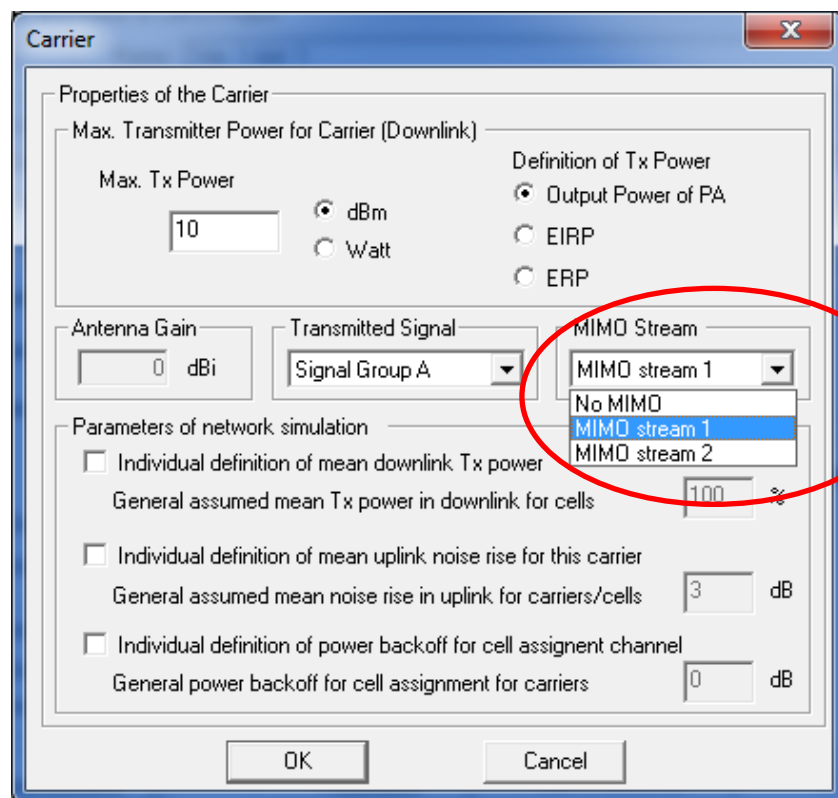

Figure D5: Carrier settings for transmitter with Signal Group selection

All antennas belonging to one MIMO system must have the same **Signal Group ID**. If only one MIMO system is available in your project it is recommended to use **Signal Group A** for all antennas which are part of the MIMO system.

D3 Theory

D3.1 Computation of MIMO Results

For the computation of the MIMO result maps the received power (dBm) and the SNIR (dB) is computed for each defined MIMO stream (according to the specified MIMO scheme) in each receiver pixel. In this context also the interference between different MIMO streams operating on the same carrier (and Signal Group ID) is considered (depending on the selected option, see Figure D4). Finally, the feasible modulation and coding scheme depending on the given SNIR is selected.

If the serving cell is a MIMO antenna the received power is the superposition of the signal power values from all antennas belonging to the MIMO system and transmitting the same MIMO stream.

Determination of Received Power

Antenna Type	Received Power
Conventional antenna	Received power from serving cell
Antenna belonging to distributed antenna system (DAS)	Superposition of received power values from all antennas belonging to DAS of serving cell
Antenna belonging to MIMO system	Superposition of received power values from all antennas transmitting the same MIMO stream as the serving cell

D3.2 Computation of Interference

Usually signals which are radiated on the same carrier but from different antennas interfere with each other as individual signals are transmitted. Signals which are radiated from different antennas but within the **same** DAS do **not** interfere (if they have the same Signal Group ID). If the antennas belong to a MIMO system the interference depends on the transmitted MIMO stream. Antennas transmitting the same MIMO stream are considered to operate like a DAS (e.g. in a 4x2 MIMO system). If the antennas transmit different MIMO streams they interfere each other depending on the individual situation (spatial separation, usage of different polarizations, LOS/NLOS scenario). The interfering effect can be reflected by selecting the appropriate option in the corresponding dialogue (see Figure D4).

Antenna 1	Antenna 2	Interference (same carrier)
Conventional antenna	Conventional antenna	Yes
Conventional antenna	Antenna belonging to **DAS A**	Yes
Antenna belonging to **DAS A**	Antenna belonging to **DAS A**	No
Antenna belonging to **DAS A** **MIMO Stream 1**	Antenna belonging to **DAS A** **MIMO Stream 1**	No
Antenna belonging to **DAS A** **MIMO Stream 1**	Antenna belonging to **DAS A** **MIMO Stream 2**	Yes
Antenna belonging to **DAS A**	Antenna belonging to **DAS B**	Yes

D4   Example

This section presents an example for the better understanding of the MIMO feature in WinProp's network analysis. Figure D6 shows an office scenario with two antennas (distributed MIMO system). Both antennas use the same carrier - otherwise there would be no co-channel interference in the scenario.
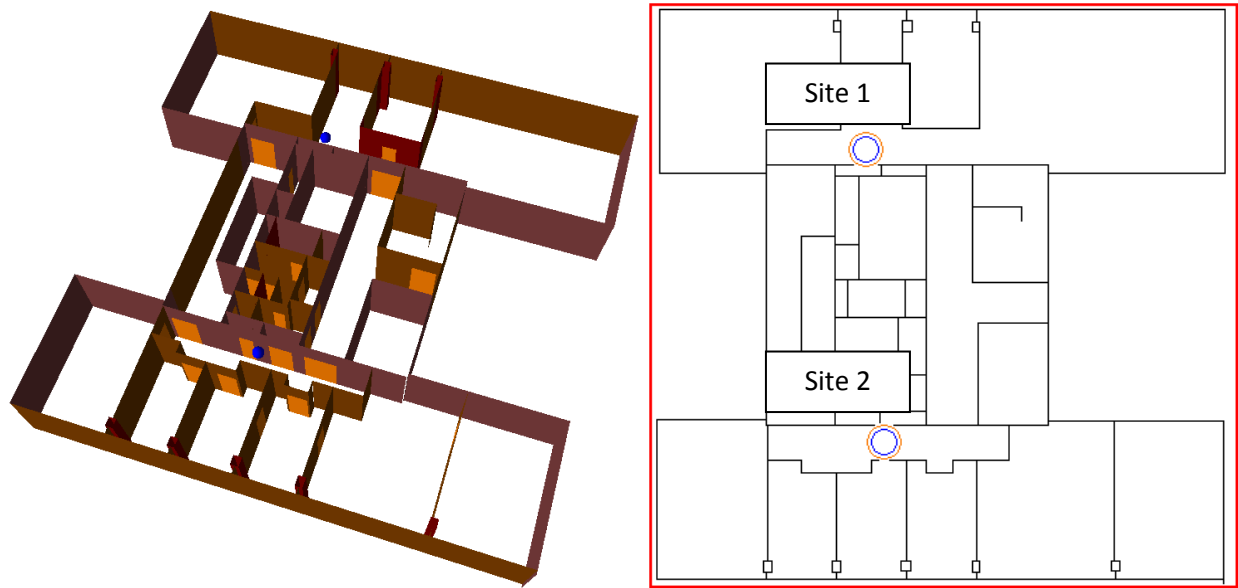

Fig. D6 Office scenario with two antennas (DAS or MIMO 2x2)

The main parameters of the network are shown in the following table.

Network parameters used in this example

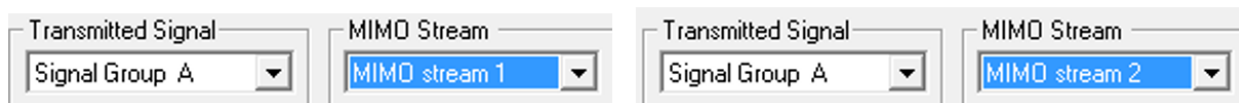| Parameter	Value
Frequency	2630 MHz
System bandwidth	20 MHz
Transmit power	5 dBm Output power of PA
Antenna height	2.5 m
Min. required SNIR (depending on MCS)	Between –5.4 and 17.2 dB
Air interface	LTE

Two different antenna configurations are analyzed in the following:

- Configuration 1: Both sites are conventional antennas forming a DAS (Signal Group **A**).

- Configuration 2: Both sites are MIMO antennas (Signal Group **A**) and transmit individual MIMO streams (site 1 MIMO stream 1 and site 2 MIMO stream 2).

Figure D7 and Figure D8 show the data rate maps for these two configurations.
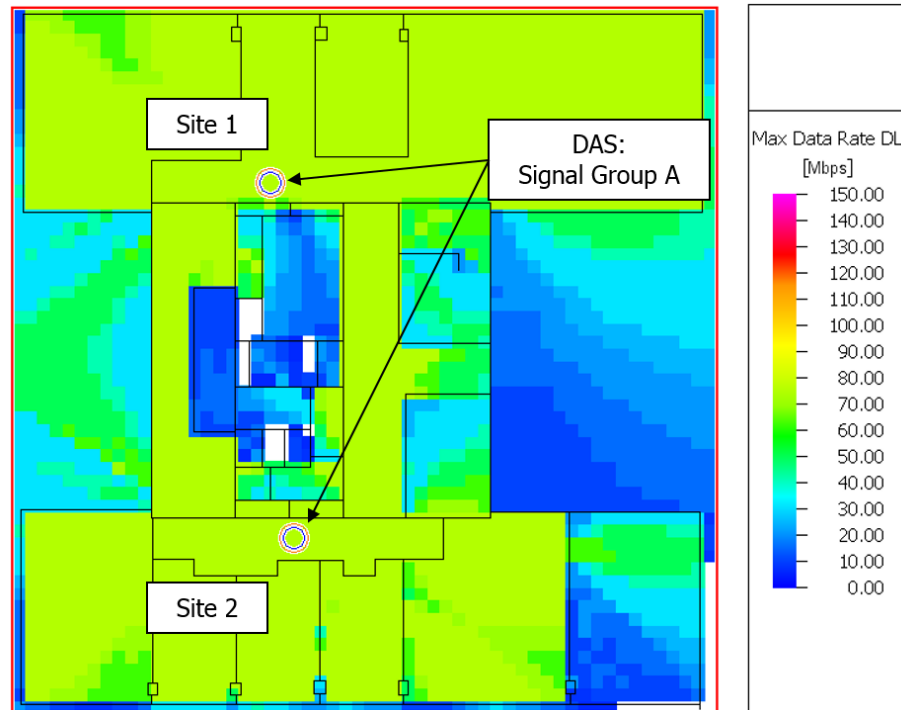
Figure D7   Maximum data rate (downlink) for DAS network (configuration 1)
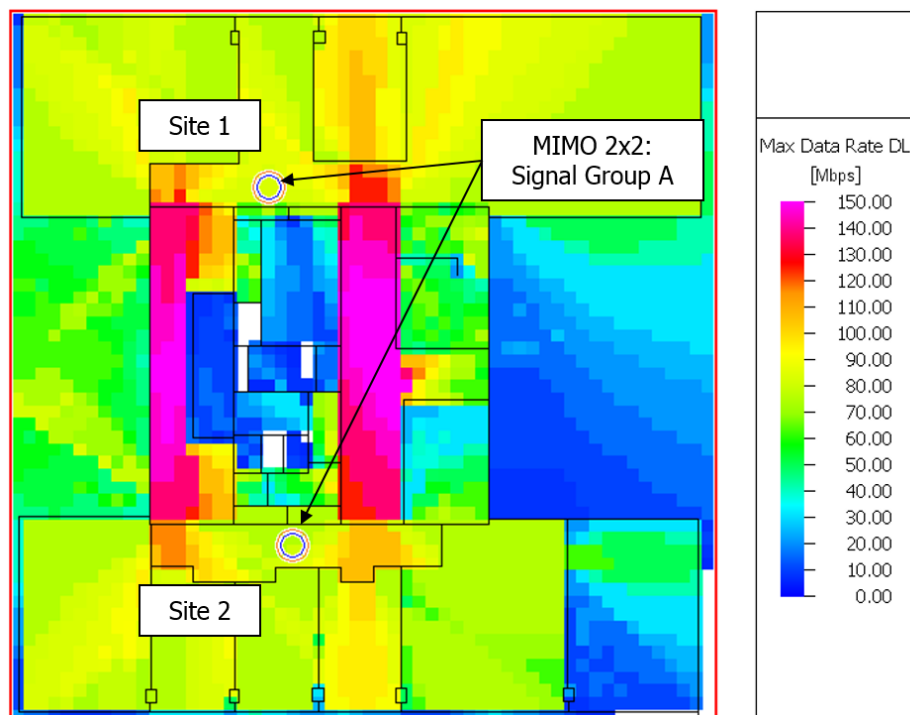

Fig. D8   Maximum data rate (downlink) for MIMO 2x2 network (configuration 2)

In Figure D7 (configuration 1), both antennas operate on the same carrier and form a Distributed Antenna System. Essential is that they both transmit the same Signal Group. Because of that the signals from both antennas are superposed constructively and improve the SNIR situation. Nevertheless the maximum data rate is limited to 75 Mbit/s as only one data stream can be transmitted.

If we had selected "Individual Signal" instead of the same Signal Group for these antennas, then the interference would have reduced the maximum data rate.

Figure D8 shows configuration 2 where again both antennas operate on the same carrier, but this time sites 1 and 2 form a 2x2 MIMO system. Here MIMO stream 1 is transmitted from site1 and MIMO stream 2 is transmitted from site 2 in spatial multiplex. Accordingly, higher data rates can be achieved for a large part of the office building (assuming here ideal separation of the different MIMO streams). Generally, the performance depends also on the interference between the MIMO streams.