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MIMOSA – Analysis of the MIMO channel for LMS systems

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Abstract. MIMO systems are already state-of-the-art in terrestrial systems. With the availability of satellites with higher EIRP the high spectrum efficiency offered by MIMO systems becomes applicable to satellite-based systems, too. The MIMOSA project covers the evaluation of the satellite MIMO channel characteristics by field measurements. In particular, the estimated capacity increase for mobile reception is evaluated. The measurements have been completed, but the analysis is still ongoing. This paper describes the measurement setup and includes selected results from the statistical analysis.

Keywords: Fading channels, Land Mobile Satellite (LMS), Multiple-Input Multiple-Output (MIMO), polarization diversity, frequency selective fading, channel measurement equipment (CME), Characterisation of the MIMO Channel for Mobile Satellite Systems (MIMOSA)

1. Introduction. Satellite MIMO systems

In modern communication systems several diversity technologies are typically combined. The following table gives an overview of the concepts. For satellite-based applications antennas with good cross-polarisation discrimination (XPD) allow the use of both polarisations. This is already widely used for direct-to-home (DTH) broadcast applications with line-of-sight (LOS) reception. The MIMOSA project mainly covers the use of both polarisations for applications with mobile reception.

TIME (time interleaving)	**SPACE**
- Provides a high gain for mobile reception. - For satellite systems the slow and very slow fading effects are dominant. Accordingly a long interleaver is required.	- Transmit side: Angle diversity (several satellites) - Receive side: Several receive antennas.

FREQUENCY (wideband systems)	**POLARISATION**
- Mainly useful in case of frequency-selective fading. - For satellite-based systems typically a low delay spread is expected and hence a diversity gain is only expected if very high bandwidth is selected.	- Already widely used for satellite-based systems to double the effectively available bandwidth. - Today mainly used for LOS and antennas with high XPD - For small antennas or NLOS reception a low XPD is expected.

In general, two types of MIMO scenarios for satellite-based systems can be distinguished:

- Single (or co-located) satellite (SS-MIMO)
- Multiple satellites (MS-MIMO).

In the case of MS-MIMO, when a minimum angle separation of the satellites is given, the propagation paths are highly uncorrelated. Only some correlation for the large scale parameters has to be taken into account depending on the angular separation and environment. This effect was analysed by the MiLADY project [1, 3, 6]. For the MiLADY project only one receive antenna was used and hence the MISO channel was characterized (Fig. 1). Assuming the fast fading is uncorrelated, the MiLADY results can also be extrapolated to a MIMO

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channel for MS-MIMO systems. SIMO (antenna diversity) was evaluated in the framework of other projects (e.g. J-ORTIGA [4, 8]). The MIMOSA project mainly covers SS-MIMO (Fig. 2). In case of SS-MIMO the spatial separation of the transmit antennas is negligible and a high correlation between the MIMO sub-channels is expected. Accordingly, the analysis of the correlation of the large-scale fading (slow fading) as well as the small-scale fading (fast fading) should be investigated.

2. MIMO configuration and antenna types

The Solaris S-Band payload hosted on the Eutelsat 10 A satellite allows transmitting LHCP and RHCP signals in parallel. Together with two receive antennas a 2×2 MIMO system will result.

MIMO relies on the decorrelation between different reception paths. The decorrelation results from:

- Transmission channel
- Environment
- Antenna position
- Antenna

The characteristics of the transmission channel and the environment are considered identical for a given measurement location.

To study the impact of the antenna configuration, five receive antennas were mounted on a ground plane on the roof of a car. This allows comparing different 2×2 MIMO configurations. The distance between the antennas is depicted in Fig. 3. A photo of the antenna setup is provided in Fig. 4. The setup included dual polarized circular antennas (DPC), which can be considered as two antennas within one housing. A DPC antenna provides two output ports. Accordingly, seven output ports were available. One port was unused, essentially resulting in a 6×2 MIMO system. The labelling for the resulting 12 sub-channels is given in Table 1.

For the SPC antennas it is obvious that the antenna patterns are different from each other. For the DPC antennas this is also the case, as can be seen in Fig. 5.

This results from slight differences in the feeding network of the antennas resulting from fabrication tolerances of the antenna PCB (printed circuit board) and used components. Hence even in a channel with 100% correlated fading decorrelation between the polarisations results. One of the key parameters for systems using several polarisations is the cross-polarisation discrimination (XPD). In case of good (high compared

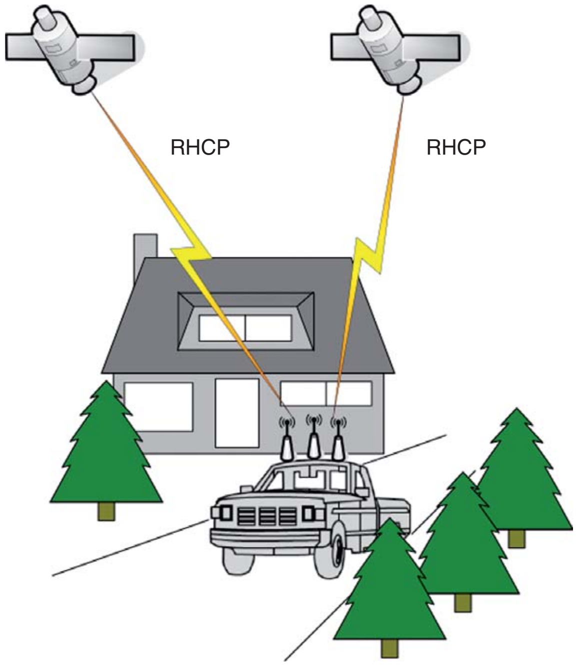


Fig. 1. MiLADY measurement campaign (MISO).

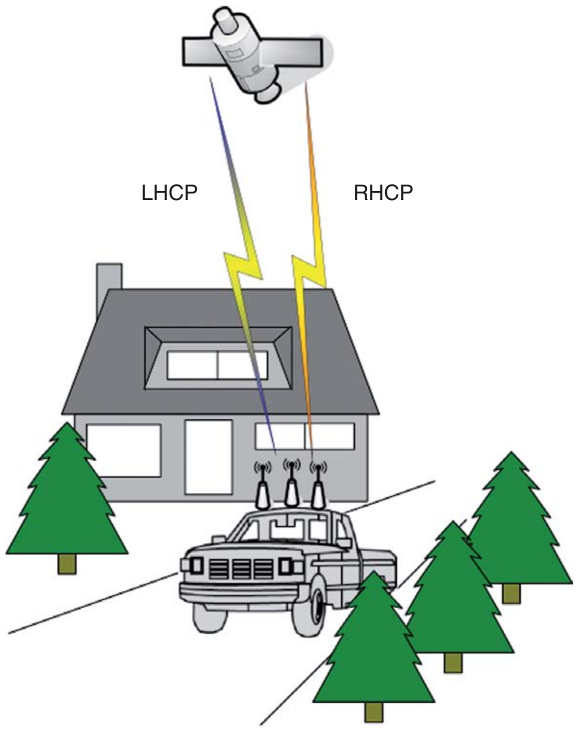


Fig. 2. MIMOSA measurement campaign (MIMO).

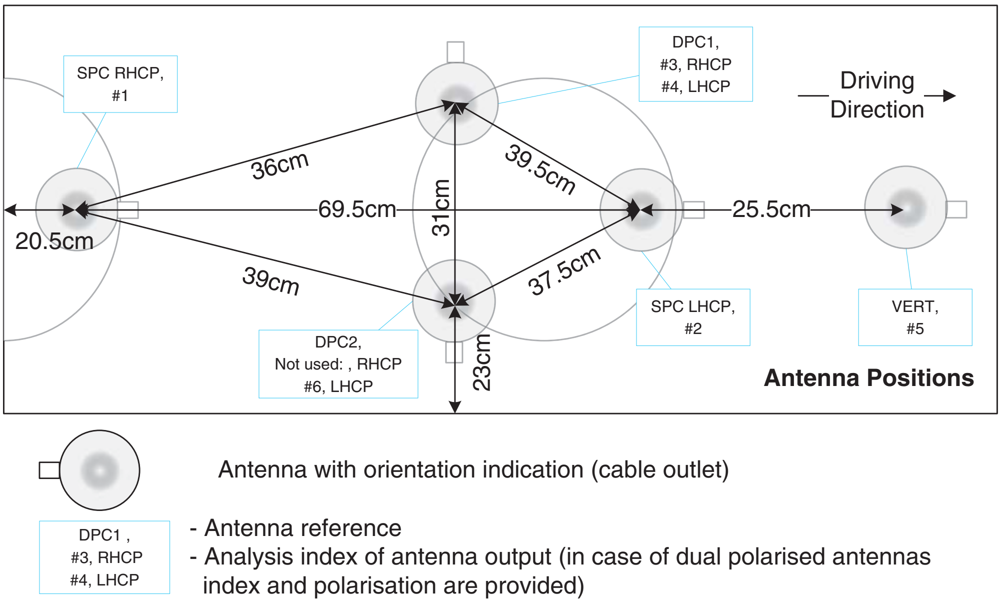


Fig. 3. Position of antennas of the MIMOSA antenna array on groundplane.

Table 1

Used Antennas and related channel index (Bold-blue: copolarized-Signal Index; black crosspolarized-Signal Index)

#		Antenna name	Description	Antenna type
1	$\mathbf{h}_{11}$	SPC1	Single polarisation circular, RHCP	Patch
	h_{12}			
2	h_{21}	SPC2	Single polarisation circular, LHCP	Patch
	$\mathbf{h}_{22}$			
3	$\mathbf{h}_{31}$	DPC1	Dual polarized circular #1	4
	h_{32}	R-Port	RHCP port	L-Monopoles
4	h_{41}	DPC1	Dual polarized circular #1	4
	$\mathbf{h}_{42}$	L-Port	LHCP port	L-Monopoles
5	$\mathbf{h}_{51}$	VERT	Vertical polarized	Monopole
	$\mathbf{h}_{52}$			
6	h_{61}	DPC2	Dual polarized circular #2	4
	$\mathbf{h}_{62}$	L-Port	LHCP port (The RHCP port of DPC 2 was unused)	L-Monopoles

to the SNR) XPD, the system can be considered as two independent SISO systems (“2*SISO”). In case of reduced XPD interference cancellation can be applied, which can be considered as a simplified MIMO system. For a full MIMO system, both signals (polarisations) have to be processed, whereas for a 2*SISO one polarisation can be selected and interference cancellation is only performed for receivers using antennas with low XPD. Depending on the receive position and the application, the following scenarios can be distinguished:

- LOS reception & receive antennas with good cross-polarisation discrimination (XPD), low/ medium SNR: The main channel capacity results from the sub-channels h_{11} and h_{22}. The contribution of h_{12} and h_{21} is marginal. The system performance is close to 2*SISO (two channels in parallel using different polarisation).
- High SNR (SNR in the same range as the XPD) or low gain antennas with limited XPD. Without MIMO processing or interference cancellation the capacity is limited by the interference.

- NLOS reception (e.g. shadowed environment): Multipath propagation and fading of the direct components will reduce the XPD. This is caused by scattering or reflections of the signal.

According to this overview of the applications, the following system scenarios shall be distinguished:

- Stationary reception, "cooperative user" (= user looks for good reception position): LOS reception can be assumed. Stationary reception allows also full link adaptation to run the system close to the theoretical capacity feasible for LOS reception. MIMO and 2*SISO essentially double the useful bandwidth. The MIMO gain (compared to 2*SISO) is mainly defined by the XPD.
- Stationary reception, limited user cooperation: The user may install the receiver at a suboptimal position. If link adaptation is performed the data rate will be reduced accordingly. Designing a system for broadcasting the system operator adds a "fade margin" according to the target service availability for this type of users.
- Mobile reception, antenna installed on the roof of a car.
- Handheld reception: Low gain antennas are assumed with low XPD.

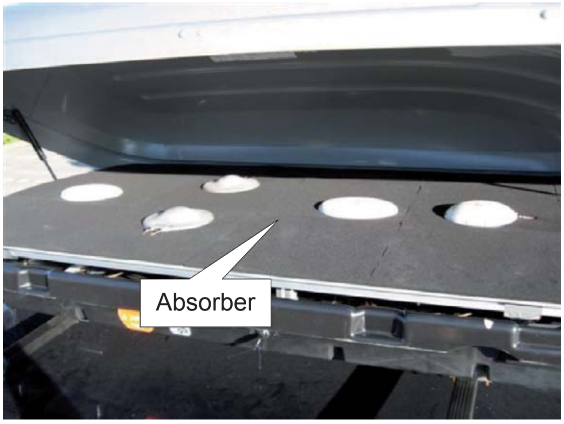


Fig. 4. Antenna assembly used for measurement campaign #1.

3. Field measurements

The MIMOSA project mainly focuses on mobile reception using small car-roof antennas considered as typical for applications such as DVB-SH. A satellite signal at 2.187 GHz centre frequency from the Solaris playload of 10 A satellite was used as transmit signal. LHCP and RHCP were transmitted in parallel using the same centre frequency. In the uplink frequency multiplex was selected and the frequency translation in the satellite was selected to transmit signals with both polar-

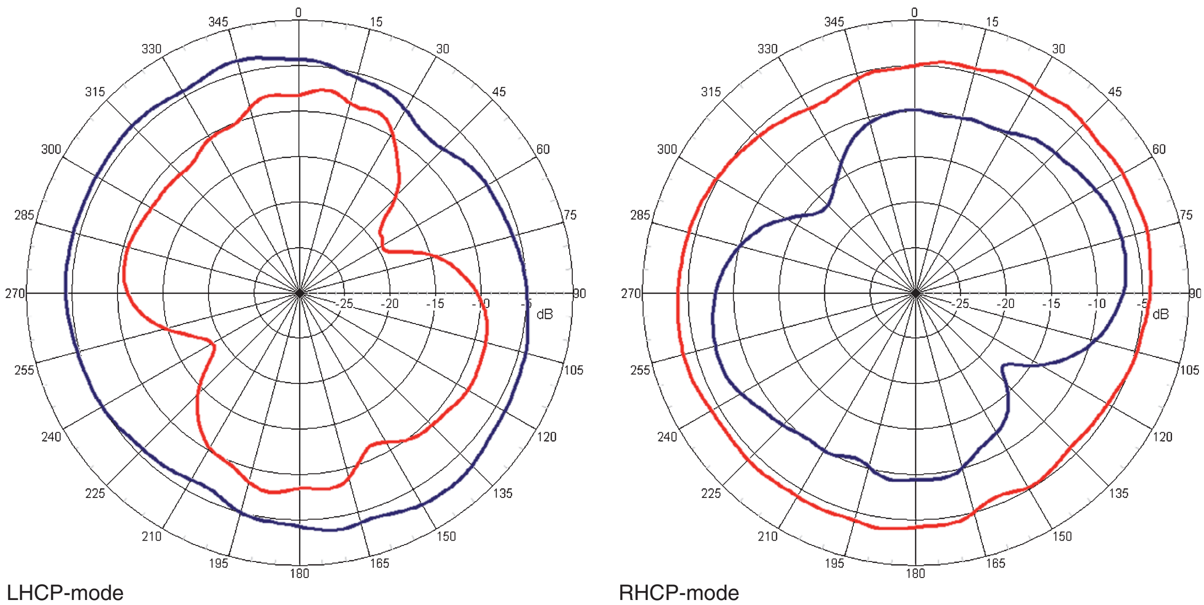


Fig. 5. Antenna patterns for FhG DPC antenna (Theta: 60°, frequency 2185 MHz; red crosspol signal, blue copol signal).

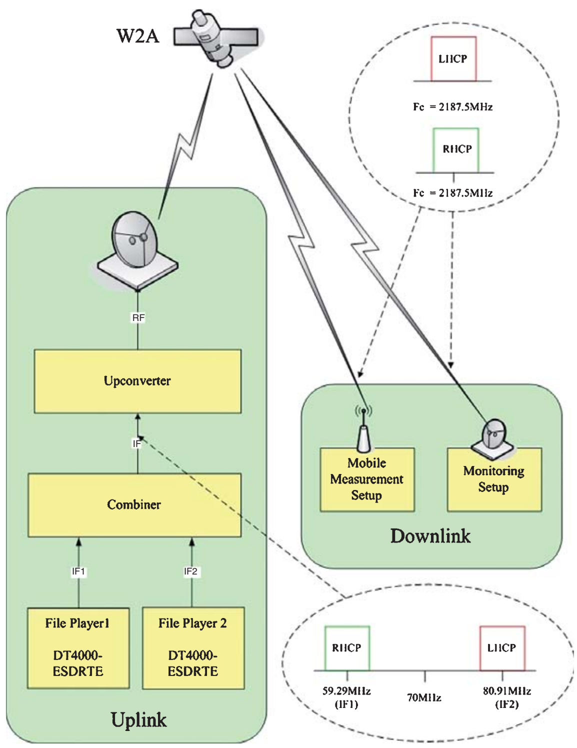


Fig. 6. Overview to the measurement setup.

isations in the same band. The overall setup is depicted in Fig. 6. The transmit signal was a multi-tone signal containing several CW signals. The phase relationship of the CW signals was optimized for peak-to-average ratio. This multi-tone signal can be considered as OFDM waveform reduced to the continuous pilots by stripping off all payload data. Using a multi-tone signal with a known phase relationship, the coherence bandwidth can be estimated to detect frequency-selective fading. A small frequency offset for one signal was introduced resulting in an interlaced signal allowing unique identification of the signal. Hence, a direct measurement of the channel coefficient of a N $\times$ 2 MIMO system was implemented. Figure 7 shows the principle.

For the recording and signal analysis a FFT-based filter bank was implemented. Figure 8 gives an overview. The time window before the FFT defines the frequency response of the filter bank. Essentially the FFT splits the signal into overlapping subbands. Only the subbands carrying a signal have to be recorded. A FFT of the length 4096 was used and a subset was recorded directly to the hard disc of a computer for all antennas in parallel. Further details on the measurement equipment ("CME") can be found in [2, 7]. The CME was adapted to the requirements of the MIMOSA measurement campaign. The frequency offset introduced by the frequency error of the oscillator on board of the satellite movement was estimated and removed by the processing tool chain.

The MIMOSA measurements can be split into 4 parts:

- #1A: Measurement using Solaris capacity as source, location Erlangen
- #1B: Measurement using Solaris capacity, location Lake Constance
- #2A: Signal from a high building, recording with CME

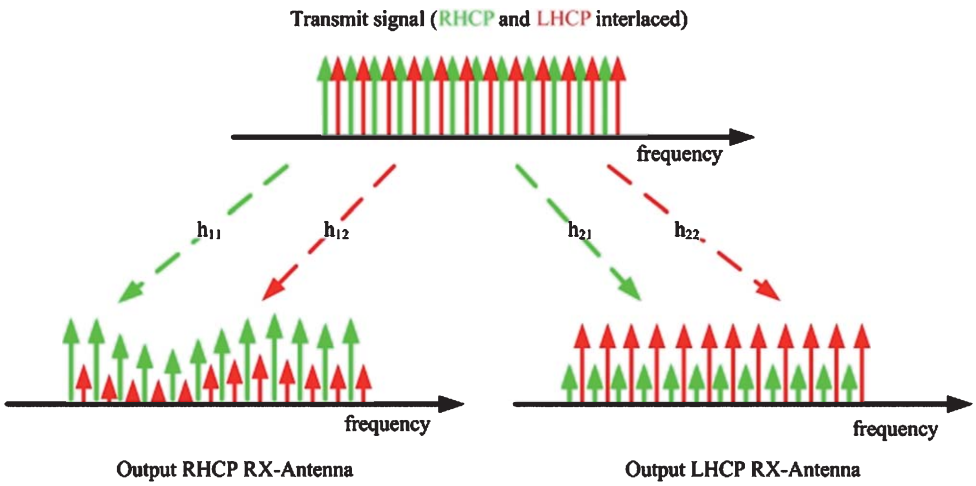


Fig. 7. Interlacing of RHCP and LHCP showing effects of transmission path (h_{11}, h_{22} co-polarized transmission, h_{12}, h_{21} cross-polarized transmission).

Table 2
Length of overall recordings sorted by environment

Environment	Erlangen (min)	Lake constance (min)
Urban	105	118
Suburban	139	233
Rural	31	120
Highway	27	30
Forest	49	50

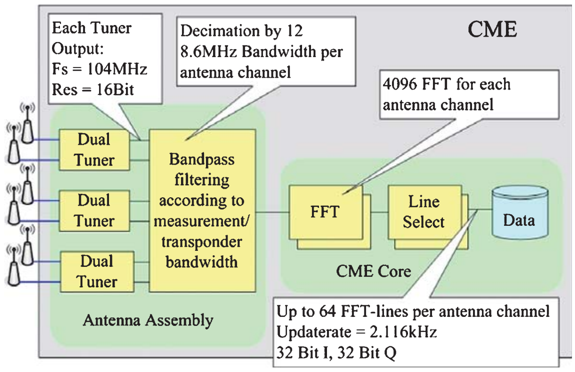


Fig. 8. Data recording principle.

Fig. 9. Overview of measurement tracks around Lake Constance.

#2B: Signal from a high building, measurement with RUSK channel sounder.

#1A and #1B covered several environments. The overall measurement durations by environment are provided in Table 2. An overview of the measurement routes around Lake Constance is provided in Fig. 9.

4. Delay spread and coherence bandwidth analysis

The classification of the environments is done in a 3 step approach:

1. The selection of the measurement area already provides a certain expectation on the possible environments for a measurement, which is taken as baseline.
2. During the fieldtrial the measurement personnel takes down their impression on the environments. Additional information (GPS, Video) is collected during the measurement. Based on that information the environment classification is refined.
3. First order analysis is done for all tracks of a given environment. From that results a mean behaviour for a given environment against which all individual tracks are compared. Tracks showing abnormal behaviour are evaluated once more.

For satellite signals a low delay spread and hence a high coherence bandwidth is expected leading to the use of narrowband models for simulation purposes [5]. For the field measurements a transponder bandwidth of 5 MHz was available. A detailed channel impulse response (CIR) measurement is not feasible with this bandwidth. The detailed CIR analysis is in the scope of the second measurement campaign using a high tower for the satellite emulation. The first measurement campaign focuses on the statistical analysis of the probability of significant frequency-selective fading. This statistical analysis is performed in the frequency domain. Figure 10 shows an example for time/frequency response of a time-variant frequency-selective channel typical for terrestrial systems. The colour represents the signal strength.

For LMS channels a higher coherence bandwidth is expected. Figure 11 shows the resulting characteristics for a measurement bandwidth of 5 MHz together with the overall power of the signal (lower part of the figure). Dominant are the slow fading effects, which show a minor frequency dependency. Figure 12 represents details of an enlarged section. It can be observed that the small scale fading shows some frequency-selective fading. If systems with high spectral efficiency are simulated and hence a high accuracy of the channel estimation is required, it may become necessary to use wideband models capable of modelling frequency-selective fading.

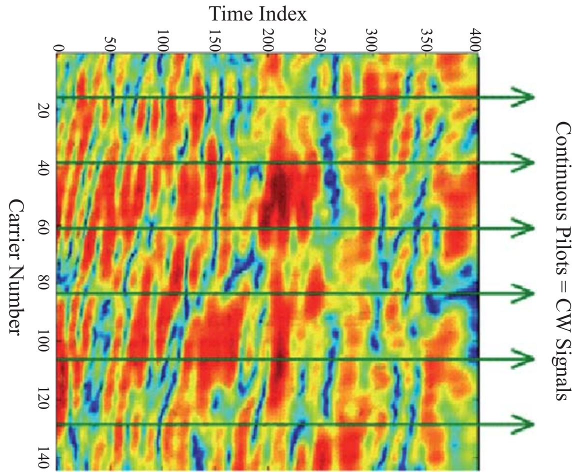


Fig. 10. Example of wideband recording of an OFDM signal showing the placement of continuous pilot signals.

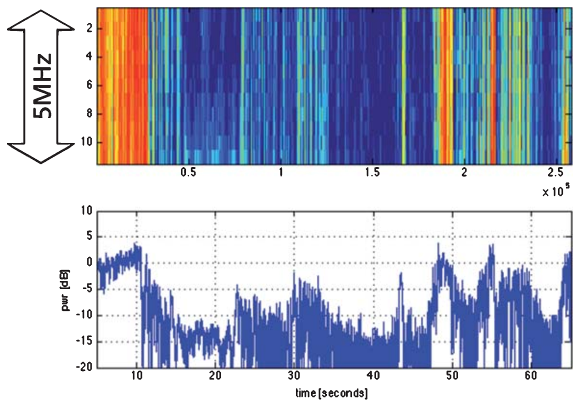
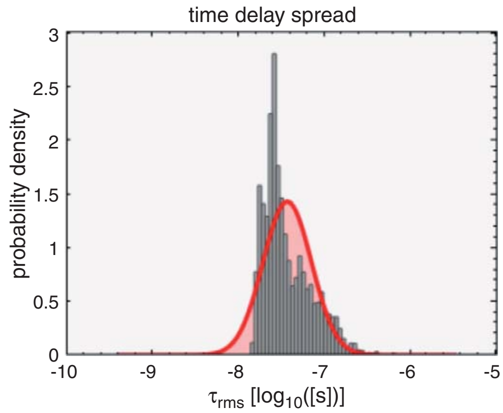
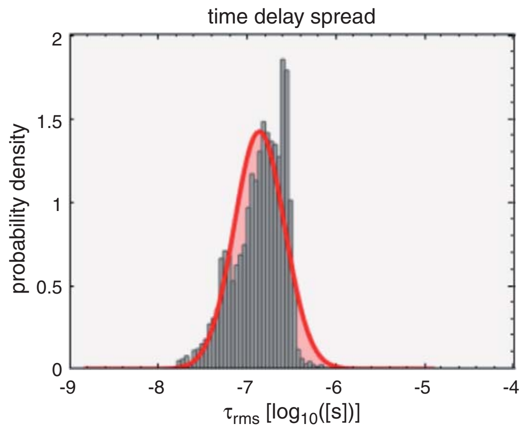


Fig. 11. Time/frequency response of a satellite channel snapshot.



LOS - 25.0..35.0° - time delay spread - N(-7.4.0.3) - #17975



NLOS - 25.0..35.0° - time delay spread - N(-6.9,0.3) - #25012

Fig. 13. (a) RMS delay spread, LOS case (Good state); (b) RMS delay spread NLOS case (bad state).

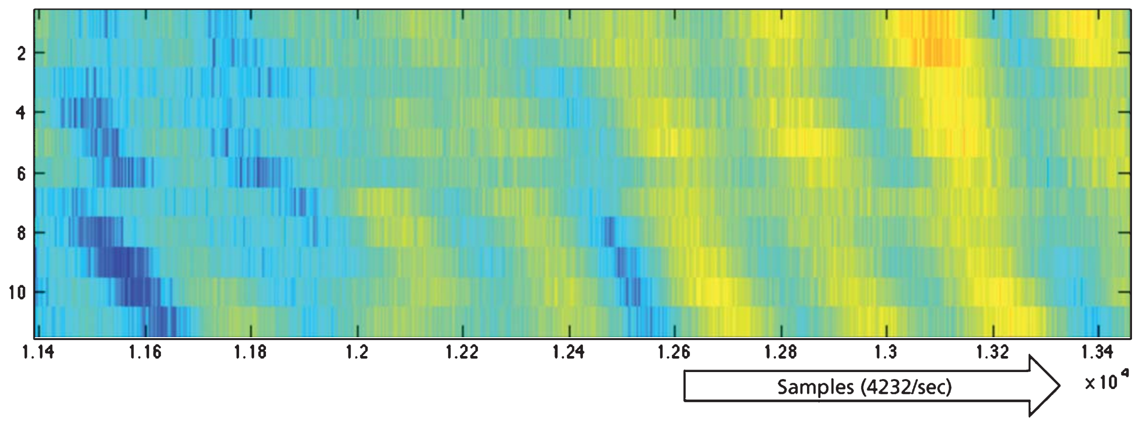


Fig. 12. Zoom of Fig. 11.

The main scope of the analysis is the estimation of the probability that, for a signal bandwidth of 5 MHz, a relevant frequency-selective fading can be observed. The analysis is ongoing. Initial results indicate that only for NLOS reception the delay spread is in a range that the frequency response of the channel shall be taken into account for the channel estimation. This assumption is also confirmed by the measured delay spread for selected scenarios. For measurement campaign #2 a channel sounder and a measurement bandwidth of 20 MHz was used. The RMS delay spread of the measured CIR was estimated and a statistical analysis performed. The resulting probability density functions are depicted in Fig. 13a and 13b together with a lognormal curve fit. The X-axis of the plots is $\log_{10}(\tau_{RMS})$. The snapshots have been sorted to a "LOS" and "NLOS" case. The mean RMS delay spread is 40 ns ($\log_{10}(40\,\text{ns}) = -7.4$) for LOS and 120 ns for NLOS. The measurement was performed in an urban environment.

5. Analysis of the correlation

The CME supports a full synchronous recording of the signals from all antenna ports. This allows a detailed analysis of the correlation between amplitudes and phases of the fading. It is also possible to compare different 2×2 subsets out of the recorded 6×2 sub-channels. Examples of useful subsets are summarized in Table 3. The table includes the antenna port, the polarisation of the co-polarized signal and the related sub-channel name of the co-polarized sub-channel. To study the impact of the spatial separation of the antennas, the pair DPC1R/DPC1L can be compared with DPC1R/DPC2L, for example. The pair DPC1R/DPC2L compared with SPC1/SPC2 shows the difference of a mounting of the antenna "left/right" versus "front/back". SIMO versus MIMO can also be compared.

The following examples shall visualize the channel characteristics. The data was classified as described in chapter III and sorted accordingly. The environment "tree-shadow1" represents areas with many trees including forest. One- or two-story buildings close to the street are typical for "Sub-urban2". The data are analysed using the following methods.

1. First order statistics (Figs. 15 and 16): The analysis was performed for all 4 sub-channels of a 2×2 MIMO subset. The plot shows the characteristics of the co-polarized signals (blue and red) and the cross-polarized signals (green and cyan). The dotted and dash lines show the behaviour for different frequencies. Especially for the XPD the antenna characteristic is not omnidirectional and also depends on the frequency. Accordingly, a high deviation for different frequencies results.
2. To visualize the correlation pseudo 3D plots are useful. First a 2-dimensional histogram is generated were the X-axis represents the first signal and the Y-axis the second signal. The colour ("Z-axis") represents the probability. In case of 100% correlation of the fading (signal 1 equal to signal 2) a 45° diagonal would result. The deviation from the 45° diagonal is a measure for the de-correlation. Figures 17 and 18 show the difference between separated antenna (distances approx. 70 cm) and co-located antennas (DPC antenna). It is observed that in both cases the fading is highly correlated. As explained in chapter II a deviation from the 45° diagonal is to be expected also for the co-located antennas even in the case of a 100% correlation of the fading.
3. If signal 1 represents the co-polarized signal (e.g. H31) and signal 2 is the cross-polarized signal the distance to the 45° diagonal is the XPD. Figure 19 shows the characteristics of the XPD in case of fading. For LOS reception the XPD depends mainly on the antenna. During the verification of the antenna in the anechoic chamber a high dependency on the azimuth was also observed. This causes the large "red area" in Fig. 19, right part. Data points beyond the 45° line represent reception conditions where the cross-polarized path is stronger than the co-polarized path. This demonstrates that the multipath propagation has a high impact on the polarisation.
4. In a similar way the characteristics of the Rice factor can be visualised. By analysing the short term Doppler spectrum the received signal was split into a "direct component" arriving from the angle of the satellite position and "indirect signals" (multipath signals). If the 2D histogram of these two signals are plotted the distance to the 45° line represents the Rice factor. Figure 20 gives an example for the environment "tree-shadow1". For LOS reception with minor multipath components the Rice factor is high. For NLOS two effects are observed: - In the transition zone from LOS to NLOS the multipath power increases. It is assumed that more scattering and reflection

Table 3
Examples for subsets which can be derived from the 6 × 2 MIMO recording

Port A, signal	Port B, signal	Scenario	Comments
DPC1L (LHCP) (h32)	DPC2L LHCP (h62)	SIMO (2 × 1) (= antenna diversity)	Antennas for same signal at different positions, approx. 31 cm distance approx. 21/4 wavelength
DPC1R RHCP (h31)	DPC2L LHCP (h62)	MIMO (2 × 2), RX antennas at different positions	Comparing to the co-located case the impact of the antenna distance 31 cm can be studied
DPC1R, RHCP (h31)	DPC1L LHCP (h42)	MIMO (2 × 2), co-located RX antennas	"co-located antenna" = two antennas in a housing ⟶ same receive position ⟶ sub-channels are separated by polarisation only. High correlation of the sub-channels is expected.
SPC1 RHCP (h11)	SPC2 LHCP (h22)	MIMO (2 × 2), RX antennas at different positions	Same scenario as DPC1/2. But different antenna type ⟶ study impact of antenna type to the measurement results
VERT (h51, h52)	-	MISO (1 × 2) scenario.	Study the correlation of LHCP and RHCP propagation using an antenna which should receive both signals equally

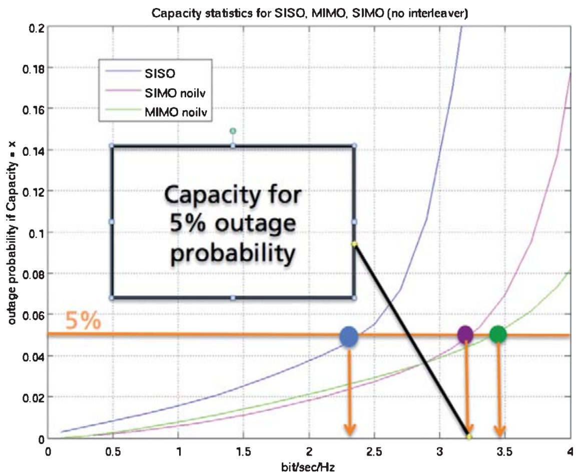


Fig. 14. Criteria used to compare configurations/environments.

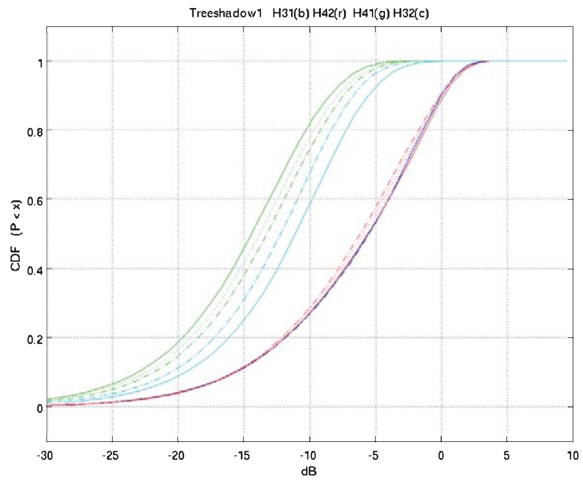


Fig. 15. First order statistics for environment "tree shadow 1" (many trees, close to forest).

objects are closer to the receive antenna. - In the NLOS region the multipath (MP) power remains nearly constant and shows a minor correlation with the fading of the direct component. For the cross-polarized signal the direct power is lower and the statistical distribution of the MP power is similar to the characteristics of the MP power for the NLOS region of the co-polarized signal.

6. MIMO capacity

The methods described above are useful to visualize the channel characteristics. To estimate the MIMO gain the channel capacity can be calculated. The following methodology was used:

1. Calculate the instantaneous capacity using the following formulas

$$C_{SISO} - log_2\left(1+\gamma\left|h_{ji}\right|^2\right) \quad (1)$$

$$C_{SIMO}\text{-}log_2\left(1+\gamma\left(\left|h_{ji}\right|^2+\left|h_{ki}\right|^2\right)\right) \quad (2)$$

$$C_{MIMO} - log_2\left(det\left[\mathrm{I}_2+\left(\gamma/2\right)\mathrm{HH}^{\mathbf{2}}\right]\right) \quad (3)$$

where $\gamma$is the signal-to-noise ratio at LOS reception and h_{ji}, h_{ki}, H the measured channel

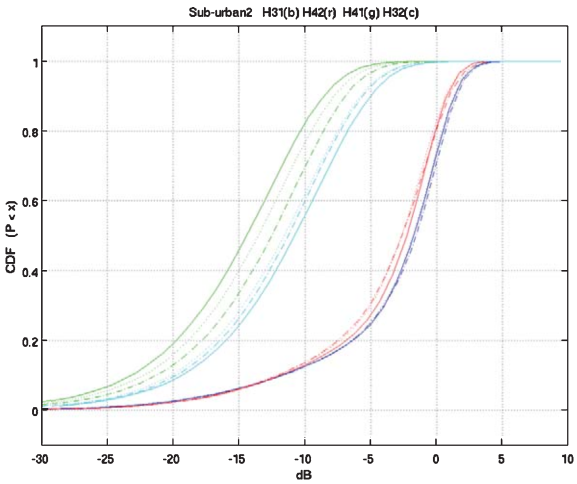


Fig. 16. First order statistics for environment "sub urban2" (small houses close to the street).

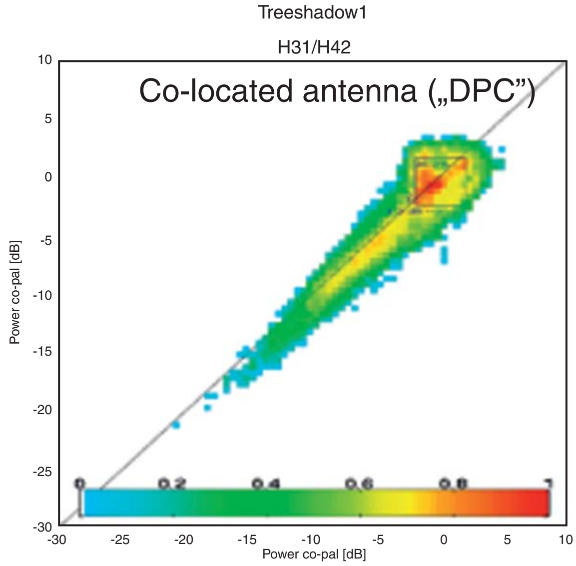


Fig. 18. Correlation of the fading, "co-located" antenna.

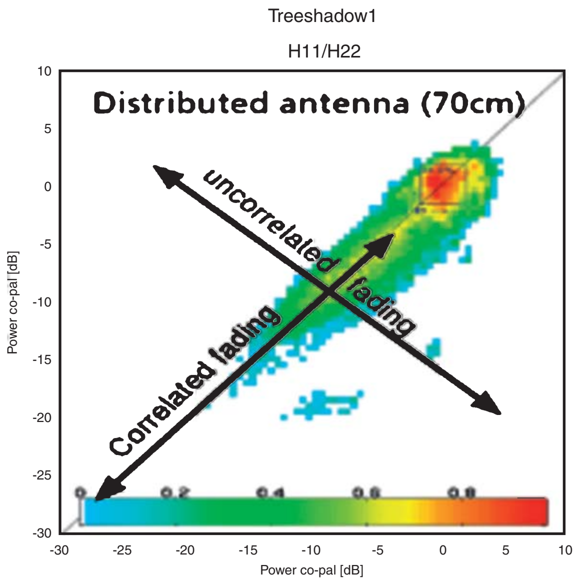


Fig. 17. Correlation of fading, antenna distance approx. 70 cm.

coefficients or a 2×2 Matrix of the channel coefficients.

2. For the "non-interleaved case" calculate the cumulated probability density function (CDF) of the calculated capacity.
3. To take into account the gain of time interleaving the following method is used
   a. In line with the interleaver concept of DVB-SH it is assumed that a code word is split into small "interleaver units" (IU). The IU represents a short burst. For the IU the average capacity obtained by calculating the mean over the length of an IU. For the results presented in this document an IU length of 529 symbols was assumed.
   b. The modulation constraints are taken into account by setting the calculated capacity to 80% of the maximum feasible capacity according to the selected modulation order. The 80% takes into account a non-perfect FEC scheme and overhead caused by pilots. The 80% is an empirical value, which matches very well the performance of schemes like DVB-S2 or DVB-SH. For SISO and SIMO 16-APSK was assumed resulting in an upper limit of the capacity of 3.2 bit/sec/Hz. For the calculation of the MIMO capacity 2*8-PSK was assumed giving a maximum capacity of 4.8 bit/sec/Hz.
   c. To emulate the capacity of a code word the sum of the capacity of all IU belonging to a code word is calculated and normalized to the number of IU belonging to the code word. The convolutional interleaver is assumed for the selection of the IU belonging to one code word.
4. The CDF of the capacity per code word is calculated.

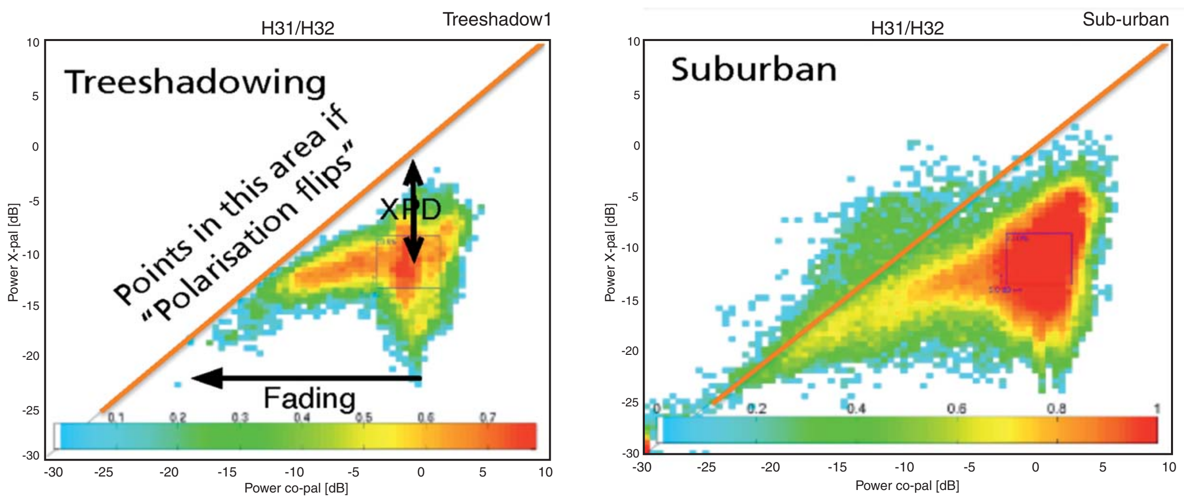


Fig. 19. Impact of the fading to the XPD.

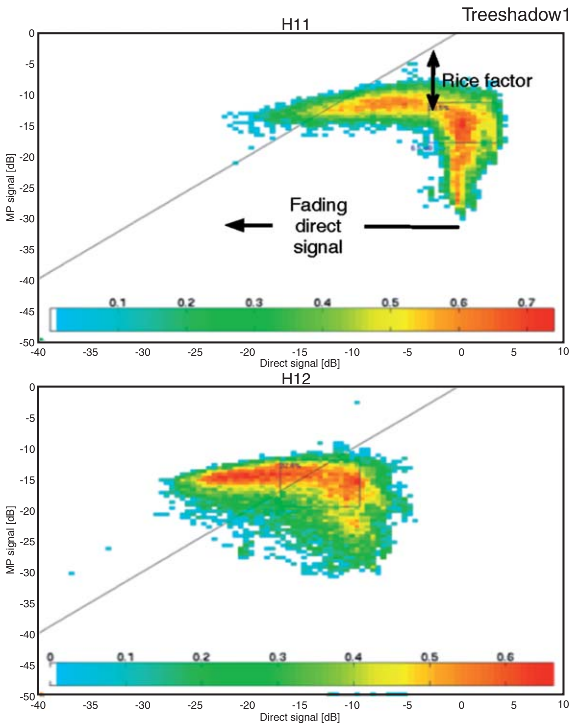


Fig. 20. Impact of the fading to the XPD

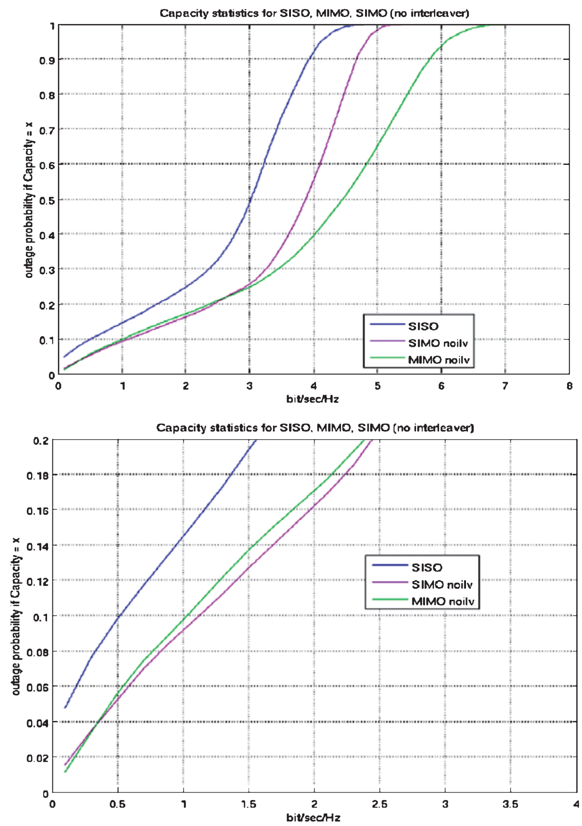


Fig. 21. Outage probability versus capacity, "instantaneous capacity" (= no interleaving), environment "sub-urban2".

5. To compare the results for different environments, MIMO/SIMO/SISO subsets the capacity which is exceeded in 95% of the cases. This value is equivalent to 5% outage probability of the code rate and other modulation parameters are selected according to the estimated capacity. Figure 14 illustrates this criteria.

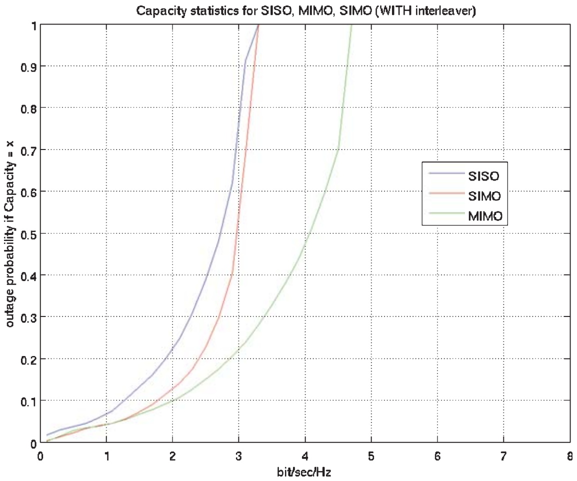


Fig. 22. Outage probability with time interleaving (10 sec).

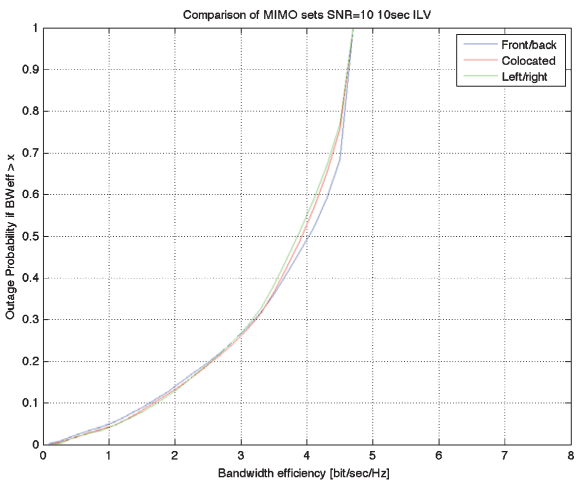


Fig. 23. Comparison of different antenna configurations.

6. Effects like non-linearity, additional output back-off (OBO) for 16-APSK or non-ideal channel estimation or MIMO processing is not taken into account.

The results are presented in Figs. 21 to 25. Figure 21 covers the analysis for the instantaneous capacity (no interleaving) for SISO, SIMO and MIMO. The upper part gives an overview. The lower part is a detailed view of the part covering a low outage probability. The selected environment is sub-urban2. The MIMO subset with separated antennas was selected for this plot. For MIMO port 3 (RCHP port of DPC1) and 6 (LHCP port of DPC2) was used. The related ports with the same antenna configuration for SIMO are port 4 (LHCP port of DPC1) and port 6 (LHCP port of DPC2). The figure highlights the gain of MIMO compared to SISO and also shows that for medium and low outage probability SIMO provides a similar performance.

Introducing a time interleaver the capacity for 5% outage probability can be significantly increased. Figure 22 shows the estimated capacity for a 10 second interleaver for the environment sub-urban2 (same as used in Fig. 21).

Figure 22 compares different antenna configurations. The figure compares pairs "front/back" (SPC1 and SPC2), "left/right" (one port of the two DPC) and co-located (both ports of the DPC1 are selected). It can be concluded that in case of long time interleaving and a moving car, the antenna distance plays a minor role and hence the main gain results from using two antennas.

The environment characteristic has a major impact on the feasible capacity. From the measurements different sequences have been extracted and the capacity for the 5% outage probability calculated. Figures 24 and 25 give an overview. The environment subsets include tree-shadowing (1 and 2), different types of sub-urban areas (3, 4, 5), urban areas (6, 7), different rural areas (8, 9, 10, 11) and industrial areas (12 and 13). Further details can be found in Table 4. Two conclusions can be taken from the diagram.

- In all cases a high gain compared to SISO is achieved.
- The difference between SIMO and MIMO becomes higher if the SNR or the environment characteristics allow higher capacity.

7. Conclusions

The datasets recorded during the MIMOSA field-trials allow the characterisation of the MIMO channel. The paper gives an overview of the different analysis methods and the expected results. The data analysis is still under way. The values given in this paper shall be considered as preliminary. From the presented material the following conclusions can be taken:

– The key parameters are the environment characteristics.
– Compared to SISO the main gain results from the use of several receive antennas.
– Comparing MIMO with SIMO especially for systems offering a high SNR, MIMO can offer significantly higher capacity.

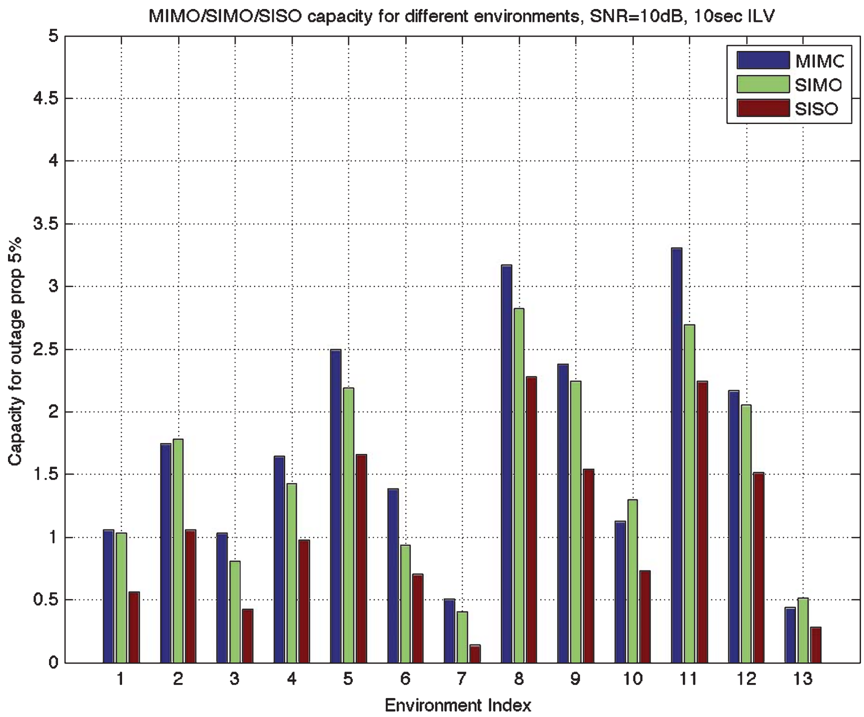


Fig. 24. Estimated capacity for different environments, SNR = 10 dB.

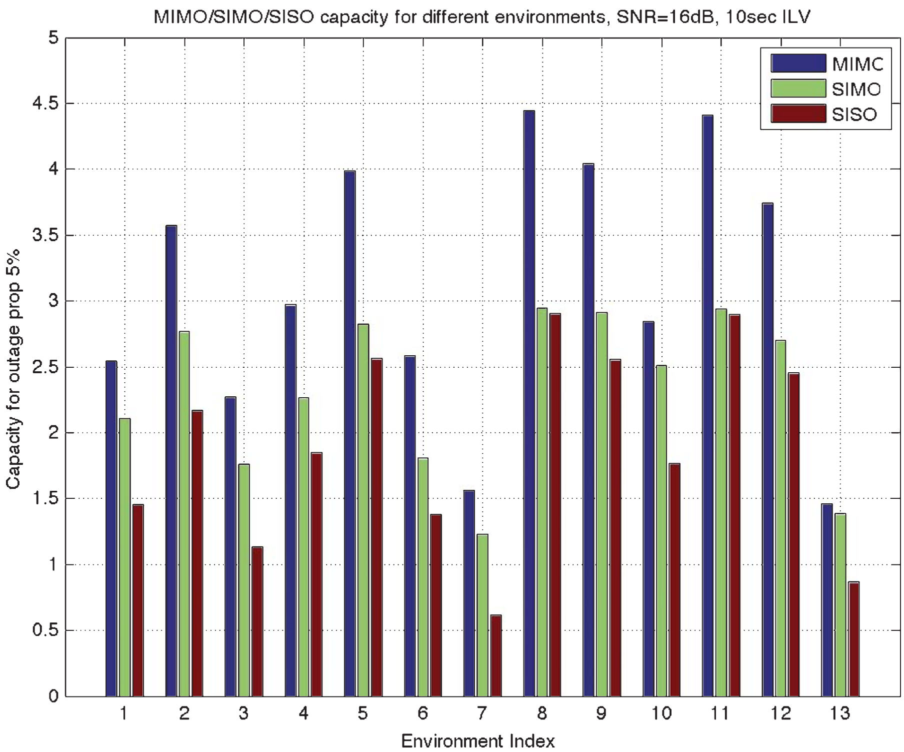


Fig. 25. Estimated capacity for different environments, SNR = 16 db.

Table 4
Environment selection criteria

ID	Characteristics
1	Tree shadowing 1: Driving through forest. Many trees close to the street.
2	Tree shadowing 2: Many trees close to the street, but many gaps between the trees
3	Sub-urban 1: Area with many tenements of medium height (typical 2 story building) close to the street. Only small gaps between buildings. Only a few trees in the street.
4	Sub-urban 2: Area with many trees and medium size houses. Many gaps between the buildings. Distance between building and street in a range that for medium elevation the satellite is sometimes visible.
5	Sub-urban 3: Area with "large gardens" around the buildings. Mainly small houses (areas which large houses and wide streets are more considered as commercial area).
6	Urban 1: Urban areas with traffic lights and sometimes stop and go traffic. For mobile receptions a variable speed should be assumed (with sometimes long stops in area with signal blockages. Result depends highly on traffic condition.
7	Urban 2: Narrow streets in urban areas
8	Rural 1: Open areas with many villages (characteristics of villages may be close to suburban, but size of village is small (e.g. diameter <1 km)
9	Rural 2: Rural area with trees
10	Rural 3: Mixed scenarios (some villages, some trees)
11	Rural 4: Mixed secnarios (some buildings, single trees)
12	Commercial 1: Industrial area with many large buildings, typically many gaps (e.g. for parking lots) between the buildings
13	Commercial 2: Industrial area, small buildings close to the street

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