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Best Practice Guide: Sensitivity of LTE R_0 measurement with respect to multipath propagation

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Table of Contents

List of Abbreviations

LTE	Long Term Evolution
MIMO	Multiple input multiple output
SNR	Signal to noise ratio
STBC	Space-time block coding
SFBC	Space-frequency block coding
RF	Radio Frequency
SI	International System of Units
dB	decibels
DC	Direct current
3GPP	3rd Generation Partnership Project
CSR	Cell-Specific Reference signal
FDD	Frequency Division Duplex
OFDMA	Orthogonal Frequency Division Multiple Access
TDD	Time Division Duplex
QAM	Quadrature amplitude modulation
DSP	Digital signal processing
SISO	Single input single output

1 Scope of the document

This report serves as the best practice guide for R_0 sensitivity measurement in the LTE downlink power measurement[1]. It provides a brief outlook of LTE architecture, multipath fading including different fading scenarios considered for exemplary evaluation and finally the uncertainty quantification of multipath fading using the proposed METAS scope measurement method with digital offline processing.

2 Introduction

The Third Generation Partnership Project (3GPP) produces globally applicable technical specifications and technical report for a 3rd Generation Mobile System based on evolved GSM core network and radio access technologies that support Universal Terrestrial Radio Access (UTRA) both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) mode[2]. This section gives an overview of the LTE downlink physical layer technical specification for the FDD mode[3].

2.1 LTE signal structure

Below are the lists of advanced technologies implemented in LTE:

1. Multicarrier technology

LTE uses OFDMA (Orthogonal Frequency Division Multiple Access) for down link and SC-FDMA (Single Carrier Frequency Division Multiple Access) for uplink.

2. Multiple Antenna technology

LTE uses MIMO (Multiple Input Multiple Output) antenna capabilities thereby increasing the spectral efficiencies of the system
For more reading please refer to the reference [1-3]
Below is the LTE frame structure is expressed as a number of time units [4-6]

$$T_s = \frac{1}{(15000 \times 2048)} \text{seconds} \tag{1}$$

LTE Downlink signal is divided into radio frame of 10 ms.

$$T_{radioframe} = 307200 \cdot T_s = 10ms \tag{2}$$

Each radio frame is sub-divided into ten equally sized sub-frames.

$$T_{subframe} = 30720 \cdot T_s = 1ms \tag{3}$$

Each sub frame is further divided into two slots.

$$T_{slot} = 15360 \cdot T_s = 0.5ms \tag{4}$$

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[1] Herein only the LTE FDD configuration is taken into account. But the idea developed herein can be further extended to LTE TDD systems.

[2] http://www.etsi.org/about/our-global-role/3gpp

[3] We focus on the FDD mode for the LTE downlink mobile communication systems since this is widely deployed in Europe.

Finally each slot is further divided into OFDM symbols.

$$T_{OFDMsym} = 2048 \cdot T_s = 66.67 \mu s \quad (5)$$

There are seven OFDM symbols in one slot in case of normal cyclic prefix

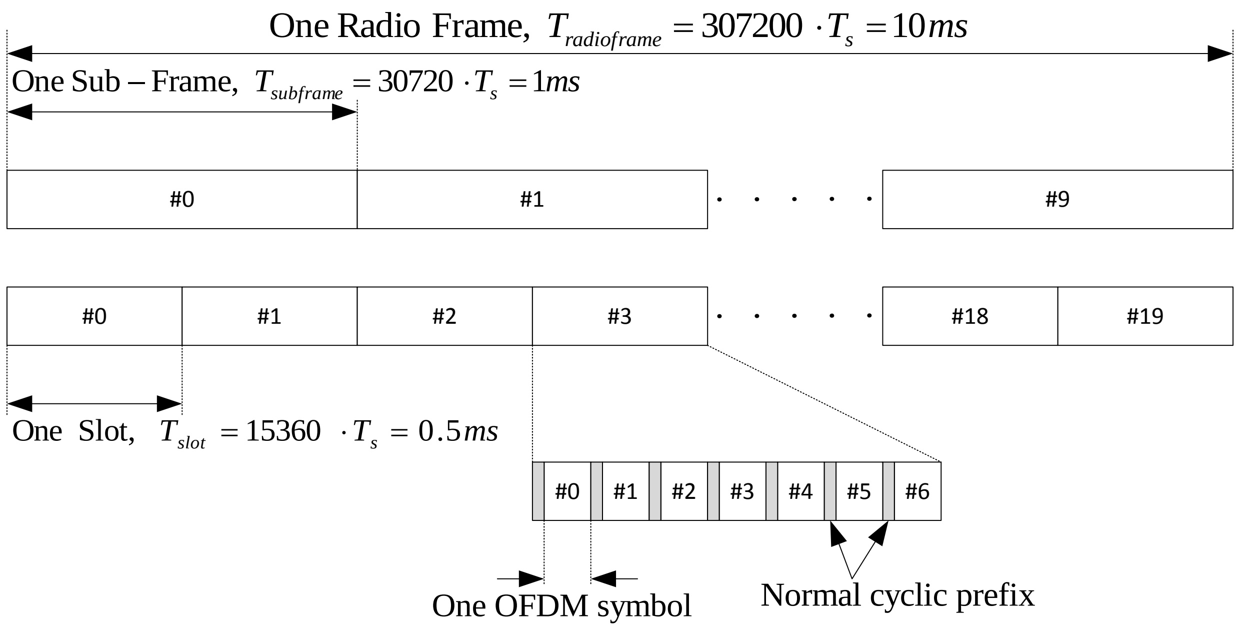

Figure 1: Frame structure of the LTE downlink FDD mode depicting the Radio frame and the sub-division of sub-frame, slot and OFDM symbol with cyclic prefix. Here 7 OFDM symbols along with normal cyclic prefix are stacked in a slot and 14 OFDM symbol in one sub-frame. Hence a radio frame consists of 140 OFDM symbols [2].

LTE is defined by its resource grid taking the advantage of the multicarrier technology i.e. OFDMA which incorporates the element of Time Division Multiple Access (TDMA) so that sub-carriers can be allocated dynamically among the users of the channel, so that several users can share the available bandwidth[5].

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[4] For the normal cyclic prefix mode

[5] For example: Some carriers can be modulated with 64-QAM while other can be modulated with QPSK simultaneously.

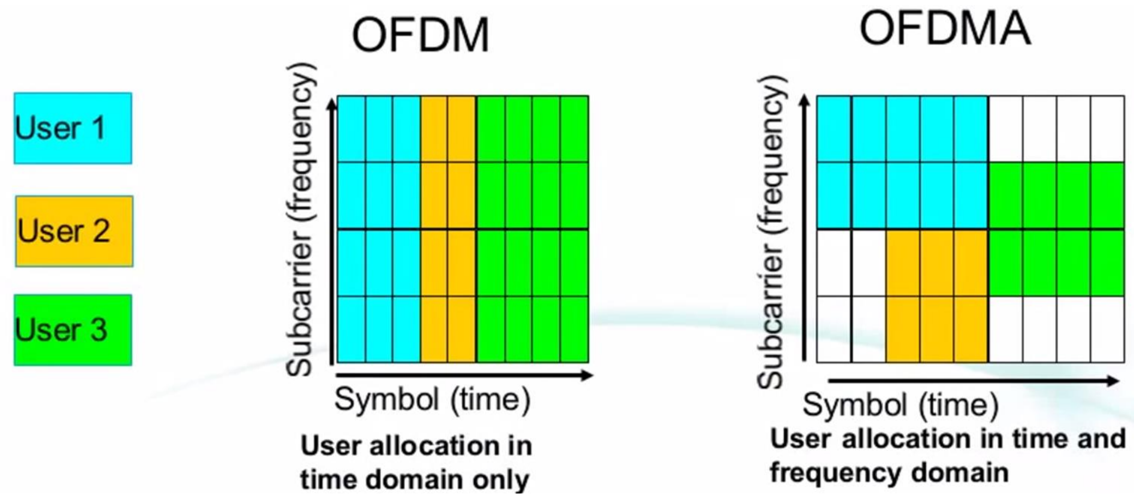

Figure 2: Dynamic user data allocation in time and frequency for OFDM and OFDMA. In OFDM the user data is allocated in time only and in OFDMA the subcarrier is allocated to the user when needed in order to take the frequency dependencies into account in the radio link. [Adapted from [9]]

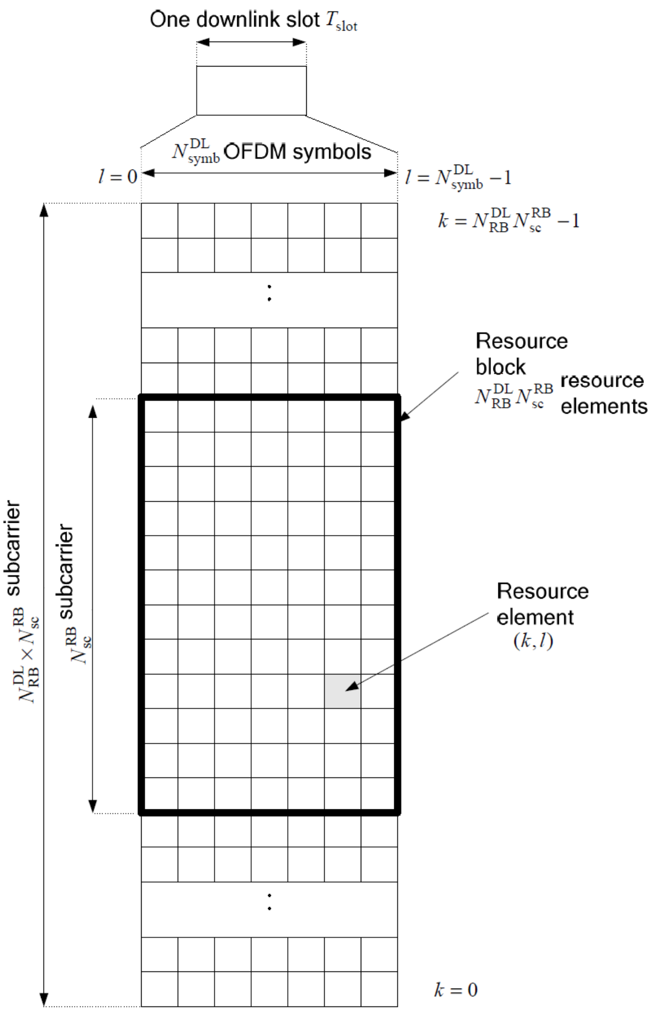

Figure 3: LTE downlink resource grid [Reproduced from [9]]

LTE takes the advantage of the MIMO technology thereby transmitting with more than one antenna at the same time and in the same frequency range by using the robust MIMO precoding techniques[6] [7].

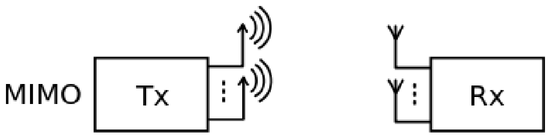

Figure 4: MIMO communication system configuration [7].

2.2 LTE CSR Signals

The Cell Specific Reference Signals (CSR) is a sequence defined in the LTE standards [5]. It consists of complex value entries which are mapped on to some of the resource elements of the LTE time-frequency grid depending on the Cell-ID. LTE Downlink (LTE DL) signal defines 504 unique physical layer cell identities $N_{ID}^{(cell)}$ which are defined as

$$N_{ID}^{(cell)} = 3 \cdot N_{ID}^{(1)} + N_{ID}^{(2)} \tag{6}$$

where the $N_{ID}^{(1)}$ is computed from the SSS sequence in the range of 0 to 167 and $N_{ID}^{(2)}$ is computed from the PSS sequence with a range of 0 to 2.

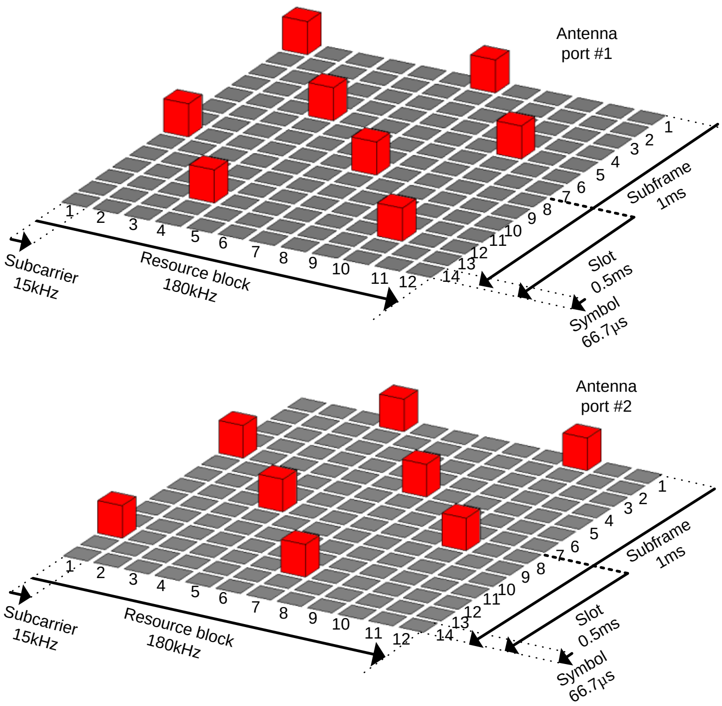

Figure 5: LTE DL CSR for two antenna ports. CSR are mapped to the resource element with red colored blocks depending upon the antenna port and the corresponding resource elements are set to zero on other antenna port [8]

[6] LTE Defines two different types of precoding techniques: (a) transmit diversity using space-time block coding (STBC) or space-frequency block coding (SFBC) and (b) Spatial multiplexing

The CSR signals are present on every symbol with index $l = 0$ and $l = 4$ for one or two antenna port configurations and $l = 1$ for higher antenna port configurations. The subcarrier position is given by

$$k = 6m + (v + v_{shift}) \bmod 6 \tag{7}$$

The variables m, v and v_{shift} are carefully defined within the LTE standard [5]. The refer to the position in the frequency domain for the different cell ID where m corresponds to m^{th} resource block, the v is given by p^{th} antenna port and l^{th} OFDM symbol and the v_{shift} is given by $N_{ID}^{cell} \bmod 6$.

2.3 Computing the RS0 power

The downlink LTE signal power is calculated from the linear average over the power distribution of all the resource elements that carry the CSR signals within the operating bandwidth. Hence the measurement in carried on in the frequency domain[7]. The Root Mean Square (RMS) power of the CSR signal for a specified OFDM symbol can be computed as below:

$$P_{CSR}^{p} = \left\langle \frac{\left|a_i^p\right|^2}{50\Omega} \right\rangle_i [\text{watt}] \tag{8}$$

where a_i^p denotes the CSR symbols with complex values [Volts] with p being the antenna port and i being the CSR symbol number in the entire operating bandwidth.
The standard deviation can be computed as below:

$$\sigma_{CSR} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(A_i - P_{CSR}\right)^2}\,[\text{watt}] \quad \text{where} \quad A_i = \frac{\left|a_i^p\right|^2}{50\Omega}[\text{watt}] \tag{9}$$

The results presented herein are expressed in dBm, the dB conversion is performed as below:

$$P_{CSR}(dBm) = 10\log_{10}\left(P_{CSR}[\text{watt}] \times 1000\right)$$
$$\sigma_{CSR}(dB) = \frac{10}{\ln(10)} \cdot \frac{\sigma_{CSR}[\text{watt}]}{P_{CSR}[\text{watt}]} \tag{10}$$

2.4 LTE Multipath propagation

The wireless signal travels from the transmitter and receiver through a channel which constitute of buildings and other objects around the path. The profile of the path is called as the channel model. In general the power profile of the received signal can be obtained by convolving the power profile of the transmitted signal and the impulse response of the channel. In frequency domain the convolution can be represented as a multiplication. Hence the transmitted signal x through a

[7] The LTE grid with different subcarrier (frequencies) is constructed for every OFDM symbol

channel H with noise n is given by y [8]

$$y(f) = H(f) \cdot x(f) + n(f) \tag{11}$$

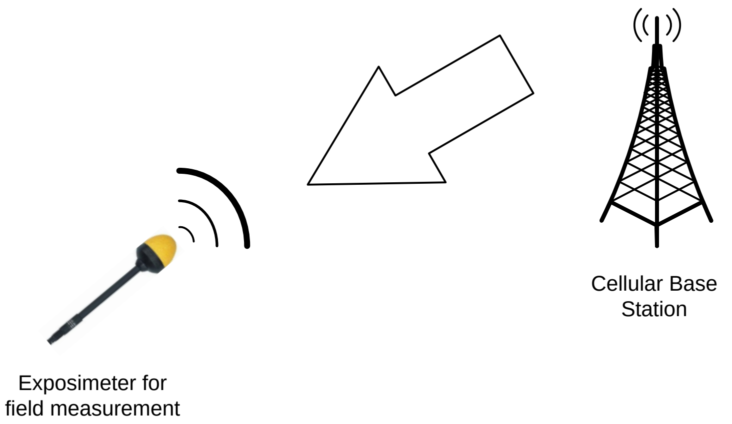

Figure 6: The real world LTE signal measurement constitute of a wireless channel including the environment around the transmitter and receiver (buildings and objects).

Now sometimes the object around the path reflects the signal and these reflected waves are also received by the receiver. Since they are the reflected signal with difference path they take different time to arrive at the same receiver with different amplitude and phase. Depending upon the signal attenuation and phase these reflected signals may result in increased or decreased received power.

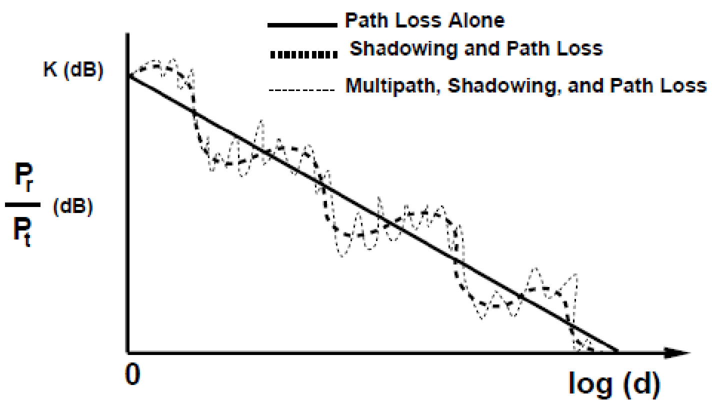

Figure 7: The path loss, shadowing and multipath versus distance [9].

Since the transmitted signal takes different path, a single impulse transmitted will result in multiple copies being received at different times as shown in Figure 8.

[8] Herein x, H, n, y are all the functions of the signal frequency f.

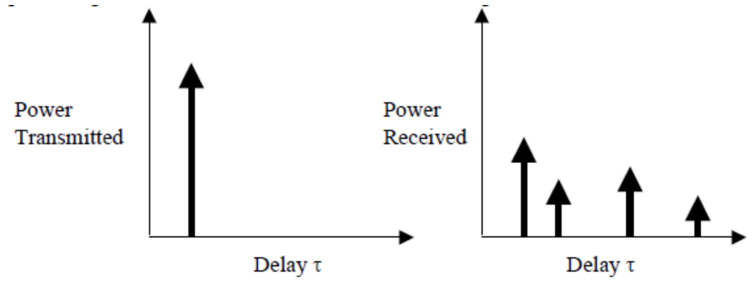

Figure 8: Multipath power delay profile

Where in maximum delay after which the signal becomes negligible is called delay spread. The best way to represent the same is with the discrete number of impulse with a tapped delay model. There are N different coefficients and delay value τ_i . Hence this model is called as delay line model. More details about the channel model can be found in the reference [9-16]

3 Experiments

METAS has proposed a scope based measurement technique [8] for measuring the RS0 resource elements in the LTE recourse grid. This section describes the experimental set-up, summary of the LTE signals and different fading scenarios.

3.1 Experimental set-up

As depicted in Figure 9 the system is composed of a LTE signal generator (with or without MIMO). The RF signal is combined using a RF power combiner and thereof mixed with a local oscillator in a frequency mixer. This process down-converts the RF signal to the difference frequency between the RF signal generated by the LTE signal generator and local oscillator also known as intermediate frequency. Now this down-converted signal is passed through a low pass filter thereby eliminating the influence of higher order frequency components generated during the non-linear frequency mixing. Finally this filtered signal is captured using a Digital Storage Oscilloscope (DSO). The DSO digitizes the received signal and records the voltage level of the signal. The measurement is thereof processed using the self-developed software for both the offline Digital Signal Processing (DSP) and the power evaluation of the LTE signals.

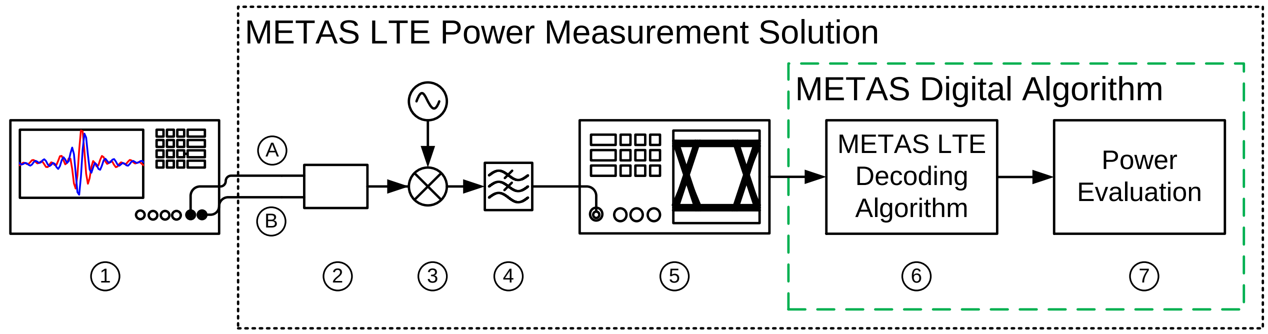

Figure 9: The experimental set-up for the LTE power measurement using the scope measurement method followed by the digital offline processing of the recorded data using the METAS digital algorithm.

Herein a computer software is used to set the appropriate scenario in the LTE generator and the thereof perform a sweep of RF signal power with different pre-defined LTE scenarios along with the different fading scenarios.

Table 1: The list of instrument used for the measurement

Device	**Manufacturer**	**Type**	**Inventory**
LTE Signal Generator	Rohde & Schwarz	SMW 200A	7737
Attenuator	Hewlett Packard	8491A (10dB)	4897
		8491B (10dB)	4864
Power Divider/Combiner	Agilent	11636A (DC – 18GHz)	6409
Local Oscillator	Rohde & Schwarz	SMIQ 03B	5085
Frequency Mixer	Mini-Circuits	ZX05-C24LH-S+	8116
Low Pass Filter	Mini-Circuits	ZX75LP-70-S+	8114
Digital Storage Oscilloscope	Agilent	DSO90254A	6587

Herein a computer software is used to set the appropriate scenario in the LTE generator and the thereof perform a sweep of RF signal power with different pre-defined LTE scenarios.

3.2 Summary of input LTE signal

Hence to ensure a good comparison of the LTE signal power measurement, it’s very important to define the LTE signal scenario. Herein three different LTE scenarios are proposed and used thereof for the comparison and validation. The description of each scenario is given in the table below:

Table 2: The LTE scenarios for the downlink configured at the LTE signal generator for the evaluation of different power sensors and scope based measurement methods.

LTE Scenario	Scenario 1	Scenario 2	Scenario 3
LTE Transmission mode	FDD	FDD	FDD
Link Direction	Downlink (OFDMA)	Downlink (OFDMA)	Downlink (OFDMA)
MIMO	2×2	2×2	2×2
Carrier Frequency	806 MHz	806 MHz	803.5 MHz
output power	Varied between -10 dBm to 0 dBm		
RS0 power per relative display	-27.579	-22.089	-20.45
LTE Bandwidth	10 MHz	10 MHz	5 MHz
Number of subcarrier	601	601	301
Occupied bandwidth	9.015 MHz	9.015 MHz	4.515
Data traffic	Full	partial	partial

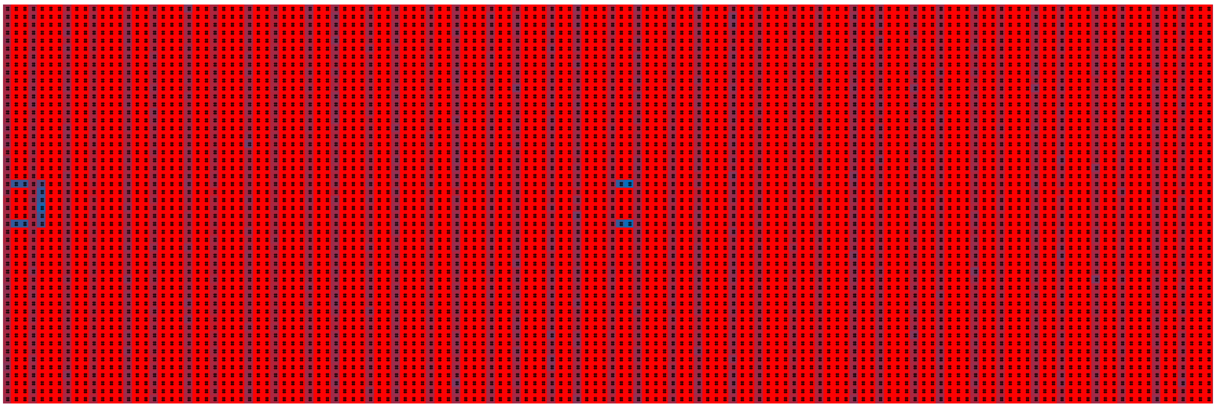

Figure 10: Processed LTE grid for scenario – 1. The red refer to the LTE resource element with high power i.e. user data and the blue corresponds to the lowest power level i.e. empty resource element.

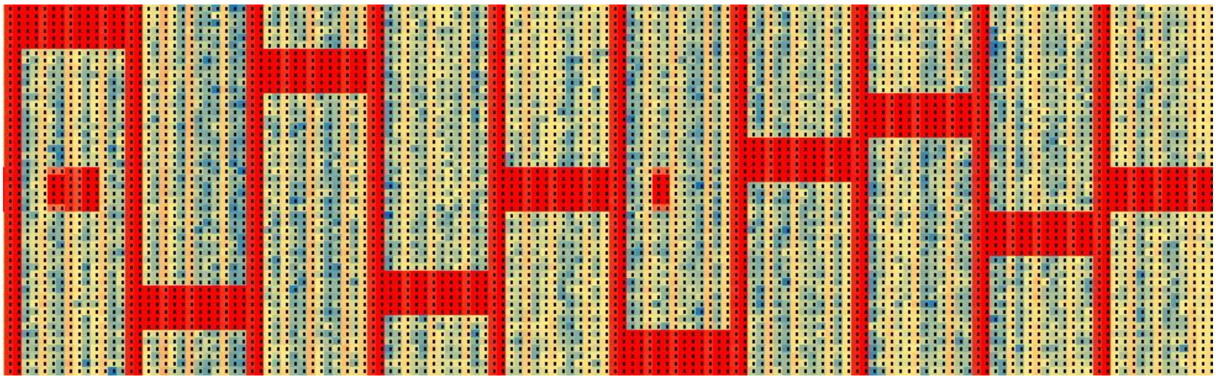

Figure 11: Processed LTE grid for scenario – 2. The red refer to the LTE resource element with high power i.e. user data

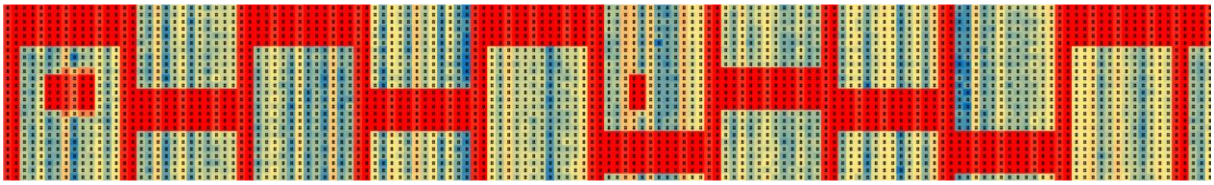

Figure 12: Processed LTE grid for scenario – 3. The red refer to the LTE resource element with high power i.e. user data

3.3 Summary of fading scenarios

To ensure a good comparison and repeatability the fading scenarios were generated with the help if in build fading generator block in the LTE generator. Five different fading scenarios were selected from the LTE standard [17]

Table 3: Summary of delay profiles for LTE channel models

Model	Number of channel taps	Delay spread (r.m.s.)	Maximum excess tap delay (span)
Extended Pedestrian A (EPA)	7	45 ns	410 ns
Extended Vehicular A model (EVA)	9	357 ns	2510 ns
Extended Typical Urban model (ETU)	9	991 ns	5000 ns

Table 4: Extended Pedestrian A model (EPA)

Excess tap delay [ns]	Relative power [dB]
0	0.0
30	-1.0
70	-2.0
[0	-3.0
110	-8.0
190	-17.2
410	-20.8

Table 5: Extended Vehicular A model (EVA)

Excess tap delay [ns]	Relative power [dB]
[0	0.0
30	-1.5
150	-1.4
310	-3.6
370	-0.6
710	-9.1
1090	-7.0
1730	-12.0
2510	-16.9

Table 6: Extended Typical Urban model (ETU)

Excess tap delay [ns]	Relative power [dB]
0	-1.0
50	-1.0
120	-1.0
200	0.0
230	0.0
500	0.0
1600	-3.0
2300	-5.0
5000	-7.0

A multipath fading propagation condition is defined by a combination of a multi-path delay profile and a maximum Doppler frequency f_D which is either 5, 70 or 300 Hz.

We use the following fading scenarios in our example:

1. LTEEPA5 (EPA model with 5Hz Doppler frequency)
2. LTEEVA5 (EVA model with 5Hz Doppler frequency)
3. LTEEVA70 (EVA model with 70Hz Doppler frequency)
4. LTEETU70 (ETU model with 300Hz Doppler frequency)
5. LTEETU300 (ETU model with 300Hz Doppler frequency)

A power sweep measurement is taken with the help of the LTE generator ranging from the generator setting in between -10dBm to 0dBm to study the effect of the multipath propagation.

3.4 Exemplary plots of varying power levels in the LTE grid for different fading scenarios

Below are some exemplary plots of the LTE signal measurement using the method described in section **Error! Reference source not found.**. In the Figure 13, we see the total signal power computed for each LTE symbol. The total signal power is plotted in dBm in vertical axis and the symbol number of the processed LTE signal is plotted in the horizontal axis. The black markers represent the signal for without any fading scenario and the green markers represent the signal with fading scenario. The LTE signal is generated with scenario – 1 configuration and RF output power of -5dBm. The applied fading scenario belongs to extended pedestrian A model (EPA) with 5Hz Doppler shift.

In this plot one can clearly see the effect of fading in computation of the total signal power. A variation of 6dB is reported for the total signal power measurement. This raises the question on quality of the RS0 measurements.

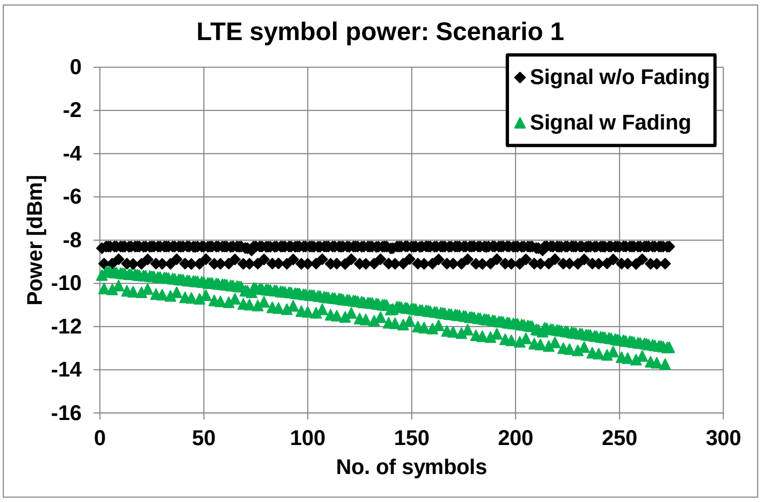

Figure 13: The total signal power measurement with the scope based measurement method using the METAS LTE DSP algorithm for the LTE scenario – 1. The black markers represent the total signal power measured without fading and the green markers represent the total signal power with the fading scenario (LTE EPA with 5Hz Doppler shift).

With our algorithm we are able to measure the RS0 power relative to the total signal power. In order to evaluate the quality of the algorithm we take into account that the mean fading experienced by each element in the LTE symbol is approximately same, we realized these different fading scenarios and we represented for each LTE symbol, the total symbol power as well as the mean RS0 power (only for the symbol carrying the RS0 signal). As depicted in the Figure 14 we see that for the signal without fading the computed RS0 power is very stable and for the signal with the fading scenario the computed RS0 power experiences the same attenuation as the total signal power. This shows qualitatively that the relative RS0 power measurement with respect to the total signal power seems to be constant even with the fading scenario.

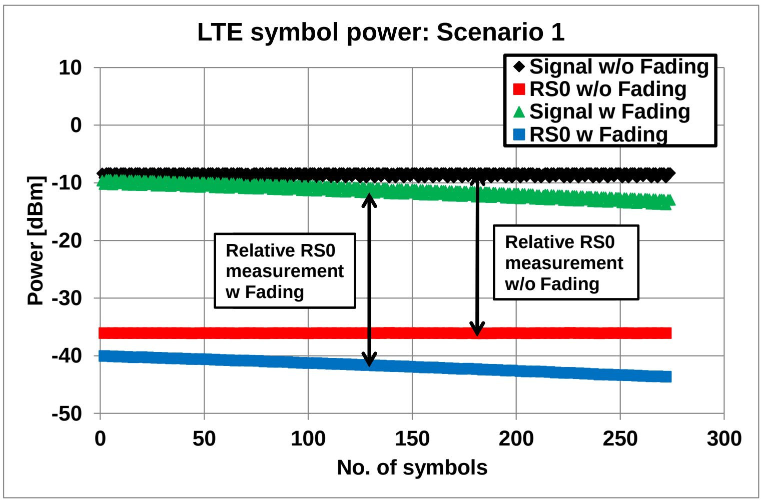

Figure 14: The total signal power measurement and the RS0 signal power measurement using the METAS LTE DSP algorithm for the LTE Scenario – 1.

4 Results

In order to assess the quality of the RS0 power measurements in faded scenario, we determined the ratio of the mean RS0 power to the total power, compared to the "theoretical" ratio of the RS0 power to the total power. This theoretical ratio is obtained directly from the generator setup, but is can be check by measuring it without fading.

$$\text{Deviation per Symbol} = \frac{\left(\frac{\langle P_{RS_0}\rangle}{P_{Symbol}}\right)_{Measured}}{\left(\frac{P_{RS_0}}{P_{Symbol}}\right)_{Theory}} \quad (12)$$

Where

- P_{RS_0} is the mean RS0 power for one symbol (only for symbols carrying RS0 signals)
- P_{Symbol} is the mean total power of symbol
- $\left(\frac{P_{RS_0}}{P_{Symbol}}\right)_{Theory}$ is the theoretical ratio of the RS0 power to the symbol power. It is a number that depends on the LTE scenario chosen (see Table 2).

Finally, by averaging the deviation per symbol over the duration of the measurement (typically 15ms) we get the "mean" deviation that is represented in the next Figures. Here in the Figure 15, Figure 16, Figure 17, Figure 18 and Figure 19 depicts the contribution for the RS0 signal measurement for different fading scenario i.e. EPA5, EVA5, EVA 70, ETU70 and ETU300 respectively. The deviation of the RS0 signal measurement is plotted in vertical axis in dB and the output signal generator power is plotted in the horizontal axis in dBm.

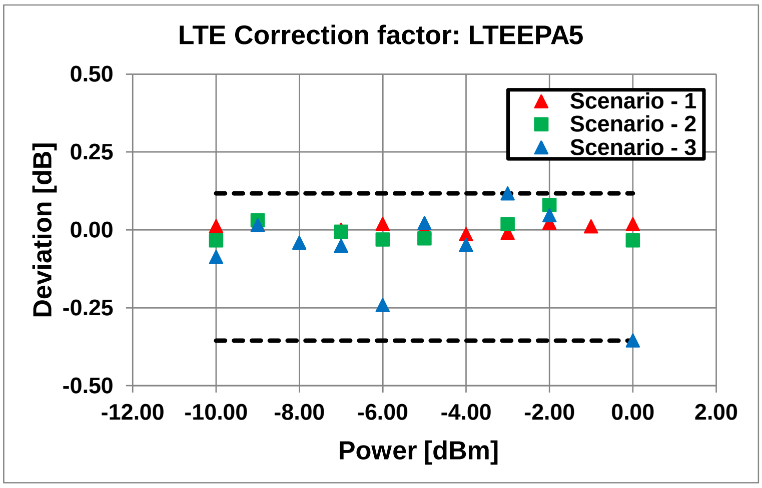

Figure 15: The uncertainty contribution for RS0 measurement in the LTE signal in a LTE fading scenario: LTE EPA model with 5Hz Doppler frequency.

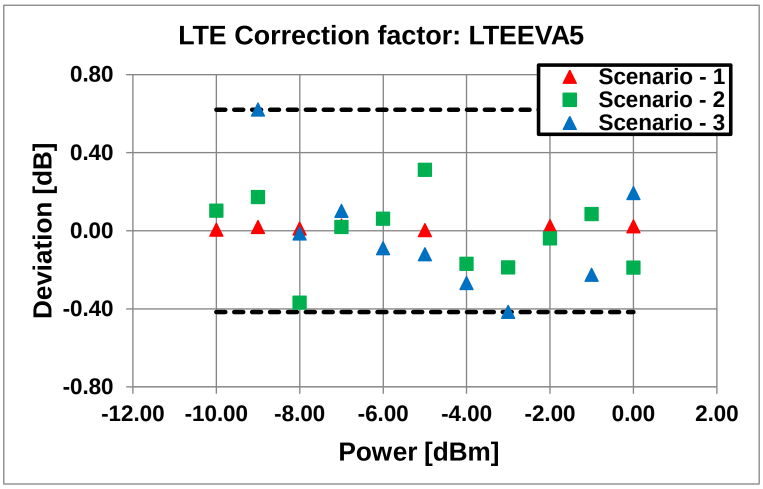

Figure 16: The uncertainty contribution for RS0 measurement in the LTE signal in a LTE fading scenario: LTE EVA model with 5Hz Doppler frequency.

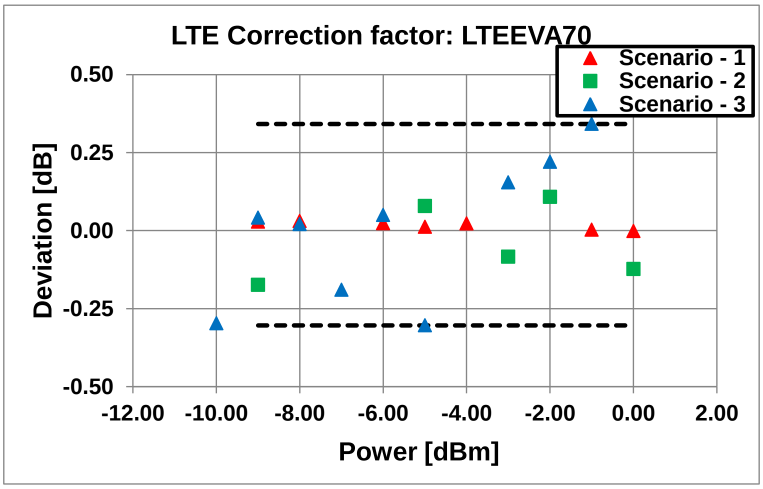

Figure 17: The uncertainty contribution for RS0 measurement in the LTE signal in a LTE fading scenario: LTE EVA model with 70Hz Doppler frequency.

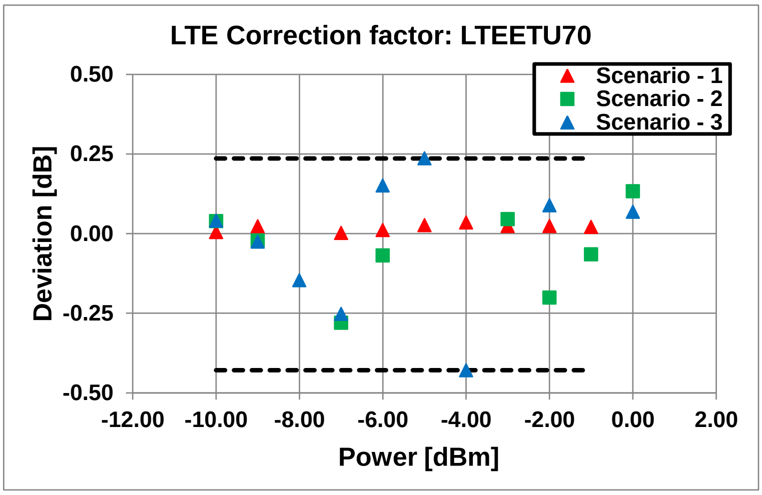

Figure 18: The uncertainty contribution for RS0 measurement in the LTE signal in a LTE fading scenario: LTE ETU model with 70Hz Doppler frequency.

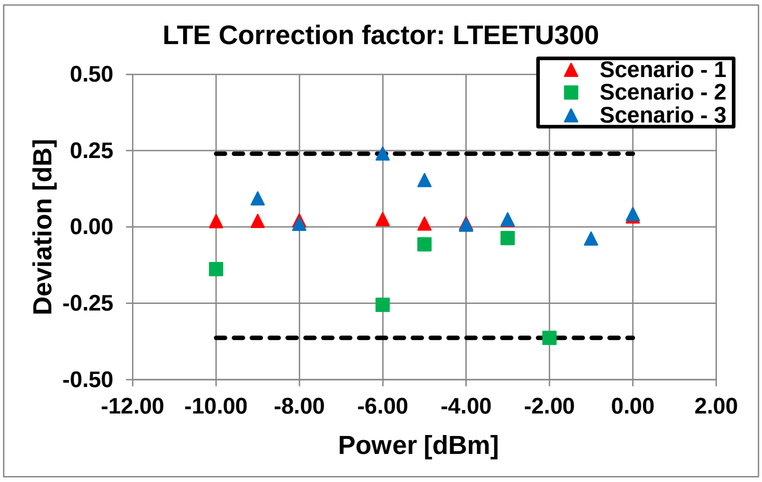

Figure 19: The uncertainty contribution for RS0 measurement in the LTE signal in a LTE fading scenario: LTE ETU model with 300Hz Doppler frequency.

These Figures can be summarized by the following table.

Scenario	Fading	Mean	Standard deviation
1	EPA 5Hz	0.01	0.01
1	EVA 5Hz	0.01	0.01
1	EVA 70Hz	0.02	0.01
1	ETU 70Hz	0.02	0.01
1	ETU 300Hz	0.02	0.01
2	EPA 5Hz	0.00	0.04
2	EVA 5Hz	-0.02	0.19
2	EVA 70Hz	-0.04	0.11
2	ETU 70Hz	-0.05	0.13
2	ETU 300Hz	-0.17	0.12
3	EPA 5Hz	-0.06	0.13
3	EVA 5Hz	-0.03	0.29

3	EVA 70Hz	0.00	0.21
3…	ETU 70Hz	-0.03	0.2
3	ETU 300Hz	0.07	0.09

5 Discussion and conclusion

The results presented in the previous section show that the quality of the measure of the total power using the RS0 mean power is

- Very good for scenario 1 (typical deviation of 0.01 dB)
- Acceptable for scenario 2 and 3 (typical deviations of 0.2 to 0.6 dB)

This is mostly due to the fact that fading does not have a uniform effect on all resource elements of one symbol. The fading might depend on the frequency.
In case of scenario 1 where the total power is distributed on all resource elements, effect of fading on a given symbol is similar to the effect of fading of the RS0 signals that are also uniformly distributed within the symbol. Therefore, the agreement between in case of scenario 1 is very good.

In case of scenario 2 and 3, the power is not distributed uniformly on the LTE grid refer to Figure 11 and Figure 12. Therefore the fading at a given frequency might have more weight than the fading at another frequency. The mean RS0 power is in these two cases (scenario 2 and 3) does not provide the same fading.

Now, if the RS0 power is used to estimate the maximum total power in cases of full transmit power (all resource elements filled up exactly like in scenario 1), the quality of the estimate is very good.

Since the uncertainty budget for field measurements has already been presented in a previous "best practice guide" [18] the additional uncertainty due to fading effects is of the order of

$$U_{\text{Fading}}(k=1) = \frac{0.2dB}{\sqrt{3}} = 0.12dB \quad (13)$$

6 References

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