OTA Evaluation of Mobile Phone Antenna Performance for VoLTE [Measurements Corner]

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Over the Air Evaluation of Mobile Phone Antenna Performance for Voice over LTE

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***Abstract*—This paper compares Over-The-Air (OTA) performance of traditional voice service and Voice over LTE (VoLTE). The results of the OTA measurements of the antenna performance of 22 mobile phones commonly used over the last two years are presented. VoLTE is a feature included into LTE which allows voice service to be delivered as data flows. Traditional investigations for LTE only include data service and therefore OTA for data services which is measured with the phone held in browsing position by the hand only, whereas the VoLTE uses the same data channel but in a position next to the head held by a hand. Traditional investigations of voice service only include voice service and OTA in voice service. The Figures of Merit (FoMs) taken into account for the ranking of the devices are the Total Radiated Power (TRP) and the Total Isotropic Sensitivity (TIS), related respectively to the transmitter and receiver antennas performance. The investigation includes results for talk mode using left and right hand phantoms next to head to calculate the maximum power radiated by the transmitter. To evaluate the sensitivity of the receiver, performances in talk mode using right hand phantom next to head as well as in data mode using only the hand phantom were considered. The results show a variation in TRP from 9 dB to 17 dB and approximately 9 dB spread in TIS among the phone models in the European LTE bands analyzed. Up to 8 dB difference in TRP between right and left hand usage were found for the worst performing phones, whereas their performances in free space are the same as the best performing phones. Key parameters of our analysis are accuracy, repeatability and testing time, since the equipment and the measurement procedure follow the CTIA Specification.**

I. Introduction

The antenna performance of the mobile phones determines the capability to ensure radio coverage in low signal conditions. The connection between the mobile phone and the base station is guaranteed in turn by both the link from the mobile phone to the base station, called uplink, and from the base station to the mobile phone, known as downlink. The quality of the connection and the radio coverage are determined by the weakest link, which is the uplink for voice service and the downlink for data service, based on the information provided by the Nordic mobile network operators and the Danish Energy Agency [1].

Antenna performance of mobile phones equipped with single antenna systems is measured in terms of Total Radiated Power (TRP) and Total Isotropic Sensitivity (TIS). These antenna gain related parameters represent respectively a measure of the amount of power radiated by the transmitter antenna and the sensitivity of the receiver antenna.

Therefore, the current paper focuses on the transmitter performance for voice service, including test using the phone on both sides of the head, and on the receiver performance for both voice service and data mode. Similar studies in 2013 [2] focused on the receiver performance, in terms of TIS, of 23 mobile phones common at that time in the bands GSM900, GSM1800, UMTS900 and UMTS2100. The devices were tested in talk mode, in the right side of the head. In the following measurement campaign, conducted in 2016 by the same authors [1], [3], the power of the transmitter antenna of 26 different mobile phones was evaluated in the same bands in both sides of the head and the sensitivity of the receiver antenna in the right side of the head. Furthermore, the TIS parameter of the same phones was evaluated in data mode, using only the right hand, in the UMTS bands and in the European LTE bands. Hence, this study represents the first attempt to measure TRP and TIS for talk mode in the bands LTE800, LTE1800 and LTE2600. In line with the previous campaigns, the best and worst performing phones were measured in free space to calculate the influence of the human body, known as body-loss.

The results confirm that the mobile phone performances are related to antenna design, in combination with how the user is holding the phone, next to the head in talk mode or in the hand in data mode. The transmitter and the receiver electronics are also involved in the analysis, but since these parts must fulfill mandatory limits in the technology standards, they do not influence significantly the performance of different phone models. Finally, the comparison with the measurements run in free space further proves that the ability to collect a radio signal is far better if the phone is in a hands-free installation or connected to a headset.

The paper is organized as follows: Section II discusses the specifications followed and the configurations analyzed. Section III describes the parameters calculated to evaluate the mobile phones antenna performance and Section IV the equipment used to run the tests. Section V shows measurement results and Section VI compares them with the ones obtained in the previous campaigns. Finally, Section VII concludes this paper.

II. Test Procedure

The aim of our measurements is to test the terminals ability to transmit to the base station and receive from the base station. In the first case, the mobile terminal is required to adjust its power according to the radio signal situations, i.e., to transmit with the highest power level, when the quality of the channel is degraded, and to decrease it, when the channel condition is better, in order to reduce the interference. The maximum transmit power depends on the mobile system, band of operation and on the power class of the mobile terminal [1], [4].

The tests conducted in the study and the phantom hands and head follow the agreed standard test procedures for mobile phones, created by the Cellular Telecommunications and Internet Association (CTIA Test Plan for Wireless Device Over-the-Air Performance v.3.6) [5], the 3GPP TS 36.213 [6] and TS 36.521 [7] reference specifications.

However, if the phone is equipped with more than one antenna, the measurements are performed in the same way as for phones with no antenna selection. This deviates from the specifications in CTIA, since each antenna must be measured individually, but the phones are not commercially available with the option to disable automatic antenna selection.

Moreover, only the frequency bands used in Europe are measured and only the center channel as a representative of the band, instead of 3 channels for each band as specified, in order to limit the number of tests on each phone.

The key parameters, TRP and TIS, are measured at a bandwidth of 10 MHz for the LTE800 and LTE1800 and 20 MHz for the LTE2600 as specified in the CTIA standard.

Further, the following situations are studied for talk mode:

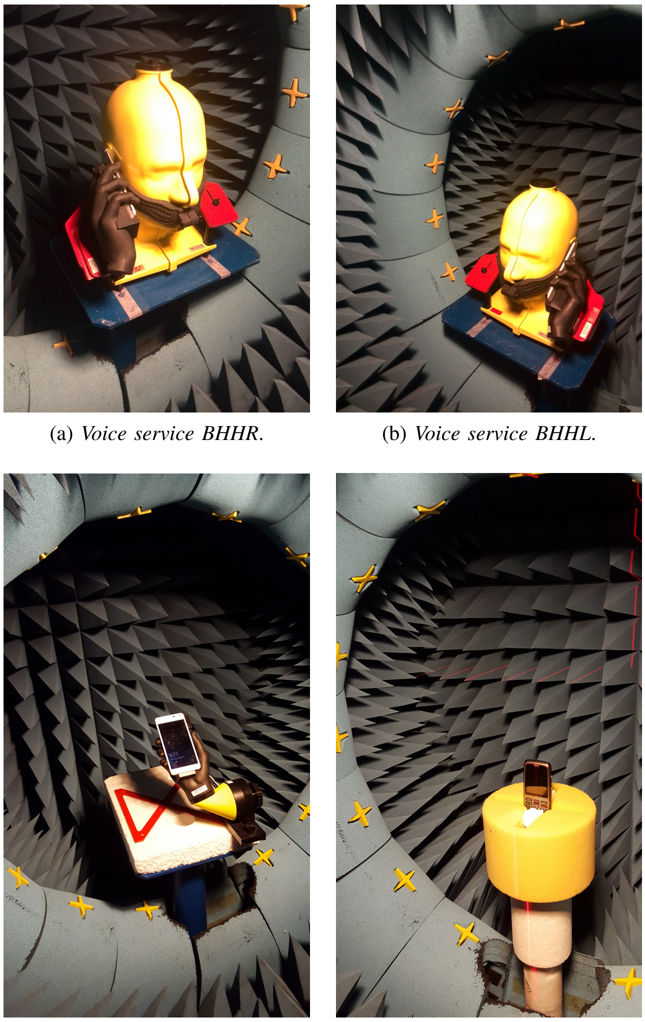
- Phone next to the phantom head, held by a right phantom hand next to the right hand side of the head, referred to as BHHR.
- Phone next to the phantom head, held by a left phantom hand next to the left hand side of the head, referred to as BHHL.

For data mode, the phone is held with the right phantom hand in browsing distance and is indicated as HR.

As shown in the figures 1a, 1b, two different hand sizes were required for both configurations, to fit the different phone types. Figure 1c shows the equipment used in the previous campaign for testing mobile phones in data service, where the phone is held with the right phantom hand in browsing distance. Moreover, to evaluate the influence of the hand and head phantoms, we tested the worst and best performing phones in free space. The setup is shown in figure 1d.

III. Performance Indicators

As stated previously, the mobile phones ability to maintain a connection with the base station is determined by the transmitter and receiver performance, quantified respectively in terms of total radiated power and total isotropic sensitivity. They are calculated from the EIRP (Effective Isotropic Radiated Power) and EIS (Effective Isotropic Sensitivity) respectively, which are measured on the full $3D$ sphere.



(a) *Voice service BHHR.* (b) *Voice service BHHL.*

(c) *Data service HR.* (d) *Free-space.*

Fig. 1: Setup for voice and data service including the head-hand phantom and the hand phantom respectively and setup for free-space measurements.

A. Total Radiated Power (TRP)

The TRP is a measure of the phones ability to radiate power. The TPR is given in dBm and is an average value over all directions and both polarizations. The higher the TRP, the stronger the signal at the base station and the better the connection. TRP is defined as the integral of the power transmitted by the DUT in all directions over the entire sphere for both polarizations:

$$TRP = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi}(EIRP_\theta(\theta,\phi))+(EIRP_\phi(\theta,\phi))\sin(\theta)d\theta d\phi \quad (1)$$

B. Total Isotropic Sensitivity (TIS)

The TIS is a measure of the minimum received power required to maintain the connection above a certain Bit Error Rate (BER). The TIS is given in dBm values and is an average over all directions and both polarizations. The lower the value of the TIS, less power is required to maintain a satisfactory downlink connection and the better the phone is to receive in weak signal areas. TIS is defined as the integral of the power received by DUT from all the directions over the $3D$ full sphere in order to achieve the BER threshold for both the polarization:

$$TIS = \frac{4\pi}{\oint \left[\frac{1}{EIS_\theta(\theta,\phi)} + \frac{1}{EIS_\phi(\theta,\phi)}\right] \sin(\theta) d\theta d\phi}, \qquad (2)$$

IV. Measurement Setup

The OTA testing of a SISO system, in which we have one TX and one RX antenna, consists in determining the transmitting and receiving properties of a wireless device by measuring the magnitude and direction of the radiating energy to determine its performance [8]. The main characteristic of OTA measurements is the absence of any wired connection between the antenna on the mobile phone and the radio communication tester. The information travels both ways over the air. Therefore, during the measurements, the connection to the mobile phone is guaranteed by a mast antenna, the *link* antenna.

The measurements were conducted in a Satimo Starlab [9] located in a shielded anechoic chamber. The test equipment consists of a ring with 15 bi-directional and dual polarized test probes, a base-station emulator, CMW500, to establish a phone call and a computer receiving the measured data from the phone under test.

To test the voice service, we fixed the mobile phone in a phantom hand next to a phantom head, the so-called SAM head. All the hand and head phantoms used in this measurement campaign are in accordance with the CTIA specifications and are produced by Speag.

The first step is the calibration of the anechoic chamber with a range calibration [10], in order to determine the range loss to use to correct the active measurements and obtain more accurate results. The calibration is followed by the evaluation of TRP and TIS over the $3D$ full sphere. The phantom setup is suitably positioned in the center of the ring, where the probe array allows to measure each point over theta-axis while the equipment can rotate in order to measure each point on the phi-axis.

For the TRP measurements, the phone is put in call mode and set to transmit with the maximum power for the given frequency band and technology being measured. The power is then recorded for the probes in the ring around the phone for both polarizations and the procedure is repeated until the full sphere is covered, rotating the phone by 15 degrees every time. A TRP measurement typically lasts 5 minutes and consists of $24 \times 12 \times 2$ (azimuth $\times$ elevation $\times$ polarization) measurement points.

For the TIS test, a single probe, set to transmit with the maximum power, sends a data stream to the DUT with a given data rate. After the BER evaluation, the power is lowered in steps of 0.5 dB, the BER is calculated again and the process is run until it reaches a set threshold. The procedure is repeated again for all directions and both polarizations. The TIS measurement takes approximately $40 - 60$ minutes and consists of $12 \times 6 \times 2$ (azimuth $\times$ elevation $\times$ polarization) measurement points.

V. Measurements Results

This paragraph presents the results of the measurements run over the 22 mobile phones and compares them with the data of the previous measurement campaign [3].

A. User Phantom

1) Results for TRP: The measurements were conducted using right and left hand phantom next to head phantom. Fig. 2 shows the values of the TRP for each phone in the three LTE bands analyzed, sorted by descending values of LTE800 in the BHHR setup. The results clearly highlight that the performance vary considerably among the different models over the bands and configurations tested.

The plot allows also to compare the performance between left hand and right hand usage, very large for most of the phones. It is also possible to notice that the performance in the BHHR configuration are better on average than in the other case, confirming the results obtained in the previous campaign, i.e., the antenna design does not take body loss in different usage positions into account.

Furthermore, Table I shows the difference in TRP between the best and the worst performing phones, across the frequency bands analyzed and left and right hand uses. Comparing the data in this table with the ones presented in [3], it appears that the variation is smaller, between 9 dB and 17 dB in the LTE system, against $6 - 18$ dB in GSM and UMTS systems.

TABLE I: Maximum variation in TRP in dB across all systems, frequency bands and configurations analyzed.

Frequency band	BHHR	BHHL
GSM 900	14.1	15.3
GSM 1800	16.6	5.7
UMTS 900	11.9	14.9
UMTS 2100	18.5	12
LTE 800	13	10.3
LTE 1800	17.3	9
LTE 2600	10.5	15.2

2) Results for TIS:

a) Talk mode: The TIS measurement results using the right hand phantom next to the head phantom is presented in Fig. 3, where the phones are sorted by descending values of LTE800 in the BHHR configuration. It is possible to notice that the performances of the receiver antenna are very different among the phones, but the variations are not as large as for

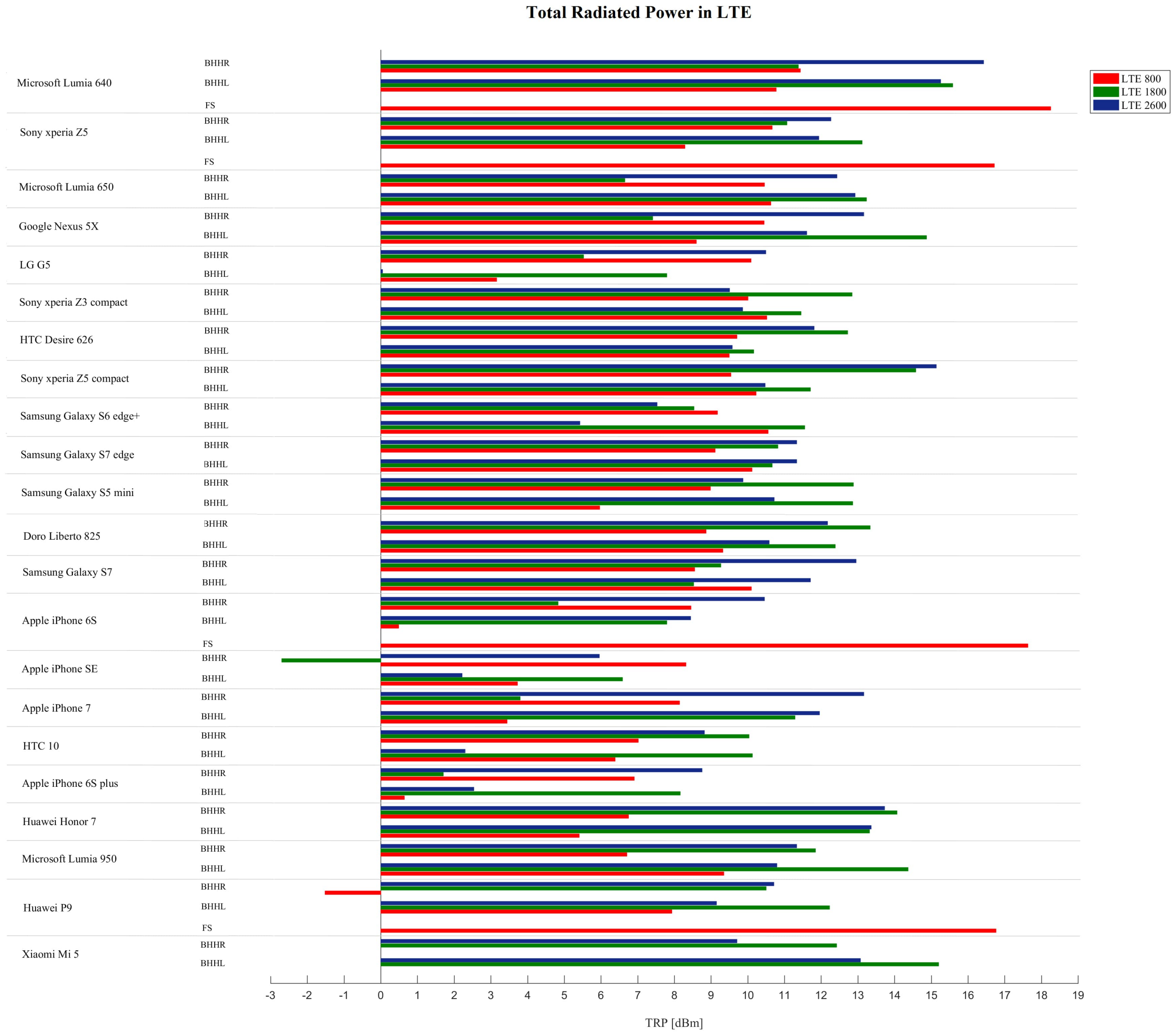


Fig. 2: Measured transmitter performance in BHHR and BHHL configurations of all phones sorted from the best to the worst performing according to LTE800 band in BHHR setup. For the best and worst performing phones in each configuration also the value in free space (FS) is shown.

the TRP values. The ranking according to TRP and TIS is not exactly the same, but rather similar for the best and worst phones.

b) Data mode: The plot in Fig. 3 shows also the values of the TIS parameter in data service, right hand phantom holding the mobile phone, measured in the previous campaign [3]. Similar considerations regarding the difference in the receiver performance among the phones are suitable also in this case. Moreover, it is a common result to all the phones tested that the performance in data mode are better than in talk mode for all the frequency bands analyzed.

Table II reports the difference in TIS between the best and the worst performing phones in talk mode in the configuration studied and compares them with the analog value in data mode, taken from [3]. The values are in both configurations very close, despite in the talk mode the head phantom is also used along with the right hand phantom.

Moreover, it turns out that the variation in TIS both in talk mode and in data mode is less than that in TRP, from 7 dB spread to a maximum of 10 dB over the bands in both cases. But in a simple case with low signal strength, a 7 dB reduction in TIS results is a significant reduction in the data-rate. The change in data-rate for a TIS difference depends on the radio channel condition, absolute signal level, receiver type, antenna

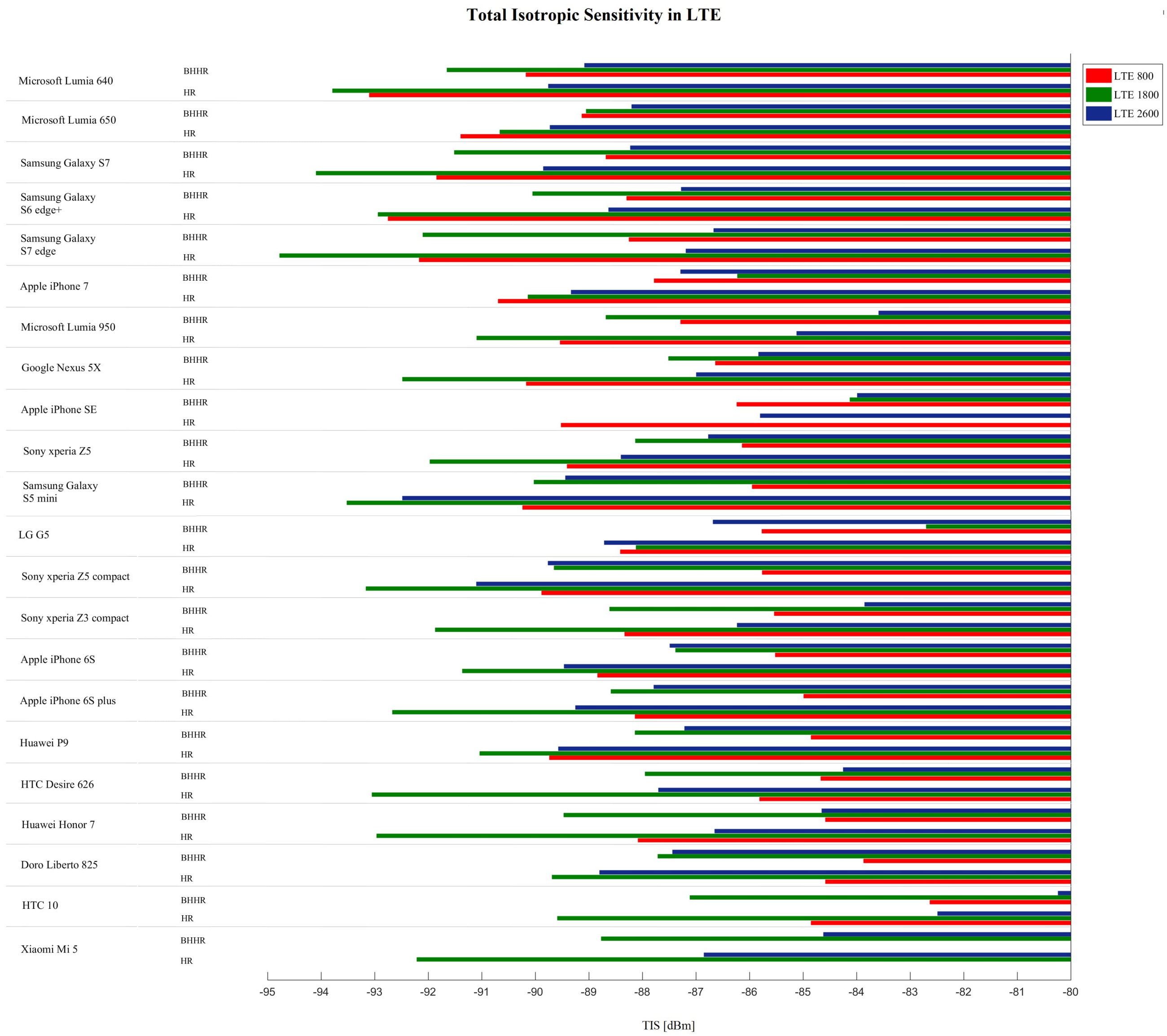


Fig. 3: Measured receiver performance in BHHR and HR configuration of all phones sorted from the best to the worst performing according to LTE800 band in BHHR setup. For the best and worst performing phones in BHHR and HR configuration, the value in free space (FS) was calculated in LTE800 and LTE2600 band respectively.

system and network settings [1].

TABLE II: Maximum variation in TIS in dB across all systems, frequency bands and configurations analyzed.

Frequency band	Talk mode	Data mode
UMTS 900	8.9	8.4
UMTS 2100	10.3	9.1
LTE 800	7.6	8.6
LTE 1800	9.4	6.7
LTE 2600	9.5	10

B. *Free-space*

The TRP and TIS parameters of the best and worst performing phones were additionally measured in free space, without the phantom hand and head, in order to disclose the influence of the human body, called body-loss, and check the phones basic performance. In fact, previous studies demonstrate that the level of communication performance degradation vary considerably among different users and phone models. In particular, the human hand, consisting of several materials, influences the performance of small terminal antennas, causing electromagnetic absorption and detuning.

In this regard, many research effort have been made, with the intent of quantifying the human body interaction [11]. The study in [12] focuses on the influence of the user's hand position on the mobile phone and shows a difference in the antenna performances of up to 3 dB, when the users freely choose the way to hold the phone. In [13], impedance mismatch loss with different phone grips was evaluated and in [14] a rigorous investigation on mobile-phone grip styles over a sample population of 100 subjects was proposed. Moreover, [15] shows the impact of the human body which can be seen from the shadow effect in the far-field pattern of the antenna in the direction of the person and [16] investigates how much the body anatomy affects the Mean Effective Gain, resulting in a variation of more than 10 dB among people with different characteristics. Furthermore, recent studies [17] focus on the user effects on the performance of the mobile antenna at 28 GHz, since this is one of the candidate bands for the upcoming $5G$ communication systems.

1) Results for TRP: The results of the measurements in free space shown in table III further confirm those achievements. The worst performing phones in TRP for LTE800 are the Huawei P9 in the right side of the head and the Apple iPhone 6S in the left side of the head. The best performing phones for LTE800 are the Microsoft Lumia 640 in both configurations and the Sony xperia Z5 in BHHL. The free space performance results in LTE800 demonstrates that both the best and the worst performing phones have the same performances in free space, i.e., when used in a hands-free installation or with head-set. Moreover, for the worst performing phones the performance is only very bad in one side of the head, showing that the antenna design does not take the body-loss in both right and left hand usages into account.

The difference between free space and the hand-head results for the worst performing phones is around 18 dB at the LTE800 band, whereas for the best performing phones the difference is only around 7 dB. A reduction in TRP performance is equivalent to a reduction of the received power at the base station, which in turn causes a significant reduction in coverage.

TABLE III: Free space TRP performance of the best and the worst performing phones in LTE800 in talk mode.

Phone model	Free space	BHHR	BHHL
Huawei P9	16.76	−1.52	7.93
Apple iPhone 6S	17.63	8.45	0.48
Sony xperia Z5	16.75	10.68	8.3
Microsoft Lumia 640	18.29	11.45	10.79

2) Results for TIS:

a) Talk mode: The same study was conducted to calculate the TIS parameter of the best and the worst performing phones in free space and the results are shown in table IV. The difference in both cases is similar, 7 dB on average, and for the worst performing phones it is moderate compared to the difference in TRP.

b) Data mode: In the previous measurement campaign [3] the two best and worst performing phones were investigated in free space in the highest frequency band and the results in Table V show that the impact of the phantom hand reduces the receiver performance by $2-5$ dB. Comparing these data with the ones in Table IV, it appears that the value of the body loss due to the hand-head phantom is very close to the one due to only the hand phantom [3], showing that the head phantom does not highly affect the receiver performance.

TABLE IV: Free space TIS performance of the best and the worst performing phones for LTE800 in talk mode.

Phone model	Free space	BHHR
HTC 10	−91.46	−82.63
Doro Liberto 825	−89.01	−83.87
Microsoft Lumia 650	−95.37	−89.15
Microsoft Lumia 640	−96.46	−90.2

TABLE V: Free space TIS performance of the best and the worst performing phones for LTE2600 in data mode.

Phone model	Free space	Hand right
HTC 10	−84.5	−82.5
Microsoft Lumia 950	−90.5	−85.1
Sony xperia Z5 compact	−92.5	−91.1
Samsung Galaxy S5 mini	−94.9	−92.5

VI. Discussion

Figure 4 shows the earlier results on the same phones [1], [3], allowing thus the comparison between voice service in the traditional systems and VoLTE. Analyzing the overall values of the TRP at comparable bands, it appears that the phones are able to radiate an amount of power around 10 dB higher in the GSM900 than the corresponding bands in the UMTS and LTE systems. In fact, in the GSM900 the values raise from 7 dB to 22 dB approximately, considering both BHHR and BHHL configurations, whereas in the UMTS900 and LTE800 the TRP varies from 1 dB to 11.5 dB on average. The same difference can be noticed comparing the phones performance in free space, around 28 dB in GSM800 versus 17 dB in LTE800. Similar considerations apply for the GSM1800 and the LTE1800 bands, even if the difference is lower, 7 dB approximately. As can be seen, the order of the phones is not exactly the same in voice service and in VoLTE but rather similar for the best and especially for the worst phones.
Looking at the results of the measurements of the TIS, the difference between VoLTE and data-mode is only 3 dB on average, due to the influence of the head phantom along with the hand, that decreases the performance of the phones by 3 dB on average. Moreover, apart from the HTC10, which is the worst performing phone in both configurations, the best performing phones in data mode (Samsung Galaxy S5 mini and Sony xperia Z5 compact) are placed in the lower part of the plot, whereas the worst performing phone (Microsoft Lumia 950) is one of the best performing phones in VoLTE.

VII. Conclusions

The 22 tested mobile phones present a very large variation in voice communication performance. From 9 dB to 17 dB is

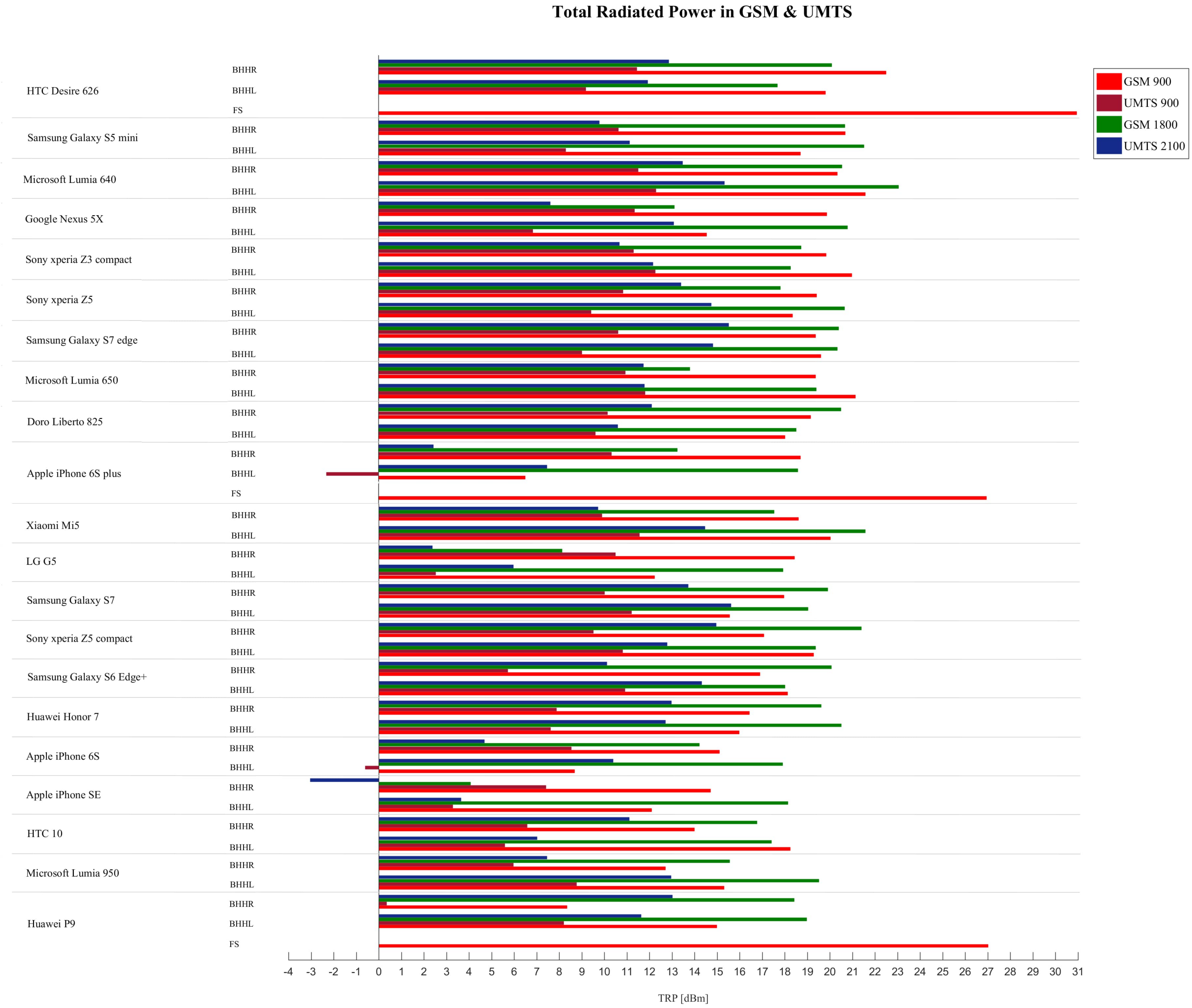


Fig. 4: Results for voice service in GSM and UMTS bands [1], [3]. Measured transmitter performance in BHHR and BHHL configurations of all phones sorted from the best to the worst performing according to GSM900 band in BHHR setup. For the best and worst performing phones in each configuration also the value in free space (FS) is shown.

the spread in TRP across the European LTE frequency bands studied and around 9 dB is the spread in TIS. This variation is larger than that seen in the previous investigations [2], [18]. Moreover, for many phones the transmitter and receiver antennas are strongly affected by which side of the head the phone is used. A variation in TRP of up to 8 dB between left and right side of the head was seen for the worst performing phone.

What is more, the worst performing phones in hand-head phantom show performance close to the best performing phones when measured in free space.

For this reason, the impact of the presence of the human body on input impedance, far-field radiation pattern, radiation efficiency and magnitude of the near field of the antenna should be fully investigated, when designing antennas [15]. Furthermore, it is necessary that a standard is set for the minimum accepted communication performance, which is fundamental to assure radio coverage.

Future studies will focus on Over-The-Air testing of MIMO-capable terminals, whose performances are not expressed in terms of TRP and TIS, but the FoM to take into account is the absolute throughput. The efforts in [8], [19] point out the need of a different OTA technology to emulate a spatial-temporal propagation environment at the DUT location. In fact, the performances of MIMO systems depend not only on antenna design but also on propagation characteristics. Hence, the need for channel modeling highlighted in [20]. It is realized by mapping the models into probe antennas positioned in a circular array which, along with a fading emulator and an anechoic chamber, is part of the setup used to test MIMO systems. Then, in recent works [21]–[23], the anechoic chamber is replaced by the multiprobe anechoic chamber (MPAC), due to the need of emulating multipath environments in a realistic and accurate way.

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