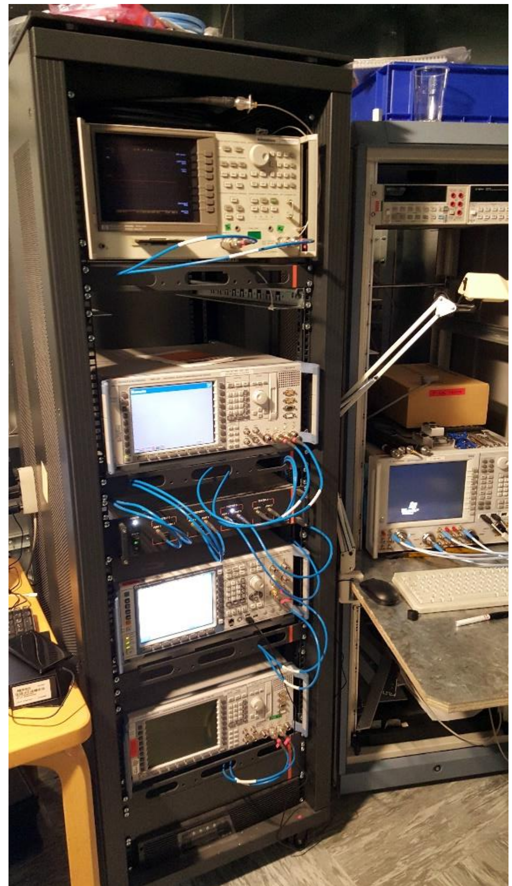
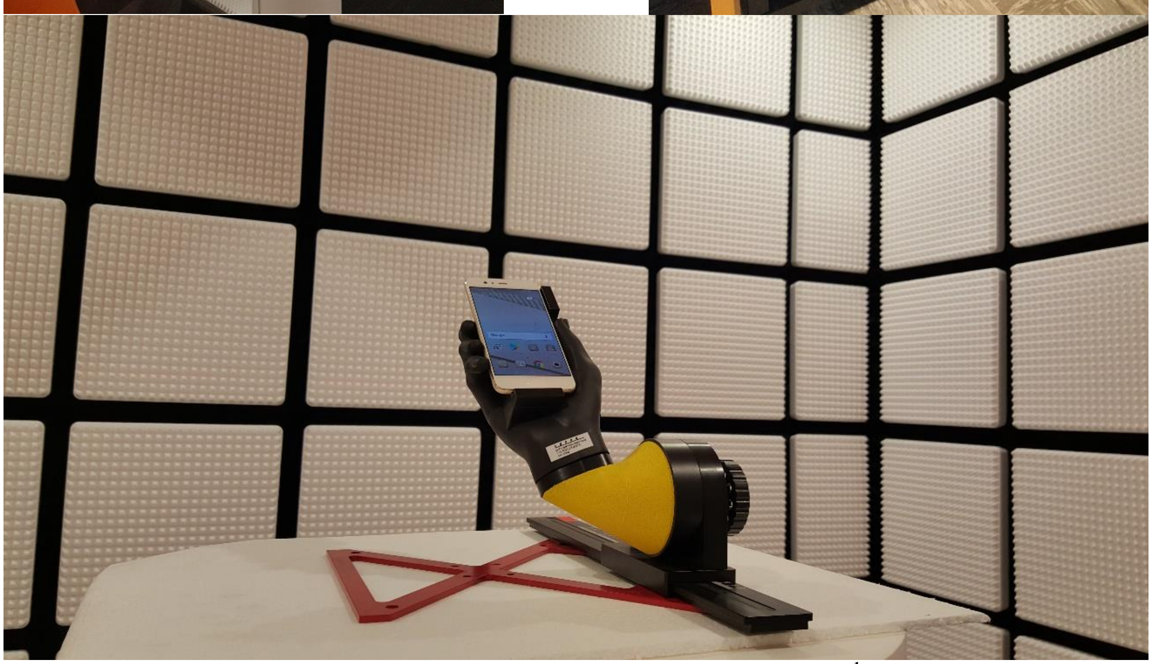
Mobile Phone Antenna Performance 2018





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Introduction

This study investigates antenna performance of the most widely used mobile phones in Denmark in 2018. Antenna performance of a phone is vital for its ability to ensure radio coverage in low signal situations. The study is based on the mobile systems in Denmark and includes both speech and data services. The selected phone models are the most popular new phones at the time of this study.

Radio coverage for a phone depends on the available signal from the antenna mast as well as the phone's ability to collect this signal. This ability depends strongly on the antenna in the phone and how the user holds the phone next to the head during a call [Pel09] or in browsing mode. If the phone is not used hand-held but instead used in, e.g., a hands-free installation or connected to a headset, the phone itself may be placed free of any close-by objects. In such case the ability to collect a radio signal is typically very different and generally better.

In order to ensure a connection between the mobile phone and the base station, a strong enough link is needed both from the phone to the base station (the phone is transmitting and the base station is receiving) and from the base station to the mobile phone (the base station is transmitting and the mobile phone is receiving). The weakest link determines the quality of the connection or service. For telephony the weakest link is from the mobile phone to the base station, called the uplink by mobile network operators. For data services, the weakest link is the one from the base station to the mobile, called the downlink, according to the network operators. The current study therefore focuses on the transmitter performance for telephony and the receiver performance for data mode, as these are the crucial links in weak radio signal conditions.

Several systems and frequencies are used for mobile communications in Denmark. The systems are the Global System for Mobile communications (GSM) also referred to as the 2nd generation system (2G), the Universal Mobile Telecommunications System (UMTS), referred to as the 3rd generation system (3G) and the Long-Term Evolution (LTE) system, referred to as the 4th generation system (4G). The 2G system was mainly for telephony, the 3G for both data and telephony and the 4G for data only. The frequencies used are in the 800 to 900 MHz bands and in the 1.8 to 2.5 GHz bands. The 800-900 MHz bands are also referred to as the low frequency bands and have generally larger coverage areas, and due to that are the most important ones in areas with weak signals, e.g. in the countryside. Due to the fact that the number of simultaneous connections is limited by the frequency bands available, the high frequency bands are mainly added and used in densely populated areas, typically in cities. To ensure a connection in a weak signal situation, the low frequency band result is therefore the most important.

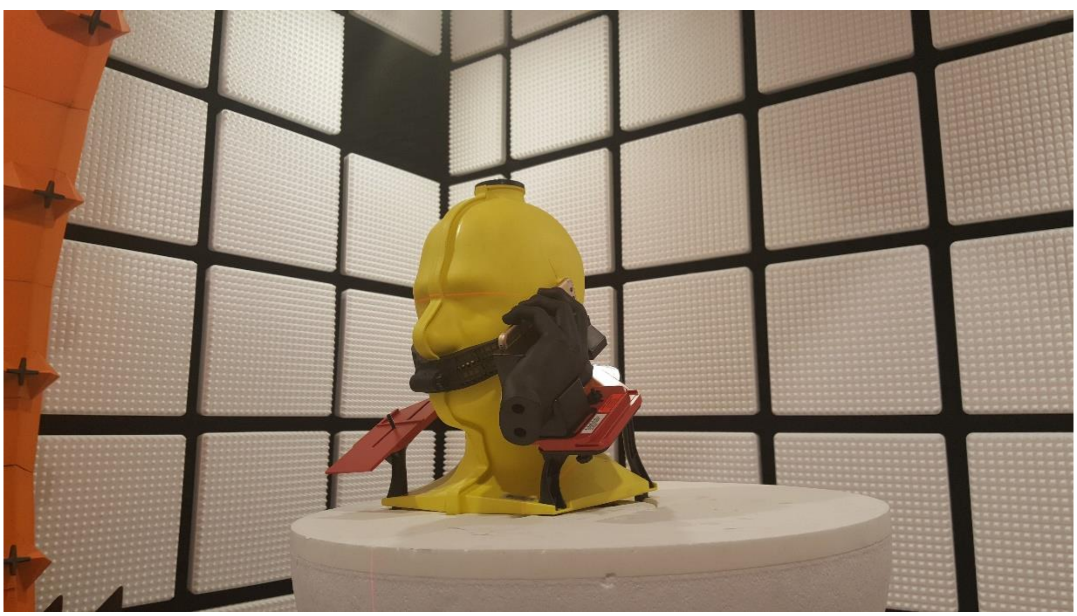
The test used in this study is often referred to as the antenna test, even though the test includes more than the antenna itself. The transmitter and receiver electronics are also included in these tests, but since these parts must fulfil mandatory limits during manufacturing, only the antennas can result in significant performance differences between phones.

The study is a follow-up on similar studies conducted in 2012, 2013 and 2016 on phone models common in the market at that time [Ped12, Ped13, Ped16]. The overall aim of the earlier studies was to establish field strength calculations for mobile telephony and to obtain the minimum field strength needed to ensure coverage, see appendix II. The predicted field strength values for all mobile networks everywhere in Denmark were then compared to the minimum values and a combined coverage map was produced by the Danish authorities [Erhvervsstyrelsen 2012 and 2013 and Energistyrelsen 2016].

The present study investigates, as the earlier studies, the ability of the phones to ensure a connection in a weak radio signal condition. Therefore, for telephony the transmit ability of each phone is measured, while the receive ability is measured for data services. Likewise in the investigation from 2016 [Ped16], this study also considers the position of the phone with respect to the head for the telephony services, i.e. the phones are tested on both sides of the head.

Test Procedure

The investigation of the communication performance of mobile terminals is based on tests of the ability of the terminals to transmit *to* the base station and receive *from* the base station. In normal operation the mobile terminal can adjust its power according to the needs so in order to test its ability to connect in a weak radio signal situation, the terminal is requested to transmit with the highest transmit power. The



Setup for telephony with phantom head and phantom hand holding the phone.

maximum transmit power depends on the mobile system and on the power class of the mobile terminal. Generally, the terminals can transmit with 33 dBm for GSM900, 24 dBm for both UMTS900 and UMTS2100,30 dBm for GSM1800 and 23 dBm for LTE. The higher transmit power for the GSM system is due to the fact that the terminal only transmits in bursts of approximately 1/8 of the time whereas the UMTS system transmits continually.

The tests conducted in the study are based on the agreed standard test procedures for mobile phones, created by the Cellular Telecommunications Industry Association (CTIA) [CTIA18], with a few exceptions. These exceptions are:

For telephony:
In the case where more than one antenna can be used for the same system the measurements are performed in the same way as for phones with no antenna selection. In the standard this is referred to as autonomous mode [CTIA18, sec 5.14.2]. This way the phone selects, by itself, the best antenna for the test situation. The deviation from the standard is made, since the special modified test phones required for the standardised test are not commercially available.

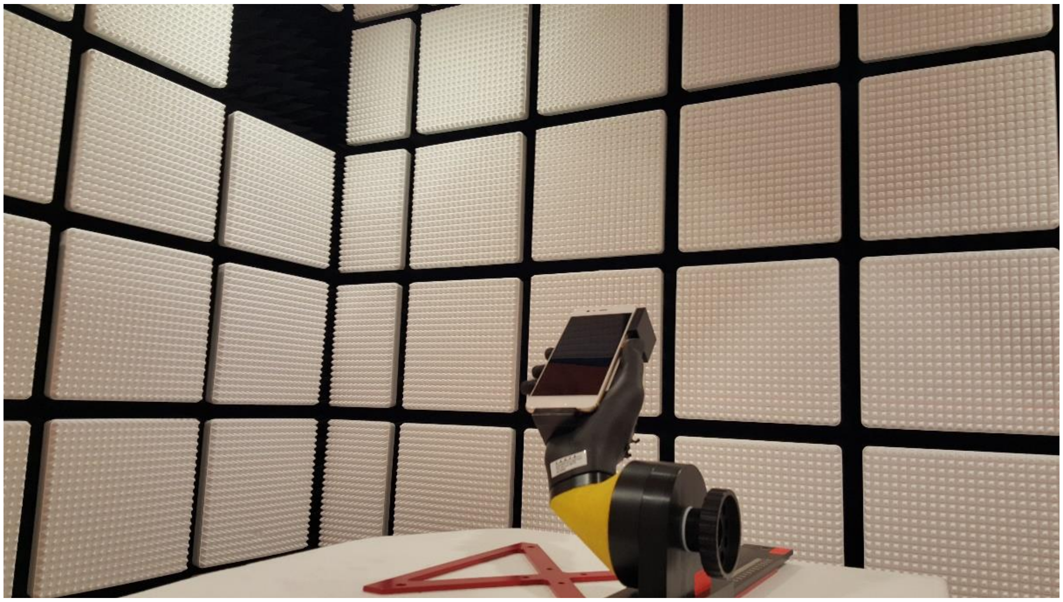
For Data service:
According to the standard test [CTIA18] each antenna (of typically two) for a dedicated system and frequency band must be measured individually by disabling the antenna switching system used in normal operation. The measurements conducted in this study allow the phone to perform the antenna switching as it sees fit (like the autonomous mode). The deviation from the standard is made, since the special modified test phones required for the standardised test are not commercially available.

To limit the number of tests on each phone only the frequency bands used in Denmark (and generally in Europe) are measured, and only the centre channel as a representative of the band is studied. Further, the following usage scenarios are investigated.

For telephony:

1. 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 (Beside Head and Hand Right side).
2. 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 (Beside Head and Hand Left side).

For phones in data services:
The phone is held with the right phantom hand in browsing stance.

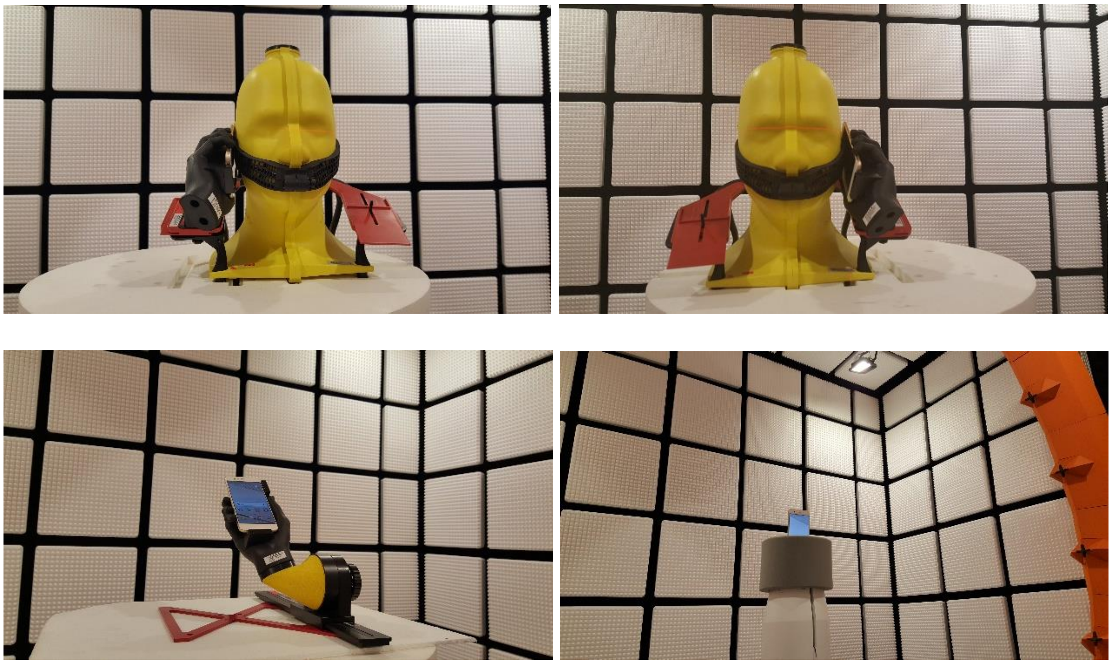


Setup for data services with phantom hand holding the phone.

The receiver performance is evaluated in terms of the so-called Total Isotropic Sensitivity (TIS) for each frequency band. The lower the value of the TIS, the smaller the signal required by the phone for operation and the better the phone is at receiving in weak signal areas. Note that TIS is a negative number and -97 dBm is smaller than e.g. -90 dBm.

For the transmitter performance, the evaluation is in terms of the so-called Total Radiated Power (TRP). The higher the TRP, the stronger signal at the base station, and the better the connection.

The phones are also measured in free space, i.e. with no phantom hand or head present. By comparing the results obtained with and without the phantom present, the robustness of the antenna to the user's influence can be seen. The difference between phantom present and free space is often called body loss.



Setup for telephony and data services including the specified phantom head and hand as well as free-space where no phantom is present.
Photo at the left top; telephony mode at the right hand side, named BHHR. Photo at the right top; telephony mode at the left hand side of the head, named BHHL. Photo at the bottom left; data service. Photo at the bottom right; free-space. All phantoms are as specified in the CTIA test plan [CTIA18] and made by SPEAG.

For telephony the performances of the phones are ranked according to the TRP values for the GSM 900 system. For radio coverage, the 900 MHz frequency band is the most important, as it gives the best coverage and has the largest penetration in Denmark. A change in TRP of more than approximately 2 dB can be taken as a significant difference with respect to coverage.

Mobile phones tested

The phone models tested are listed below. The list was provided by the Danish Energy Agency based on information from the Danish mobile operators.

Device	**Phone model**
1	Doro 7070
2	Huawei P10
3	Huawei P10 lite
4	Huawei P20 Pro
5	Huawei P9 lite mini
6	iPhone 7
7	iPhone 8
8	iPhone 8 Plus
9	iPhone X
10	iPhone XS Max
11	Nokia 7 plus
12	OnePlus 6
13	Samsung Galaxy S8
14	Samsung Galaxy S9
15	Samsung Galaxy S9+
16	Sony Xperia XA2

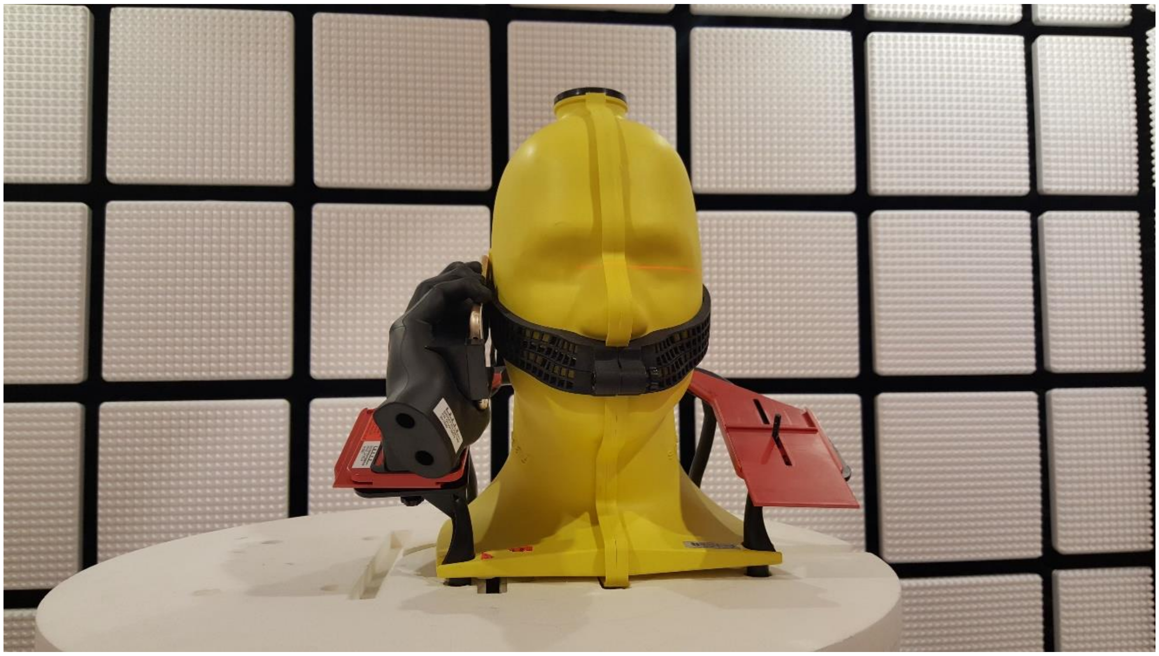
Table 1. *List of all the tested phones. The list is provided by the Danish Energy Agency.*

Photo of all the tested phones. The list of the phone models is provided by the Danish Energy Agency.

Results

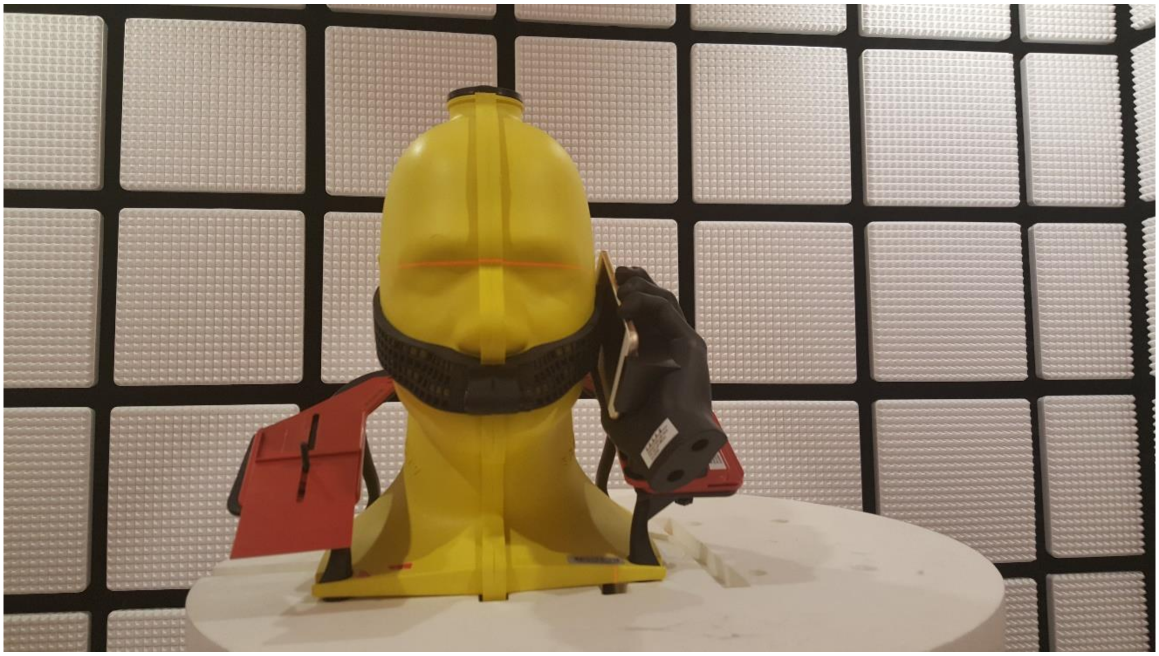
All the values of measured receiver sensitivities (TIS) and transmitter powers (TRP) are listed in the tables below. The values are averages over all directions and both polarisations, for the so-called Total Isotropic Sensitivity (TIS) for receivers and Total Radiated Powers (TRP) for transmitters, defined in the CTIA test plan [CTIA18]. The values are in logarithmic scale, as customary for these measurements, and given in *dBm* values (dB above 1 *mW*). The best phone for receiving has the smallest value of TIS, i.e. the more negative number, since it requires the smallest signal for a satisfying connection. In contrast, higher values of the TRP means a stronger signal at the base station and a better connection. For data services TIS is measured and a bandwidth of 10 MHz is used for the LTE 700, LTE800 and LTE1800, and 20 MHz for LTE2600, as specified in the CTIA standard.

The phones are sorted according to the performance in the most important system and band; GSM900 for the ability to transmit in the case of telephony.



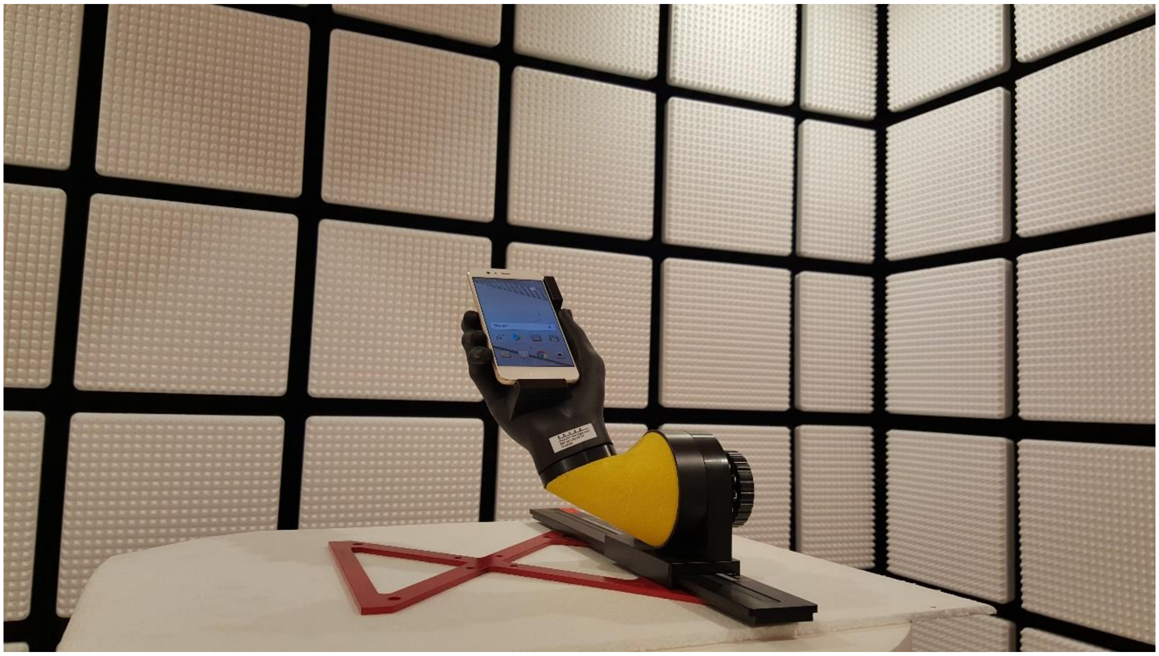
Telephony Right hand (BHHR). TRP values, [dBm]					
Ranking	**Phone model**	**GSM900**	**UMTS900**	**GSM1800**	**UMTS2100**
1	Doro 7070	**23,5**	**14,5**	**25,2**	**17,4**
2	Samsung Galaxy S9	20,7	10,5	21,6	13,4
3	Samsung Galaxy S9+	20,5	11,5	18,8	11,8
4	Samsung Galaxy S8	19,9	10,4	21,3	13,8
5	Huawei P20 Pro	18,5	7,2	19,0	11,0
6	Nokia 7 plus	17,8	9,8	20,7	14,7
7	iPhone 7	17,5	9,2	**11,0**	**7,3**
8	iPhone 8	17,4	9,1	18,1	7,5
9	iPhone X	17,4	9,0	16,9	11,7
10	iPhone 8 Plus	17,3	8,3	17,5	10,6
11	Sony Xperia XA2	17,3	8,1	19,9	14,9
12	OnePlus 6	16,3	6,8	20,6	12,9
13	Huawel P10 lite	15,8	7,9	19,0	11,9
14	Huawei P9 lite mini	14,6	5,1	23,1	13,2
15	iPhone XS Max	14,4	**-1,3**	14,2	9,9
16	Huawei P10	**12,0**	3,5	11,5	13,6

Table 2. *Measured* right hand *performance of all phones sorted from the best performing (phone no. 1) to the worst performing (phone no. 16) according to GSM900 performance, as this is the most important band for coverage. Measurements according to the CTIA specifications for talk mode in right hand, labelled as BHHR [CTIA18].*



Telephony Left hand (BHHL). TRP values, [dBm]					
Ranking	**Phone model**	**GSM900**	**UMTS900**	**GSM1800**	**UMTS2100**
1	Doro 7070	**23,6**	**14,8**	**26,0**	**17,2**
2	Samsung Galaxy S8	20,9	10,9	22,7	17,1
3	Samsung Galaxy S9	20,7	10,9	23,5	16,2
4	Samsung Galaxy S9+	20,3	10,0	21,7	15,8
5	Huawei P20 Pro	19,7	9,5	17,8	9,7
6	Huawei P10	18,2	9,3	19,6	10,8
7	Sony Xperia XA2	18,0	9,6	16,8	9,8
8	iPhone X	16,2	6,4	18,1	14,1
9	Huawei P9 lite mini	16,2	7,3	20,5	14,0
10	iPhone XS Max	15,2	6,2	18,3	14
11	Huawel P10 lite	15,1	6,7	19,3	12,9
12	Nokia 7 plus	15,0	6,0	19,9	15,3
13	iPhone 7	14,0	3,3	20,4	14,5
14	OnePlus 6	12,8	2,9	**16,6**	**9,4**
15	iPhone 8	10,5	-0,7	18,8	12,3
16	iPhone 8 Plus	**7,7**	**-1,4**	18,8	13,7

Table 3. *Measured* left hand *performance of all phones sorted from the best performing (phone no. 1) to the worst performing (phone no. 16) according to GSM900 performance, as this is the most important band for coverage. Measurements according to the CTIA specifications for talk mode in left hand, labelled as BHHL [CTIA18].*

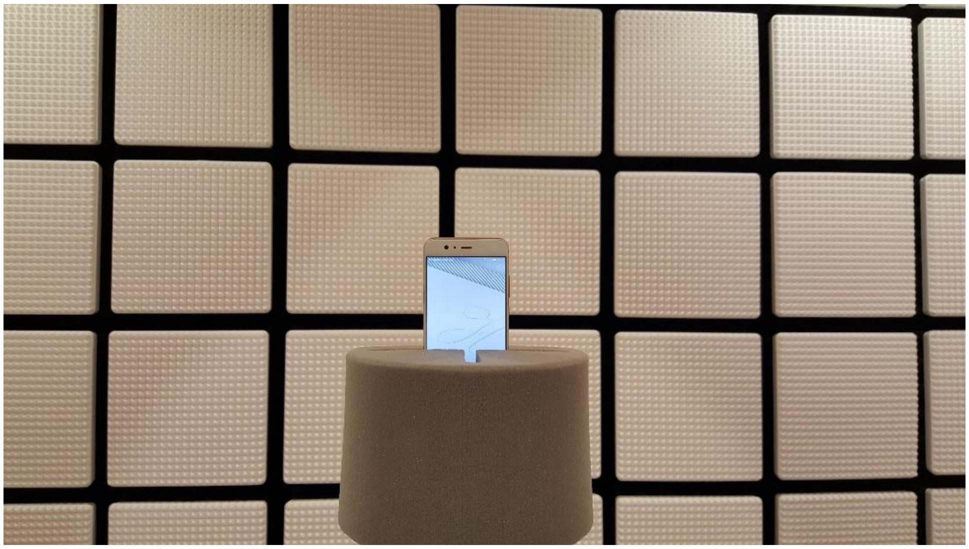


Data service Right hand. TIS values, [dBm]							
Ranking	**Phone model**	**LTE700**	**LTE800**	**LTE1800**	**LTE2600**	**UMTS900**	**UMTS2100**
1	Samsung Galaxy S9+	**-93,3**	**-93,3**	**-96,6**	-90,6	-107,9	-107,7
2	Samsung Galaxy S9	-92,6	-92,6	**-96,6**	-90,0	-105,9	-108,2
3	iPhone 8 Plus	-91,7	-91,5	-94,5	-88,3	**-108,4**	-108,7
4	iPhone 8	-91,4	-91,5	-94,6	-88,8	-106,7	-108,0
5	iPhone 7	-91,2	-91,3	**-91,9**	-90,5	-106,3	-106,9
6	Huawei P20 Pro	-91,1	-91,0	-95,2	-88,3	-105,5	-107,9
7	Samsung Galaxy S8	-90,8	-92,8	-94,9	**-92,1**	-105,0	-107,8
8	OnePlus 6	-90,2	-89,0	-94,3	-89,5	-104,5	-107,5
9	iPhone X	-90,0	-91,1	-92,0	**-86,5**	-103,4	-106,4
10	Huawei P10	-89,7	-90,8	-92,2	-89,4	-106,4	-108,5
11	Nokia 7 plus	-89,6	-91,0	-93,3	-87,8	-105,6	**-104,7**
12	iPhone Xs Max	**-88,8**	**-88,2**	-93,5	-90,7	-105,1	-104,8
13	Doro 7070	N/A	-91,2	-95,3	-89,8	-105,2	-108,7
14	Huawei P9 lite mini	N/A	-88,8	-93,1	-91,1	**-98,4**	**-109,9**
15	Huawei P10 lite	N/A	-92,6	-94,1	-89,6	-104,8	-106,5
16	Sony Xperia XA2	N/A	-90,0	-93,6	-88,2	-104,8	-104,9

Table 4. *Measured* data service *performance of all phones sorted from the best performing (phone no. 1) to the worst performing (phone no. 16) according to the results for LTE700 performance. Measurements according to the CTIA specifications for data mode in right hand [CTIA18]*.

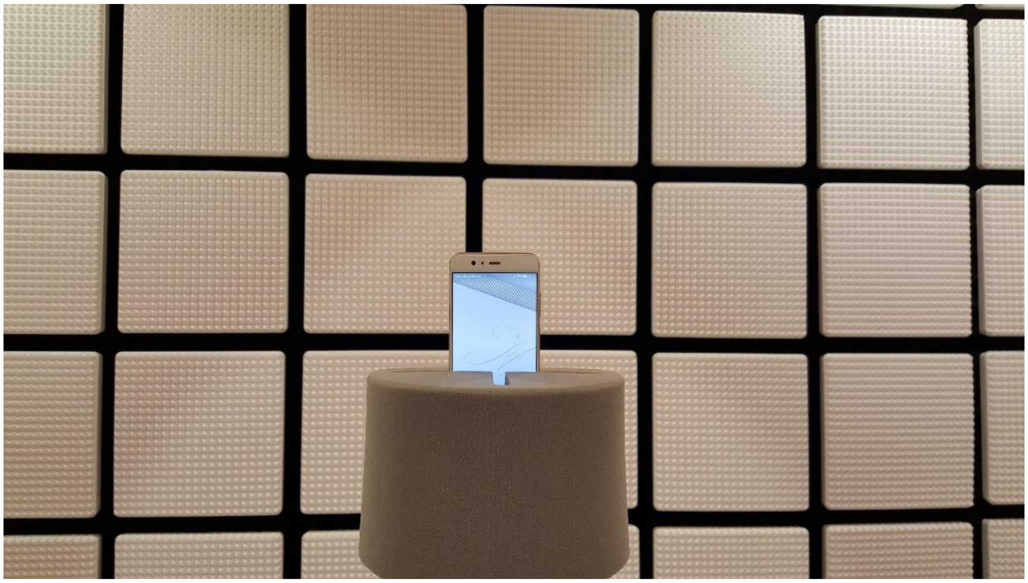
Measurements of Free Space Performance

All phones are also measured with no hand or head present as a reference case. This represents the situation where the phone is placed freely standing in e.g. a handsfree-kit and the like and a wired or wireless connection is used between the user and the phone. Often the best performance is obtained in this case.



Telephony Free space. TRP values, [dBm]					
Ranking	**Phone model**	**GSM900**	**UMTS900**	**GSM1800**	**UMTS2100**
1	Huawei P10 lite	**29,7**	20,2	25,9	19,6
2	Doro 7070	28,7	**20,7**	**27,6**	18,9
3	Huawei P10	28,0	18,7	25,9	18,8
4	Sony Xperia XA2	27,8	18,9	**22,5**	18,0
5	iPhone 7	27,4	18,2	25,3	18,5
6	Samsung Galaxy S8	27,4	16,9	25,8	**19,7**
7	Samsung Galaxy S9+	27,6	18,1	26,0	18,6
8	Samsung Galaxy S9	27,2	17,0	26,1	18,4
9	Huawei P9 lite mini	27,0	18,8	26,3	**16,4**
10	iPhone 8	26,8	17,9	23,7	18,1
11	Huawei P20 Pro	26,7	17,5	23,6	18,8
12	iPhone 8 Plus	26,2	17,7	24,6	18,8
13	OnePlus 6	25,6	16,1	24,1	16,5
14	iPhone X	25,4	16,3	22,7	17,0
15	Nokia 7 plus	24,7	**15,6**	24,6	19,5
16	iPhone XS Max	**20,5**	15,9	22,6	16,9

Table 5. *Measured performance of the phones ability to transmit in free-space.*



Data service Free space. TIS values, [dBm]							
Ranking	**Phone model**	**LTE700**	**LTE800**	**LTE1800**	**LTE2600**	**UMTS900**	**UMTS2100**
1	iPhone 8	**-96,2**	**-95,6**	-97,0	-90,8	-109,5	-110,0
2	iPhone 7	-95,7	-95,3	-96,0	-92,7	**-109,8**	-110,5
3	iPhone 8 Plus	-95,6	-94,6	-96,8	-91,3	-109,2	**-111,7**
4	Samsung Galaxy S9	-95,5	-94,5	**-98,9**	-91,7	-106,5	-110,2
5	Samsung Galaxy S9+	-94,8	-94,8	-98,6	-91,9	-108,4	-110,5
6	Huawei P10	-94,4	-94,0	-96,1	-90,8	-108,9	-110,3
7	iPhone XS Max	-94,4	-93,5	-96,2	-93,0	-106,8	**-107,4**
8	iPhone X	-94,2	-94,6	-94,2	-89,7	-107,3	-109,1
9	Samsung Galaxy S8	-94,0	-95,0	-97,5	-93,0	-107,2	-108,1
10	Huawei P20 Pro	-93,6	**-92,9**	-98,1	-89,5	-107,7	-110,4
11	Nokia 7 plus	-93,6	-93,0	-95,1	**-88,3**	**-106,4**	**-107,4**
12	OnePlus 6	**-93,3**	-93,3	-96,6	**-93,3**	-107,1	-109,7
13	Doro 7070	N/A	-94,2	-96,5	-92,4	-109,3	-111,3
14	Huawei P9 lite mini	N/A	-93,7	**-94,2**	-92,3	-106,8	-111,3
15	Huawei P10 lite	N/A	-95,4	-97,6	-92,8	-107,9	-109,9
16	Sony Xperia XA2	N/A	-94,7	-95,3	-90,1	-108,1	-107,9

Table 6. *Measured performance of the phones ability to receive in free-space.*

Discussion

From the table with the free space performance results it is clear that all phones perform very well if not used next to the human head and hand. Free space is the situation when the phone is used in, e.g., a hands-free installation. In addition, the performance of the worst performing phones is actually very good in free space.

The results clearly show that the performance of the different models vary considerably. Most variation is observed for the case of telephony while a significantly smaller variation is seen in the case of data services. The variation among the phones for **telephony** depend mainly on the frequency bands. The largest variation is for the lower frequency bands with some 12-16 dB variation for the different systems and left or right hand usages. For the high bands the variation is some 8-10 dB.

The performance variation between left hand and right hand usage is very large for several cases. This shows that the antenna and/or the location of the antenna in some phones is not designed well.

The differences between free space and the hand-head results for the best phones are only some 6 dB. For the worst preforming phones the difference is some 16-18 dB at the GSM900 band. The worst performing phones typically only have very bad performance at one side of the head. A 17 dB reduced TRP performance is equivalent to a reduction of the received power at the base station of 50 times or, in other words, the phone must transmit with 50 times as much power to obtain the same power level at the base station.

The absolute performance is improved compared to the earlier study in 2016 [Ped16]. The best performing phones transmit some 2 dB more in the present study over all bands and systems compared to the 2016 study. The worse performing phones perform some 3 dB better across all bands and systems compared to the 2016 study. For the UMTS2100 system, the improvement is some 8 dB in the present study compared to the 2016 study.

For **data services**, the variation among the phones is lower than for telephony and always less than 5 dB, with only one exception in only one system and band, the UMTS900. The variation in free-space is only some 3 dB for the low bands (700, 800 and 900 band) and some 5 dB at the high bands.
The absolute performance and the spread in performance for data service is significantly better than in the last study in 2016 [Ped16]. The best phones are in average over the bands and systems some 1 dB better in the present study compared to the 2016 study. The worst preforming phones are for most bands some 4 dB better in the present study than in the 2016 study.

The LTE system is designed for data only and initially it was not possible to make telephony calls. Later, a feature was included in the LTE standard called Voice over LTE (VoLTE). This feature is now used in many LTE networks and if enabled in the network and supported by the phone the data channels are used for telephony similar to services as

Skype calls etc. The VoLTE service has not been tested in this study as not all phones support this feature and further it is possible to disable the VoLTE feature in the phone. Often the call-drops are fewer when not using VoLTE for the calls. In [DiP18] the VoLTE performance is investigated in details and it is seen that also very large variations is found in the case of VoLTE calls.

All phones were initially tested in free space to ensure that they were fully functioning. As a result, 2 more phones were acquired as there were problems with the initially acquired phones. One phone model did only work at one of all its LTE bands where the second acquired phone of the same model did not show this problems.

Conclusions

For telephony a very large variation in the communication performance was found among the tested mobile phones. Up to 16 dB variation was seen which is even more that found in the previous investigations [Ped12, Ped13, Ped16].

The absolutely best phone for telephony is the Doro 7070 phone. The Doro has the best performance for all frequency bands and for both sides of the head. The Doro transmit some 3 dB better than all other phones in all bands and at both left and right side of the head, with only one exception. The extra 3 dB means doubling of the transmitter power, which is exceptional. The Doro is a feature phone and not a full smartphone. The best smartphones for telephony are the Samsung S8, S9 and S9+.

For several phones the telephony communication performance depends strongly on which side of the head the phone is used. Up to 10 dB variation in the low band (iPhone 8 plus) and up to 9 dB for the high band (iPhone 7) are seen.

Variation among phones for **data service** is significantly lower than for telephony. The variation is also significantly lower than what was seen in the earlier investigation [Ped16]. The absolute performance is also significantly better in the present study than in the 2016 study. For many phones the difference caused by the hand holding the phone compared to free-space is only 2-3 dB. All in all a very positive development in data service performance is observed.
For the low bands, which generally provide the best coverage, the best phone for data calls is the Samsung S9+ and the worst is the iPhone XS Max.

Main conclusion is that the variation in communication performance among the tested mobile phones is very large and will result in a very large variation in perceived coverage. Earlier it has been demonstrated that a 7 dB difference in phone performance can results in a large reduction in coverage [Erst12]. It is recommended that a standard is set for the minimum accepted communication performance or at least the test results for each phone should be publicly available in order to guide the consumers when buying mobile phones.

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Appendix I: Measurement equipment used

Equipment	Serial number	Uncertainty on TIS
TIS test system StarGate 24	1102287-0010	< ± 1,6 dB
TRP test system StarGate 24	1102287-0010	< ± 1,5 dB
Communication tester R&S CMW 500	1201.000K50- 106102-W1	< ± 1,0 dB
Communication tester R&S Cmu 200	110106	< ± 1,0 dB
Phantom hand incl. spacer + test cube Speag SHOV 2 RP Right PDA Hand	25382	
Phantom hand incl. spacer + test cube Speag SHOV 2 RC Right Clam Hand	15203	
Phantom hand incl. spacer + test cube Speag SHOV 2 LP Left PDA Hand	20258	
Phantom hand incl. spacer + test cube Speag SHOV 2 LC Left Clam Hand	11129	
Phantom head V 4.5 BS Speag SAM	3481	
Phantom hand incl. spacer + test cube Speag SHOV 2 RD Data Hand Right	35205	
Phantom hand incl. spacer + test cube Speag SHOV 2 RW Right Ultra Wide Hand	2328	
Phantom hand incl. spacer + test cube Speag SHOV 2 LW Left Ultra Wide Hand	1312	

The test equipment consists of a ring with test probes and additional instruments to establish a phone call and receive the measured data from the phone under test. The antenna ring with the probes is from Satimo, called StarGsate-24, the tester for communication with the phone is the CMU200 for UMTS and GSM and the CMW500 for LTE. Further a head-phantom is used; it is the so called SAM head as specified by the CTIA [CTIA18]. The last parts are the phantom hands where 4 different hands are used to fit the different types of phones tested as specified by CTIA [CTIA18] for each side of the head. Further two hands for tablet tests are used.

Appendix II: Calculation of limits

The reported values are field strengths and the required minimum levels by the mobile phones are power values. The relation is:

$$P = \frac{|E|^2 \lambda^2 G_0}{4\pi\eta}$$

Where E is the RMS value of the electric field strength, λ the free space wavelength, η is the free space impedance equal to 120 π, and G_0 the maximum gain. Assuming that the incoming power to the mobile phone is arriving equally likely from all directions and in both polarisations, as is the common assumption made in mobile communication [Jak74], it is possible to use the term Total Isotropic Sensitivity (TIS) as agreed upon by 3GPP and CTIA [CTI18]. The TIS includes all the losses in the phone (like impedance matching losses, ohmic and dielectric losses) and can include the losses in the human user of the phone.
This gives the following relation between TIS and the Root Mean Square (RMS) value of the magnitude of the electric field strength:

$$|E| = \frac{\sqrt{4\pi\eta \cdot TIS}}{\lambda}$$

The wavelength is related to the frequency of operation and the medium of radio propagation. The medium is free air and the relation is simply

$$\lambda = \frac{c}{f}$$

Where *c* is the speed of light. The frequency is given by the table below. For the calculations the centre frequency is used.

Mobile System	Frequency Band	Downlink frequency [MHz]	Wavelength [meters]
GSM	900	925 – 960 MHz	0,3183
GSM	1800	1805 – 1880 MHz	0,1628
UMTS	900	925 – 960 MHz	0,3183
UMTS	2100	2110 – 2170 MHz	0,1402
LTE	700	729 – 746 MHz	0,4068
LTE	800	791 – 821 MHz	0,3722
LTE	1800	1805 – 1880 MHz	0,1628
LTE	2600	2620 – 2690 MHz	0,1123

Frequency of operation for the downlink in the mobile systems investigated and the free space wavelength at the centre of the downlink.