Power and Delay Domain Parameters of Channel Measurements at 2.53 GHz in an Urban Macro Cell Scenario

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***Abstract*—Realistic channel data have shown to be a mandatory pre-request for performance studies of recent mobile system designs beyond 3G, in particular when considering novel multi-antenna techniques. Channel models conceived in IST-WINNER, COST273 or standardisation bodies are based on real-field measurement data. This paper presents analysis results of so called large-scale parameters derived from an extensive multi-user and multi-base station MIMO measurement campaign in an urban macro cell scenario. The focus is on the parameters of the delay and power domains, their distribution as well as auto and crosscorrelations. Parameters from WINNER II channel model could be verified, furthermore missing gaps among them could be closed. A third contribution shows strong variations of the parameters depending on the base station position. Parts of the considered measurement data are free accessible and can be used for free research.**

***Index Terms*—large scale parameter, transmission loss, shadow fading, delay spread, k-factor, measurement data, channel sounding, spatial channel modelling, reference scenario, auto and crosscorrelation**

I. Introduction

In order to derive reliable channel models in particular for evaluation of multi antenna system designs [1] channel measurements within the targeted deployment and propagation scenario are necessary [2], [3]. Channel models developed within European projects COST [1], [4], WINNER II [5], or standardisation bodies [6] rely on carefully analysis of mobile radio measurements. Furthermore they are based on scenario classifications. This contribution focused on the analysis of the large scale parameters (LSP) derived from power and delay domain including their statistics and auto/crosscorrelation. The analysis follows the procedures from the WINNER II channel model [5]. The underlying measurement data sets were gathered in an urban macro cell environment and are taken from an extensive MIMO channel sounding campaign in the center of Ilmenau, Germany. Whereby parts of the measurement data are free accessible via the web site [6] and can be considered as reference scenario for channel modelling and system evaluation [8]. In particular the used measurement configuration targets many system aspects that are of interest for the current standardisation process, e.g. configurations as multiple base stations and multiple users, relaying as well as frequency and bandwidth. Furthermore the presented data offers huge potential for scientific research, because of the considered system setup, high quality of the acquired data and applicability for high resolution multipath parameter estimations. The underlying paper is structured as follows: a short summary of the MIMO measurement campaign is given in Section II. In Section III detailed explanation of the analysis procedures is presented and in Section IV the results are shown in terms of figures and tables. The paper ends with the summary in Section V.

II. MIMO Channel Measurement Campaign

The Measurement and antenna setups, which match the requirements of the 3GPP Long Term Evolution (LTE and LTE-A [7]) are described in detail in [8]. The channel sounding was performed at 2.53GHz in a band of 2×45MHz. To allow high resolution path parameter estimations, dedicated antenna arrays at transmit (Tx) and receive (Rx) side are used. On the Tx side (base station), an uniform linear array is used with 8 dualpolarised (H/V) elements, each of which consists of a stack of 4 patches in order to form a narrow transmit beam in elevation. At the mobile (passenger car), a circular array with 2 rings of 12 patches with H/V polarisations is used. Additionally, a MIMO cube is placed on top. The mobile acts as Rx. For each of the tracks and for each measured snapshot, geo-data information based on GPS, odometer and separated distance measurements via laser are available. The accuracy around the start and end points for each track is approximately 0.1m and along the route 1m. A typical length of a track is 50m-70m. In total the measurement campaign covers 3 base station positions with 25m and 15m height and additionally a relay point (3.5m) in the middle of the scenario. Only the height of 25m is considered. The intersite distance between the base stations is found to be for BS1-BS2 = 680m, BS2-BS3 = 580m and BS3-BS1 = 640m. More than 20 individual tracks with more than 120 measurement runs were performed.

III. Data Analysis Procedure

To develop suitable channel models as from WINNER II [5], the large scale parameters (LSP) like the delay spread

(DS), the transmission loss (TL), shadow fading (SF) and the narrowband K-factor are needed. The LSP's have a fundamental role, because as global scenario dependent parameters they control the behaviour of the modelled channel. In the following detailed analysis steps of the LSP's based on the WINNER II document D1.1.2 V1.0 [5] are shown. Furthermore a second level of analysis is introduced by the auto and crosscorrelations among the aforementioned parameters.

From the RUSK channel sounder 4-dimensional channel transfer matrices $H(t, f, s, u)$ are provided. The variable t denotes time, when one snapshot is measured, f is the frequency and s is the s-th Rx and u the u-th Tx antenna, respectively. For our evaluation we only use 40MHz in the lower band. Additionally the snapshots where a line of sight (LOS) exists and where no line of sight (NLOS) is given were disjoined and the following calculations are made separate for each group of snapshots. The channel transfer matrices are transformed into channel impulse response matrices $h(t, \tau, s, u)$, where τ denotes delay. Due to noise that is included in the measured channel data, a noise power estimation and subsequently a thresholding in delay domain is applied to reduce the effect of the noise.

Based on the noise reduced data $\tilde{h}(t, \tau, s, u)$ the power delay profile $P(t, \tau)$ is calculated. For this purpose the instantaneous power is estimated

$$P(t, \tau, s, u) = |\tilde{h}(t, \tau, s, u)|^2. \tag{1}$$

For a better comparison per snapshot, different delays regarding to the maximum peak have to be eliminated. A delay shift τ_m is introduced and the maximal peaks are aligned. To reduce the dimensions additional, the delay aligned instant power is averaged over the (Tx, Rx)-antenna pairs and it results in

$$P(t, \tau') = \frac{1}{N_s N_u} \sum_{s=1}^{N_s} \sum_{u=1}^{N_u} P(t, \tau - \tau_m, s, u), \tag{2}$$

with

$$\tau_m = \arg\max_{\tau} P(t, \tau, s, u). \tag{3}$$

N_s and N_u is the number of Rx antennas and Tx antennas, respectively. The values for $\tau' < 0$ are discarded. Now the power delay profile per discrete snapshot t_0 is named $P_{t_0}(\tau') := P(t_0, \tau')$ and the preproceeding of the data per snapshot is done. For estimating the LSP's, the power delay profile $P(t, \tau')$ has to be averaged over $N_t(l)$ snapshots, where N_t is variable depending on the size of the stationarity interval. Here l denotes the number of the stationarity interval which is given by $|t_{l_{N_t}} - t_{l_1}| \leq 10\lambda$ where λ is the wavelength corresponding to the carrier frequency of the system. The value of time t in the middle of the interval is denoted by t_l

$$P_{t_l}(\tau') := P(t_l, \tau') = \frac{1}{N_t(l)} \sum_{i=1}^{N_t(l)} P(t_{l_i}, \tau'). \tag{4}$$

Based on this preprocessed data the LSP determination can be started. For a better readability in the following subsections τ' is substituted by τ.

A. Transmission Loss and Shadow Fading

The first parameters which are of great interest are the transmission loss and the deductive shadow fading. For the calculation of the transmission loss the total power

$$P_{t_l} = \sum_{i=1}^{N_\tau} P_{t_l}(\tau_i) \tag{5}$$

per LOS/NLOS stationarity interval is needed. N_τ represents the number of samples of the channel impulse response in the delay domain. Based on the position date the distance d between Tx and Rx for each stationarity interval l is derived and can be assigned to the distance d at time t_l: $P_{t_l} \rightarrow P(d)$. The transmission loss is then calculated as

$$\begin{aligned} T(d) &= 46\text{dBm} - 10\text{dB} - 10\log_{10}(P(d)/0.001) && (6) \\ &= 46\text{dBm} - 40\text{dB} - 10\log_{10}(P(d)) && (7) \end{aligned}$$

depending on the distance. The constant 46dBm is the transmit power at the channel sounder and the 10dB represents a correction factor which includes the antenna gains on Tx and Rx and the insertion losses of the corresponding multiplexing units. To estimate the shadow fading a linear regression of the transmission loss has to be performed:

$$\begin{bmatrix} T(d_1) \\ \vdots \\ T(d_n) \end{bmatrix} = \begin{bmatrix} 1 & \log_{10}(d_1) \\ \vdots & \vdots \\ 1 & \log_{10}(d_n) \end{bmatrix} \begin{bmatrix} B \\ A \end{bmatrix}. \tag{8}$$

The approximate transmission loss is

$$\overline{T}(d) = B + A \cdot \log_{10}(d) \tag{9}$$

and the shadow fading is calculated as follows:

$$SF(d) = T(d) - \overline{T}(d). \tag{10}$$

According to this results the probability density function (PDF) and the cumulative distribution function (CDF) has to be estimated.

B. RMS Delay Spread

An other important parameter is the root mean square (RMS) delay spread. Per stationarity interval a 20dB threshold below the maximum peak is applied to the respective power delay profile

$$P^*_{t_l}(\tau_i) = \begin{cases} P_{t_l}(\tau_i), & P_{t_l}(\tau_i) \geq \max P_{t_l}(\tau_i)/100 \\ 0, & \text{otherwise.} \end{cases} \tag{11}$$

Based on this restriction $P^*_{t_l}(\tau_i)$ is averaged over the total power to get the so called power distribution function

$$p_{t_l}(\tau_i) = \frac{P^*_{t_l}(\tau_i)}{\sum_{k=1}^{N_\tau} P^*_{t_l}(\tau_k)}. \tag{12}$$

The RMS delay spread is now the standard deviation of $p_{t_l}(\tau_i)$ and is calculated as follows:

$$\sigma_{t_l} = \sqrt{\left(\sum_{i=1}^{N_\tau} \tau_i^2 p_{t_l}(\tau_i)\right) - \left(\sum_{i=1}^{N_\tau} \tau_i p_{t_l}(\tau_i)\right)^2}. \tag{13}$$

The next task is the determination of the PDF and the CDF.

C. Narrowband K-Factor

For the estimation of the narrowband K-factor the preproceeded and delay shifted channel impulse response $\tilde{h}(t,\tau,s,u)$ with $\tau \widehat{=} \tau'$ per snapshot is used. To get the narrowband impulse response, the complex sum over the delay domain has to be made

$$h_{narr}(t,s,u) = \sum_{i=1}^{N_\tau} \tilde{h}(t,\tau_i,s,u). \tag{14}$$

The narrowband channel coefficients with the same automatic gain control (AGC) value per MIMO subchannel are grouped together. Additionally segmentation into stationarity intervals is considered and leads to $h_{narr}^{(L)}(t_l, agc)$. The dimension of L is dependent on the number of coefficients which have the same AGC value and which are in the same stationarity interval. Now for each group (i.e. for different values of t_l and agc) the power of the normalised values has to be estimated

$$\hat{P}_{narr}^{(L)}(t_l, agc) := \left(\frac{|h_{narr}^{(L)}(t_l, agc)|}{\max\limits_{L} |h_{narr}^{(L)}(t_l, agc)|} \right)^2. \tag{15}$$

To calculate the K-factor for every group, the moment method proposed in [10] is used. For this purpose the expectation

$$E(t_l, agc) = \frac{1}{N_{t_l,agc}} \sum_{L=1}^{N_{t_l,agc}} \hat{P}_{narr}^{(L)}(t_l, agc) \tag{16}$$

and the variance

$$Var(t_l, agc) = \frac{1}{N_{t_l,agc} - 1} \sum_{L=1}^{N_{t_l,agc}} \left(\hat{P}_{narr}^{(L)}(t_l, agc) - E(t_l, agc) \right)^2 \tag{17}$$

for every group is needed and the K-factor results in

$$K(t_l, agc) = \frac{1}{\frac{E(t_l,agc)}{m(t_l,agc)} - 1} \tag{18}$$

with

$$m(t_l, agc) = \sqrt{E(t_l, agc)^2 - Var(t_l, agc)}. \tag{19}$$

To get only one value of the K-factor per stationarity interval the mean value is chosen

$$K(t_l) = E_{agc}(K(t_l, agc)). \tag{20}$$

Now the PDF and the CDF has to be calculated.

D. Autocorrelation and Crosscorrelation

After determining the LSP's as described above, the correlation characteristics can be analysed. For the different LSP's the normalised autocorrelation function is calculated and related to the distance d which the MS covers during a measurement. The values are compared with the threshold $\frac{1}{e}$ and they are uncorrelated if they decrease below this boundary. To compare two different LSP's the crosscorrelation coefficient is estimated.

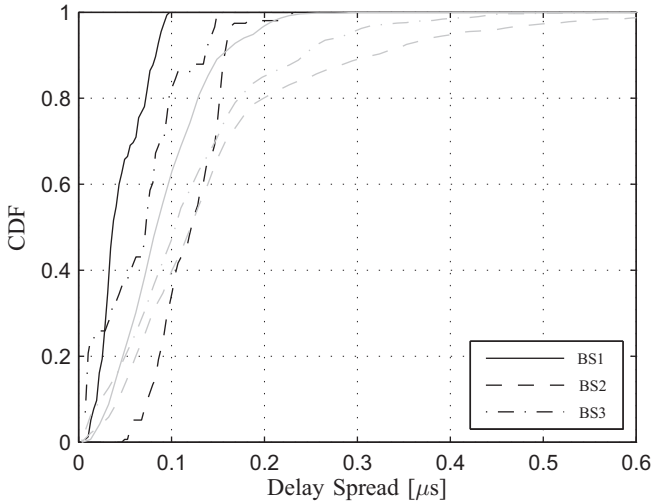

Fig. 1. CDF's of RMS delay spread under LOS (black) and NLOS (gray) propagation

IV. Empirical Results on Data Analysis

In this section results from the data analysis of the LSP's differentiated between LOS and NLOS are presented. Furthermore the influence of different base stations on the values of the LSP's is investigated. The findings are compared to outcomes published in the WINNER II document [5].

A. RMS Delay Spread

First the evaluation of the RMS delay spread will be considered. Figure 1 depict the cumulative distribution function of the RMS delay spread estimated from the data measured from the three different base stations BS1, BS2 and BS3. Furthermore it is differentiated between LOS and NLOS. Obviously the RMS delay spread match the expectation: mean values for LOS are smaller than NLOS propagation and the results support the corresponding WINNER II C2 model parameter. It is interestingly to note that the RMS delay spreads from all tracks to the 3 individual base stations show different results. The DS under LOS for BS1 is 2.5 times smaller compared to BS2 and under NLOS the difference is in the ratio of 1.6. The values of the mean RMS delay spread and the standard deviation are presented in Table I.

B. Transmission Loss and Shadow Fading

Figure 2 shows the transmission loss separately for the LOS and the NLOS snapshots and their related linear regression. Additionally the WINNER II C2 transmission loss model for LOS and NLOS are depicted in Figure 2. A comparison

	RMS DS NLOS		RMS DS LOS	
	Mean	Std	Mean	Std
BS1	$0.09\mu s$	$0.05\mu s$	$0.05\mu s$	$0.02\mu s$
BS2	$0.15\mu s$	$0.12\mu s$	$0.12\mu s$	$0.05\mu s$
BS3	$0.13\mu s$	$0.09\mu s$	$0.07\mu s$	$0.04\mu s$
All	$0.13\mu s$	$0.09\mu s$	$0.08\mu s$	$0.05\mu s$
WINNER II	$0.09\mu s$	$0.08\mu s$	$0.06\mu s$	n.a.

TABLE I
Comparison of measurement results for Delay Spread

		Linear Regression	
		NLOS	LOS
All	A	36.02	28.17
	B	41.91	56.34
WINNER II	A	35.7	26
	B	36.70	50.68
		Shadow Fading	
		NLOS	LOS
All	mean	$7.93 \cdot 10^{-15}$dB	$-1.65 \cdot 10^{-14}$dB
	std	5.01dB	3.79dB
WINNER II	mean	0.00dB	0.00dB
	std	8.30dB	6.81dB

TABLE II
COMPARISON OF MEASUREMENT RESULTS FOR TRANSMISSION LOSS COEFFICIENTS A AND B AND SHADOW FADING

between the linear regression and the WINNER II C2 model show pretty good parallel alignment. The absolute difference between the curves can be explained e.g. by the deviation in terms of the gains of the antenna beam pattern and the multiplexing units. The transmission loss coefficients A and B corresponding to (9) are summarised in Table II. Figure 3 shows the PDF of the shadow fading in dB for the NLOS case, which corresponds to a normal distribution (as expected). To verify the results, the normal distribution with $\mu = 0.13$dB and $\sigma = 4.92$dB is depicted in Figure 3, additionally. Table II also summarise the mean value and the standard deviation of the shadow fading. The value of the standard deviation for the WINNER II C2 scenario is reported to lie in-between 7.3dB and 9.3dB. In [11] the standard deviation is found to be 5.59dB-7.56dB for LOS propagation.

C. Narrowband K-Factor

In this subsection results of the narrowband K-factor are presented. Figure 4 shows the CDF's of the K-factor differentiated for LOS and NLOS and for all three base stations. The K-Factor shows considerable variations between -15dB and $+15$dB. The mean value and the standard deviation are presented in Table III. These results are conform with the outcomes in, e.g. [13] and [14] whereby no results where found within the WINNER II publications [5].

	K-Factor NLOS		K-Factor LOS	
	Mean	Std	Mean	Std
BS1	-1.21dB	6.00dB	1.47dB	5.96dB
BS2	-0.39dB	6.74dB	0.32dB	4.98dB
BS3	-1.07dB	7.14dB	0.49dB	6.86dB
All	-0.96dB	6.68dB	0.89dB	5.80dB

TABLE III
COMPARISON OF MEASUREMENT RESULTS FOR K-FACTOR

D. Autocorrelation and Crosscorrelation

First the autocovariance function of the estimated RMS delay spread, the shadow fading and the K-factor for the NLOS case is depicted in Figure 5. The x-axis indicates the distance between individual mobile positions and the relative distance of other mobile positions along a measurement track. The track 9a-9b is chosen exemplary and represents the general behaviour. Additionally the threshold $\frac{1}{e}$ is plotted in these figures. The decorrelation distance of the exponentially decaying autocovariance function shows different results for the three LSP's, which match the findings in WINNER II and literature [5], [12] and [15]. Decorrelation distance for the delay spread was found to be 8m-9m, for the shadow fading 2.1m-7.5m and for the K-factor 1.5m-3m. This highlights again a site specific behaviour, because the decorrelation distance among the LSP's can change significantly depending on the considered base station. The crosscorrelation coefficients of different LSP's for NLOS and LOS are presented in Table IV. Only rare information can be found in the literature about the crosscorrelation behaviour of the LSP's. When the shadow fading increases, the probability of a LOS gets smaller and consequently the K-factor decreases. Hence the correlation coefficient of them is negative. The behaviour of the delay spread and the K-factor is similar. Therefor the correlation

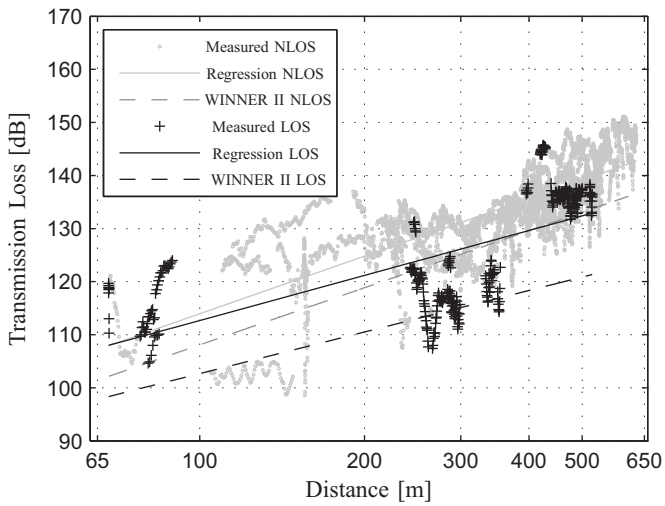

Fig. 2. Transmission loss over all base stations and all measurement tracks under LOS (black) and NLOS (gray) propagation

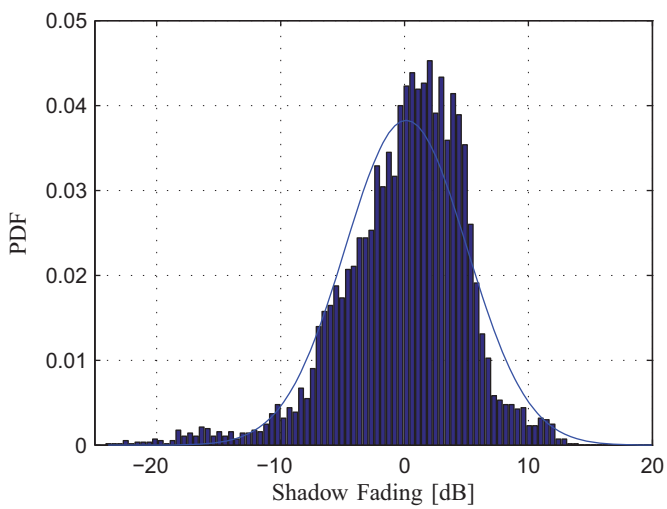

Fig. 3. PDF of shadow fading under NLOS propagation for all base stations and all tracks and idealised curve

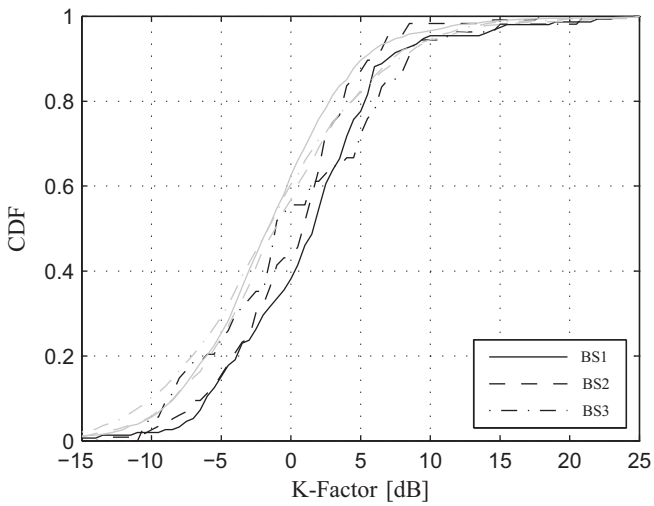

Fig. 4. CDF's of narrowband K-factor under LOS (black) and NLOS (gray) propagation

coefficient of the delay spread and the shadow fading has to be positive. In the case of LOS a few divergences are recognised, e.g. the coefficients of shadow fading and delay spread and shadow fading and K-factor at BS1. The reason is not slightly evident.

V. Conclusion

Large scale parameter according to the WINNER II channel model are analysed based on an extensive MIMO measurement campaign in an urban macro cell scenario. The findings for RMS delay spread, transmission loss, shadow fading and the narrowband K-factor show a reasonable good match to WINNEII C2. The results close several gaps among the LSP's and their correlations published for the WINNER II C2 scenario and other literature so far. A third contribution is derived by studying a base station dependend analysis. Even a LSP analysis can be very site specific, because significant

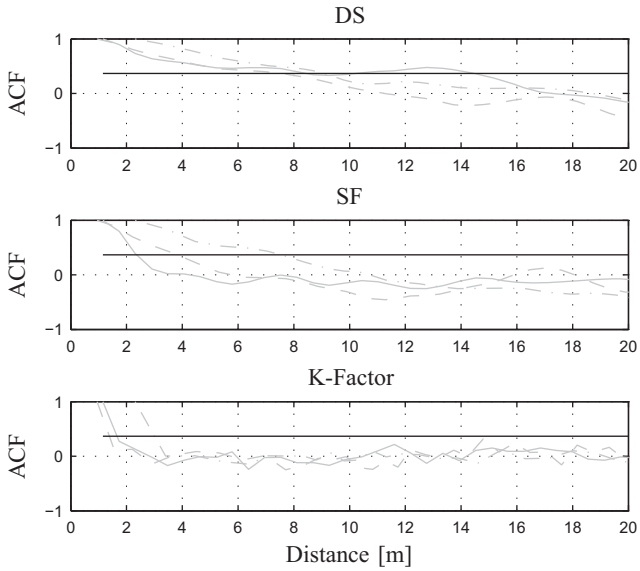

Fig. 5. Autocovariance function of DS, SF and K-factor for one track under influence of different base stations (BS1 - BS2 - - BS3 - ·)

	Crosscorrelation coeff NLOS			Crosscorrelation coeff LOS		
	DS & SF	DS & K	SF & K	DS & SF	DS & K	SF & K
BS1	0.38	−0.17	−0.14	−0.11	−0.37	0.19
BS2	0.36	−0.10	−0.09	0.12	−0.38	−0.06
BS3	0.19	−0.29	−0.27	0.69	−0.34	−0.53
All	0.27	−0.16	−0.19	0.14	−0.31	−0.06

TABLE IV
Crosscorrelation coefficients for different LSP's

variation under the LSP statistics for different base stations were found. Future analysis steps which can be easily covered by the used measurement campaign will be polarisation, base station antenna height, multi user and multi base station crosscorrelations as well as azimuth and elevation LSP studies.

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