# Power Level Distributions of Radio Base Station Equipment and User Devices in a 3G Mobile Communication Network in India and the Impact on Assessments of Realistic RF EMF Exposure

Paramananda Joshi, Mukesh Agrawal, Björn Thors, Davide Colombi, Ashwani Kumar, and Christer Törnevik

***Abstract*—The aim of this paper is to present results on output power level distributions of radio base stations (RBSs) and user devices connected to a Wideband Code Division Multiple Access-based third generation (3G) mobile communication network in India and relate the results to realistic human exposure to radio frequency (RF) electromagnetic field (EMF) emitted by the corresponding RBSs and devices. The output power level distributions have been obtained through network-based measurements. In downlink, data from 868 radio base stations were gathered during seven days. The RBSs were connected to five different radio network controllers (RNCs) located in different regions of India. The mean, median, and 95$^{th}$ percentile RBS output power values were found to be 24%, 21%, and 53%, respectively, of the maximum available power. In the uplink direction, output power levels of 3G devices connected to 1,256 RBSs and the same five RNCs as in the downlink, were assessed separately for voice, data, voice + data, and video applications. In total, more than 1 million hours of data traffic and more than 700,000 hours of voice calls were measured in uplink. The mean output power for voice, data, voice + data, and video were found to be around 1%, 3%, 2%, and 4%, respectively, of the maximum available power for 3G user devices. The findings are in line with previously published results obtained in other networks in Europe, and demonstrate that knowledge on realistic power levels is important for accurate assessments of radio frequency electromagnetic field exposure.**

***Index Terms*—Output power, Power distributions, Realistic exposure, UMTS, WCDMA.**

## I. Introduction

HUMAN exposure to radio frequency (RF) electromagnetic fields (EMF) is directly proportional to the output power of the radio transmitters. Before radio base station (RBS) equipment and user devices are placed on the market they are tested by the manufacturers to make sure that the RF EMF exposure is in compliance with internationally recognized exposure limits, such as the ones specified by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [1]. Also network operators conduct EMF compliance assessment of RBS installations before they are put into service. According to most RF EMF compliance assessment standards developed by the International Electrotechnical Commission (IEC) and the European Committee for Electrotechnical Standardization (CENELEC) [2], [3], [4], [5], [6], continuous transmission at the maximum available power shall be assumed during the assessments of radio products.

In practice, however, the actual power levels depend on different factors, such as fast and advanced power control mechanisms, soft handover, traffic variations, and discontinuous transmission (DTX) [7]. This implies that the standardized RF exposure assessment procedures provide a conservative estimate of the actual exposure, which is further emphasized by the fact that the ICNIRP exposure limits for mobile communication frequencies are intended to be taken as an average over 6 min. For realistic exposure assessments of interest (e.g. epidemiological investigations), it is of fundamental importance to have knowledge on the actual output power levels in real usage scenarios for RBS equipment and user devices.

A possible method for quantifying the actual power levels used by RBSs in downlink is to conduct in-situ measurements. This approach has been employed by several research groups for different 2G, 3G, and 4G radio access technologies [8], [9], [10]. In [10], the mean output power level for 3G Universal Mobile Telecommunications System (UMTS) over 24 h was found to be 31% of the maximum theoretical value.

Similarly, realistic output power levels in uplink have been quantified using special test terminals [11], [12], [13]. In [13], the mean output power was found to be less than 1% of the maximum available power for voice applications. For data, a linear increase of the mean output power as a function of the

P. Joshi, B. Thors, D. Colombi, and C. Törnevik are with Ericsson Research, Ericsson AB, Stockholm, SE 164 80, Sweden. (e-mail: paramananda.joshi@ericsson.com; bjorn.thors@ericsson.com; davide.colombi@ericsson.com; christer.tornevik@ericsson.com).

M. Agrawal and A. Kumar are with Ericsson India, Gurgaon, India. (e-mail: mukesh.m.agrawal@ericsson.com; ashwani.k.kumar@ericsson.com).

throughput compared to voice was observed.

Both the in-situ and the test terminal measurements are quite time-consuming and cumbersome to conduct, which will limit the number of samples collected and the statistical base of the investigations. An alternative approach, which allows for the collection of much larger data sets, is to conduct network-based measurements using the operations support system (OSS) normally employed by the operators for network management. Network-based measurements have been conducted in downlink for Global System for Mobile Communications (GSM), UMTS, and Long Term Evolution (LTE) [14], [15], [16] as well as in uplink for GSM and UMTS [17], [18].

In [14], downlink power data for UMTS were gathered in the Swedish TeliaSonera network during 24 h from three radio network controllers (RNCs), comprising 223 RBSs. The reported mean, median, and 90$^{th}$ percentile downlink output power levels were 23%, 17%, and 35%, respectively, of the maximum available power. In [16], which studied 37 UMTS base stations in the Swisscom network (Switzerland), the mean downlink output power was found to be 32% of the maximum power.

Uplink power measurements have also been conducted in the TeliaSonera 3G network in Sweden [18]. Measurement data were gathered from six RNCs for one week. For voice calls, the mean output power was found to be less than 1% of the maximum available power, while data applications resulted in 6 to 8 dB (about 4 to 6 times) higher output power levels.

Although some large scale network measurement studies of output power levels in uplink and downlink are available, questions on their general applicability to other networks remain. Of special interest is to consider countries with larger population densities and possible different usage patterns. Another question is if the results in [18], with data gathered during 2008, have changed over time with the growing number of smartphone users. To shed some light on these questions, network-based measurements of downlink and uplink output power levels have been conducted in a 3G Wideband Code Division Multiple Access (WCDMA) network in India. Another reason for selecting a network in India for these measurements is the public concern across the country regarding human exposure to RF EMF.

In WCDMA systems, information is spread over a relatively wide bandwidth (5 MHz), which increases robustness of the system to interference and thus leads to a reduced average output power for terminals compared with systems like GSM that do not make use of this spreading [7], [19]. A fast closed loop power control mechanism is implemented in both uplink and downlink at the rate of 1500 Hz to keep interference at a minimum level. Furthermore, an open loop power control algorithm is implemented in uplink, to estimate an appropriate power level when a connection is initialized [7]. Another feature of WCDMA is so called "soft" and "softer" handover, which allows the output power in uplink to remain low as the device moves from one cell to another [20].

## II. Materials and Methods

Network-based measurements were conducted in the Bharti Airtel 3G network in India, for both uplink and downlink, using the Operations Support System – Radio and Core (OSS-RC, Ericsson AB, Stockholm, Sweden). The OSS-RC is part of the Ericsson WCDMA radio access network (RAN) system, and constitutes a collection of functions for network management. The use of OSS-RC made it possible to gather large amounts of data from many RBSs during several days. The measurements were conducted for five RNCs located in five different geographical regions of India, namely Delhi, Srinagar, Kota, Guwahati, and Vijayawada as shown in Fig. 1. Data were gathered for 2,475 cells in downlink, and 3,589 cells in uplink. Each cell in this context corresponds to a

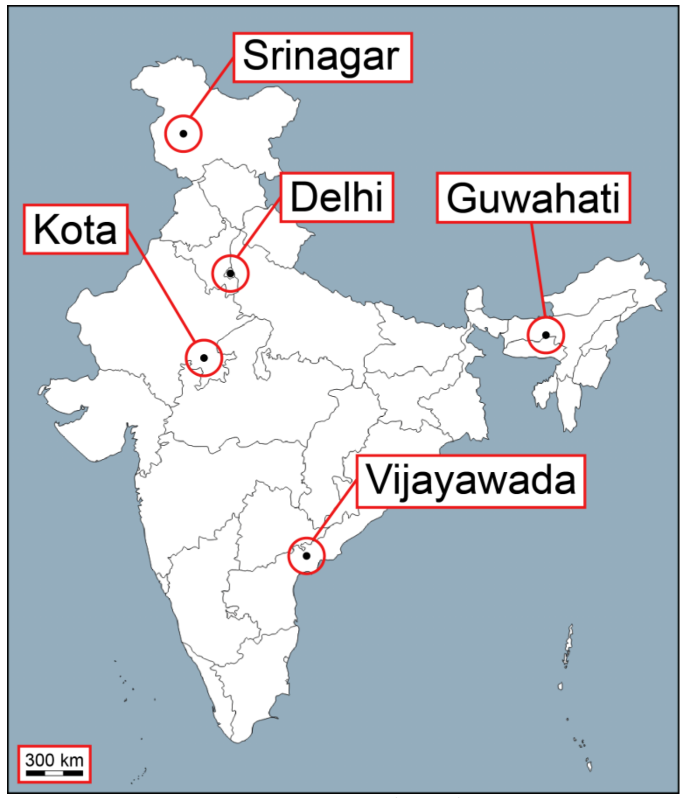
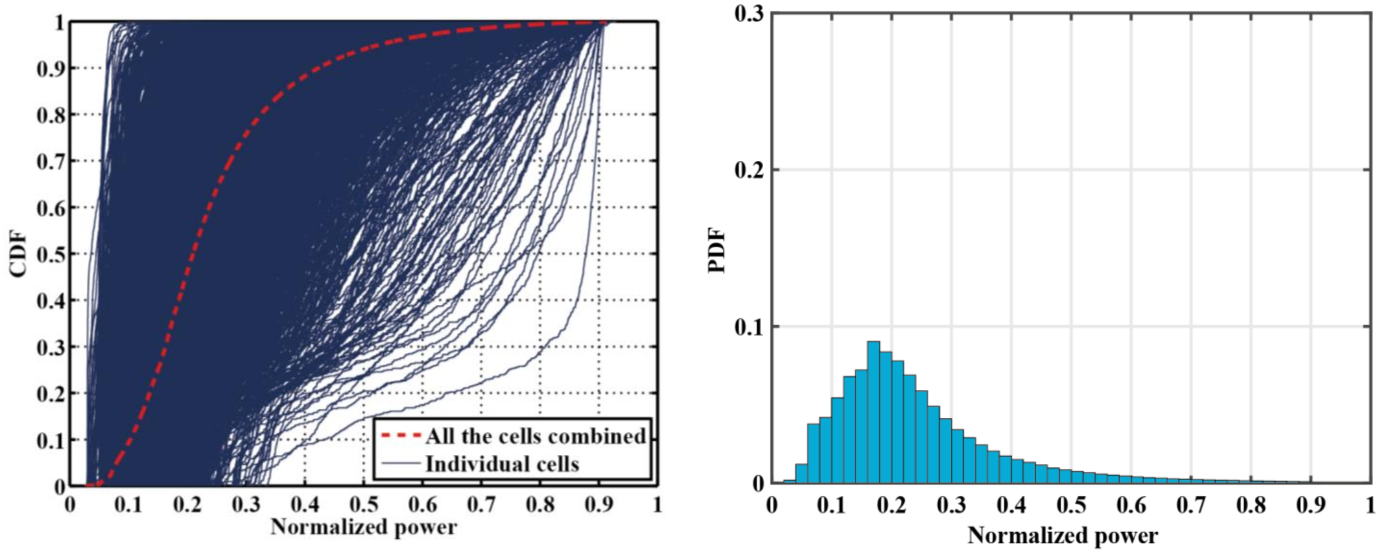



Fig. 1. Map indicating the location of the five RNCs used in the measurements.

geographical area in which 3G user devices have access to the radio signals emitted by a RBS transmitter in a specific UMTS channel. The cells are sorted into one of the categories rural, suburban, urban, and dense urban depending on the environment in which they are located. The measurements were made in UMTS band I (1920 to 1980 MHz in uplink, 2110 to 2170 MHz in downlink) during a full week for each RNC in the period June 24 to July 13, 2014. No festivities or national events took place during the measurement period.




(a) (b)

Fig. 2. (a) Empirical cumulative distribution function (CDF) of normalized 3G RBS output power for all 2,475 cells during the week-long measurement. (b) Probability Density Function (PDF) of the red curve in Fig. 2a.

### *A. Downlink Measurements*

An RBS counter, which provides the transmitted carrier power at the antenna reference point as a percentage of the maximum allocated power to the antenna, was used for the downlink measurements. The sampling time of the counter is 100 ms, and every sample constitutes an average during the sampling period. Each sample was sorted into one out of 50 possible bins (ranges) and the range counter for the corresponding bin was incremented accordingly. The statistical data was fetched by the OSS-RC from the RBS every 15 min corresponding to the smallest possible result output period (ROP).

MATLAB (The Mathworks, Natick, MA) was used to post-process the data acquired by the OSS-RC. The number of samples in each bin was multiplied by the mid-value of the corresponding counter range, and the resulting numbers were summed. This result was then divided by the total number of samples over 15 min for each cell, in order to get the average output power during each ROP.

The accuracy of the network-based measurement approach was verified with in-situ measurements in [14]. A single WCDMA cell in Stockholm was measured during 24 h using both the OSS-RC tool employed in this paper as well as a Narda SRM 3006 selective radiation meter (Narda Safety Test Solutions, Hauppauge, NY). The SRM 3006 instrument was equipped with a three axis E-field probe (Narda Safety Test Solutions, model 3502/01). Power density, integrated over the appropriate WCDMA band, was measured and recorded every 12 s within line-of-sight from the RBS antenna. Simultaneously, instantaneous measurements of the common pilot channel (CPICH) were conducted. These results were subsequently extrapolated to the theoretical maximum power density that would be obtained if the RBS was transmitting at full power [21]. A strong correlation between the 15 min averaged in-situ and network-based measurement results was observed with an average relative error magnitude of 2.7 %.

TABLE I
MAXIMUM UPLINK BITRATES OF DIFFERENT SERVICES IN KILOBITS PER SECOND AND THE TOTAL NUMBER OF SERVICE HOURS MEASURED

| Service | Maximum uplink bitrates (kbps) | Measurement service hours |
|---|---|---|
| Voice | 12.65 | 722,804 |
| Data | 5,760 | 1,182,022 |
| Voice + Data | 12.2 + 64 | 66,168 |
| Video | 64 | 692 |

### *B. Uplink Measurements*

Recordings of 3G user device output power levels were initiated and collected through the OSS-RC, utilizing the WCDMA Measurement Result Recording (WMRR) application, which is the user interface defining and managing the measurements of the Radio Environment Statistics (RES) module (Ericsson AB, Stockholm, Sweden). RES is a measurement function implemented in the RNC, which performs the measurements of required quantities per cell and saves the results as statistical distributions. The RES functionality allows up to 12 simultaneous measurements.

In this work, output power measurements were conducted in parallel for different services, such as “voice”, “data”, “video”, and “voice + data”. The uplink bitrates of the different services and the number of hours for which data were obtained during the measurements are given in Table I.

The sampling time in WMRR was set to 2 s, which was the fastest possible option available. Samples, taken for each cell with a resolution of 1 dB, were subsequently sorted into bins of various sizes corresponding to predefined range counters. The first counter ranged from -50 dBm (0.00001 mW) to -21 dBm (0.0079 mW). The second one ranged from -20 dBm (0.01 mW) to -17 dBm (0.02 mW). In the same manner, the rest of the counters, except the last one, were defined with a range of 3 dB up to and including the power level 23 dBm (200 mW). The last counter included the maximum output power level of 24 dBm (250 mW). If the sampled data fell within a certain range, the range counter was incremented.

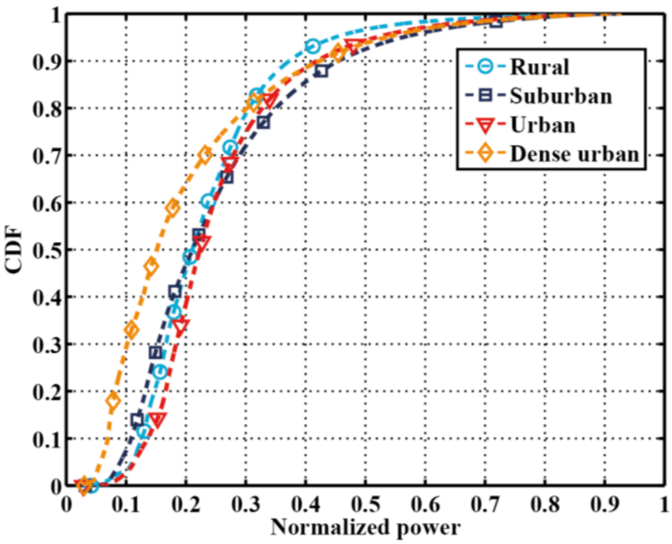



Fig. 3. Empirical CDFs of normalized 3G RBS output power for different environments.

Information on the actual power levels for the individual samples within each bin was not available. Four different 6 h long measurement periods – 00:00 to 06:00, 06:00 to 12:00, 12:00 to 18:00, and 18:00 to 24:00 – were defined in WMRR to investigate the time variation of the output power levels.

Also for uplink, the post-processing of the collected samples was done in MATLAB (The Mathworks, Natick, MA). The number of samples from all the cells was summed for each range counter, in order to get the probability density function (PDF) for all terminals. The cumulative distribution function (CDF) was determined conservatively from the PDF by setting the power level of all samples to the upper limit of the corresponding counter. For example, the values of the samples in the first bin were set to -21 dBm (0.0079 mW). This approach is different compared with the downlink post-processing, where the samples in each bin were assigned the mid power value of the corresponding range counter. The reason for this is the logarithmic increase of the range of the uplink power level counters, with a bin size of 3 dB, leading to a significant risk for an underestimation of the actual power levels if the mid power value had been used. Continuous CDF curves were determined from discrete CDF values, using the cubic spline interpolation algorithm in MATLAB. From the continuous CDF, a PDF with 0.1 dB resolution was determined from which the mean output power was determined.

## III. RESULTS

TABLE II
NORMALIZED 3G RBS OUTPUT POWER STATISTICS FOR DIFFERENT ENVIRONMENTS

| | Normalized RBS output power | | | |
|---|---|---|---|---|
| | Rural | Suburban | Urban | Dense urban |
| Mean | 24% | 25% | 26% | 20% |
| Median | 21% | 21% | 22% | 15% |
| 90th percentile | 37% | 45% | 42% | 42% |
| 95th percentile | 45% | 56% | 52% | 54% |

TABLE III
NORMALIZED 3G RBS OUTPUT POWER STATISTICS DURING HIGH AND LOW TRAFFIC HOURS

| | Normalized RBS output power | |
|---|---|---|
| | High traffic hours | Low traffic hours |
| Mean | 29% | 15% |
| Median | 26% | 15% |
| 90th percentile | 51% | 23% |
| 95th percentile | 63% | 27% |

### A. Downlink

A CDF of the normalized RBS output power for all cells in the measurements are shown in Fig. 2a. The blue lines correspond to results obtained for the individual cells during the week-long measurements. Since the ROP is 15 min, each blue line is based on 4 x 24 x 7 = 672 samples of normalized output power. The density of blue lines is larger in the left region of the figure indicating that the output power is significantly below the maximum in most cases. The red line in the figure is the CDF for all cells combined. Fig. 2b shows the PDF of the red curve in Fig. 2a, indicating that the bin between 16% to 18% received most samples during the measurements. The mean, median, 90th percentile, and 95th percentile of the normalized RBS output power have been determined from the combined measurement data as 24%, 21%, 42%, and 53%, respectively.

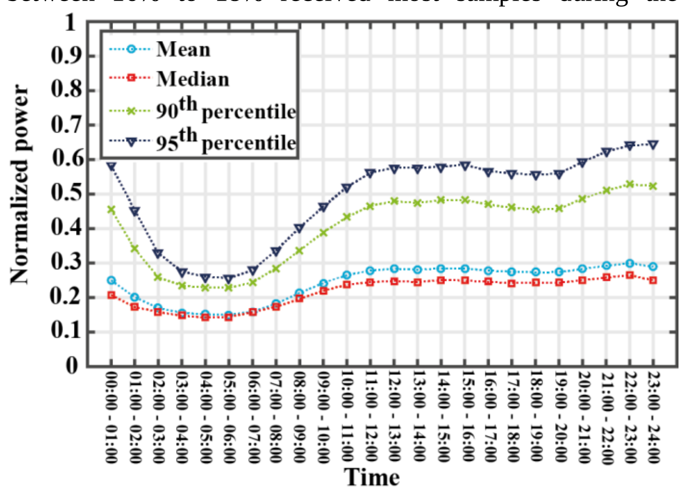



Fig. 4. Variation in normalized 3G RBS output power during the day.

The results are in good agreement with the findings in [14] where mean, median, and 90th percentile normalized RBS output power levels of 23%, 17%, and 35%, respectively, were reported. More than 1.5 million downlink samples were collected during the measurements. In no single case did the normalized RBS output power reach 100%.

CDFs of normalized RBS output power for different environments are shown in Fig. 3. Here, 13% of the cells were located in rural regions, while 20%, 46%, and 21% were located in suburban, urban, and dense urban regions, respectively. The CDF curves are quite similar in all environments with the lowest power level being obtained for the rural or dense urban cases. As shown in Table II, the mean RBS output power varied between 20% and 26% of the maximum available power for the different environments. The corresponding variation for the median, 90th percentile, and

95th percentile power levels ranged from 15% to 22%, 37% to 45%, and 45% to 56%, respectively.

To investigate the variation in RBS output power during the day, the measurement values were first grouped by the hour they were gathered before the mean, median, and 90th percentile values were determined. The results are given in Fig. 4. Similarly to [10] and [22], a variation in traffic was observed during the day with low traffic during the night and early morning and higher traffic during the day and evening. From the figure, two 4 h long periods of high and low traffic hours were identified, ranging from 20:00 to 24:00 and from 03:00 to 07:00, respectively. The mean, median, 90th percentile, and 95th percentile normalized RBS output power for the high and low traffic hours are given in Table III.

No significant differences were observed between weekdays and weekends.

## B. Uplink

CDFs of user device output power for different applications are shown in Fig. 5. As expected, the user device output power is lower for voice than for the other applications considered. Mean, median, 90th percentile, and 95th percentile user device output power levels are given for all environments combined in the last column of Table IV. The mean, 90th percentile, and 95th percentile output power for voice was 5 dBm (3.2 mW), 5.4 dBm (3.5 mW), and 10.1 dBm (10.2 mW), respectively, which is below 2 % to 4.1 % of the maximum available power for terminals. The much lower median value of -11.5 dBm (0.07 mW), which is <0.1% of the maximum available power, is a consequence of a skewed output power distribution. For data, the mean, median, 90th percentile, and 95th percentile user device output power levels were 2.6%, <0.1%, 4.6%, and 13.9%, respectively, of the maximum available power. The highest power levels were obtained for video with mean, median, 90th percentile, and 95th percentile values of 4.3%, <1%, 8.4%, and 25.2%, respectively, of the maximum available power.

Since the total number of cells is different in the uplink and downlink studies, the proportions of cells belonging to different environment are also somewhat different. In the uplink, 16% of the cells were located in rural regions, while 25%, 43%, and 16% were located in the suburban, urban, and in dense urban regions, respectively. As shown in Table IV and Fig. 6, no significant difference in user device output power levels were obtained between different environments.

According to Table V, the variation in user device output power levels during the day was in general less than 4 dB for all applications. In contrast to the other applications, the power levels obtained for video during the night from 00:00 to 06:00 were found to be higher than the power values obtained during the morning from 06:00 to 12:00 and during the day from 12:00 to 06:00.

As for the downlink measurements, no significant differences were observed between weekdays and weekends.

TABLE IV
3G USER DEVICE OUTPUT POWER STATISTICS FOR DIFFERENT APPLICATIONS IN DIFFERENT ENVIRONMENTS

| Applications | | Output power for different environments (dBm) | | | | |
|---|---|---|---|---|---|---|
| | | Rural | Suburban | Urban | Dense urban | All combined |
| Voice | Mean | 6.2 | 5.2 | 3.8 | 5.8 | 5.0 |
| | Median | -9.0 | -10.7 | -12.3 | -11.6 | -11.5 |
| | 90th percentile | 7.1 | 5.9 | 4.0 | 6.3 | 5.4 |
| | 95th percentile | 11.9 | 10.5 | 8.4 | 11.2 | 10.1 |
| Data | Mean | 9.7 | 8.5 | 7.8 | 7.8 | 8.2 |
| | Median | -2.6 | -5.6 | -6.8 | -10.0 | -6.8 |
| | 90th percentile | 13.2 | 11.2 | 10.1 | 9.2 | 10.6 |
| | 95th percentile | 17.4 | 15.8 | 14.7 | 14.7 | 15.4 |
| Voice + Data | Mean | 8.0 | 6.7 | 5.5 | 7.9 | 7.0 |
| | Median | -6.2 | -8.8 | -10.4 | -9.4 | -9.5 |
| | 90th percentile | 10.4 | 8.4 | 6.5 | 9.7 | 8.4 |
| | 95th percentile | 14.9 | 13.0 | 11.2 | 15.1 | 13.4 |
| Video | Mean | 11.2 | 11.4 | 9.1 | 10.5 | 10.3 |
| | Median | -0.2 | -2.2 | -3.8 | -5.3 | -3.3 |
| | 90th percentile | 15.6 | 15.4 | 11.7 | 11.6 | 13.2 |
| | 95th percentile | 18.9 | 19.8 | 16.04 | 17.8 | 18.0 |

# IV. DISCUSSION

The fact that measurements were conducted for five different RNCs located in different regions of India ensures that the measurements include a wide range of environments, equipment, and radio propagation characteristics. Furthermore, the week-long measurements provide very large amounts of data, which give good confidence in the validity of the obtained statistical distributions.

As mentioned above, most RF EMF compliance assessment standards require that assessments in both uplink and downlink are conducted assuming continuous transmission at the maximum available power level. As shown in this work, however, the actual transmitted power levels are usually significantly below the maximum. Since the RF EMF exposure is directly proportional to the transmitted power, the obtained statistics on normalized actual output power values of RBSs and user devices also represent statistics on actual

TABLE V
3G USER DEVICE OUTPUT POWER STATISTICS FOR DIFFERENT APPLICATIONS AND DURING DIFFERENT PERIODS OF THE DAY

| Applications | | Output power for different periods (dBm) | | | |
|---|---|---|---|---|---|
| | | 00:00 – 06:00 | 06:00 – 12:00 | 12:00 – 18:00 | 18:00 – 24:00 |
| Voice | Mean | 3.4 | 4.6 | 5.7 | 4.5 |
| | Median | -13.1 | -11.4 | -10.7 | -12.3 |
| | 90th percentile | 3.6 | 5.1 | 6.3 | 4.7 |
| | 95th percentile | 8.1 | 9.7 | 11.1 | 9.4 |
| Data | Mean | 7.2 | 7.9 | 8.7 | 8.3 |
| | Median | -7.7 | -7.2 | -6.3 | -6.7 |
| | 90th percentile | 9.2 | 10.2 | 11.3 | 10.8 |
| | 95th percentile | 13.7 | 14.9 | 16.1 | 15.5 |
| Voice + Data | Mean | 5.3 | 6.3 | 7.8 | 6.3 |
| | Median | -11.1 | -9.7 | -8.5 | -10.3 |
| | 90th percentile | 6.3 | 7.7 | 9.6 | 7.4 |
| | 95th percentile | 11.0 | 12.5 | 14.8 | 12.4 |
| Video | Mean | 11.0 | 9.4 | 9.6 | 11.3 |
| | Median | -2.1 | -3.4 | -4.3 | -2.3 |
| | 90th percentile | 13.8 | 12.2 | 12.2 | 14.5 |
| | 95th percentile | 19.2 | 16.6 | 17.0 | 19.6 |

exposure levels normalized to the maximum possible exposure. For example, the 95th percentile RBSs output power, which was found to be 53% of the maximum, can also be interpreted as the 95th percentile actual RF EMF exposure normalized to the maximum possible exposure. As all RBS installations should be made to achieve compliance with the relevant exposure limits in all regions accessible to the general public, this particular example implies that with a probability of 95% the actual exposure levels is at most 53% of the maximum possible exposure. This type of information is of fundamental importance for epidemiological investigations and for communications related to actual RF EMF exposure levels.

### *A. Downlink*

As stated in [14], for 3G data transmissions the available RBS power is exploited to maximize the throughput. It is therefore not unlikely that the RBS will transmit at maximum power or close to the maximum during short periods of time. With a maximized data rate, however, the transmission time is minimized, which reduces the average power correspondingly.

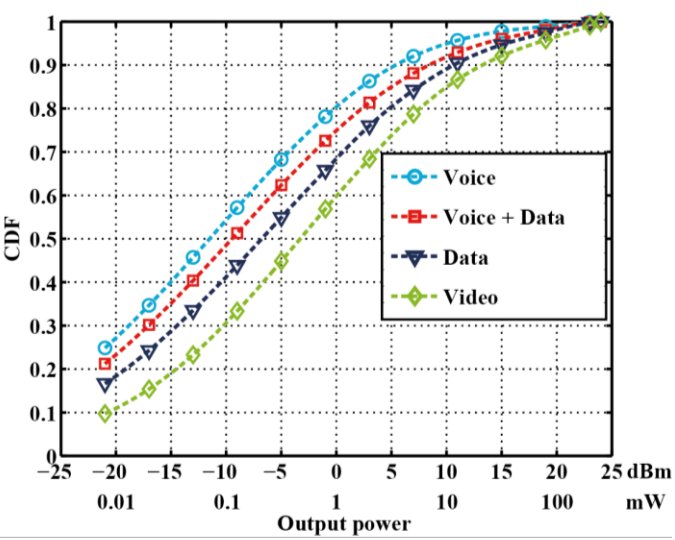



Fig. 5. CDFs of 3G user device output power for voice, voice+data, data, and video applications.

Long periods of maximum power transmission imply a saturated network and a reduced quality of service which most operators will seek to avoid. This is also true for LTE downlink transmission, in which RBSs aim to maximize the throughput by using all available resource blocks (RBs). Similar to WCDMA, the average output power values of LTE RBSs are reduced with short transmission time because of maximized data rate, although the RBSs tend to momentarily transmit at or close to maximum power [15]. In network-based measurements conducted in Sweden in 2013, mean, median, and 90th percentile output power values of LTE RBSs during high traffic hours were found to be 7.9%, 6.5%, and 12%, respectively, of the maximum available power [15]. The lower output power values for LTE compared with the WCDMA results reported in [14] and in this study may be attributed to a lower amount of traffic in the LTE network.

The RBS output power measurements were obtained as values averaged over 15 min from the OSS-RC. According to the most widely adopted EMF exposure guidelines, however, the exposure metrics for mobile communication frequencies are intended to be averaged over 6 min [1], [23]. The effect of using different averaging times was investigated in [14] where it was found that time averaging over 6 and 15 min resulted in very similar statistics, indicating that the obtained measurement results are relevant for realistic EMF exposure assessments.

The RBS output power results presented include the power required for the Common Pilot Channel (CPICH). Continuous consumption of 2% to 10% of the maximum available power by CPICH explains why the normalized power values in Fig. 2a and 3 never fall below 0.02.

The output power in downlink depends on the relative amount of traffic in the network. The effect of different environments was found to be quite small, which probably reflects that a similar strategy for network usage in different environments is used by the operator. Although the number of users per unit area is most likely smaller in rural environments, the cell sizes are probably larger, resulting in similar traffic patterns.

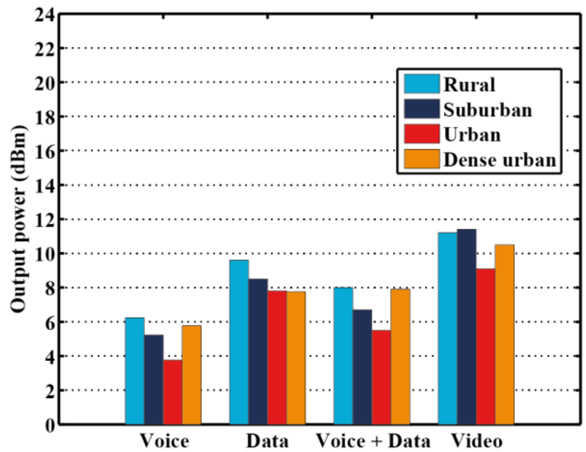



Fig. 6. Mean 3G user device output power for different applications in different environments.

### *B. Uplink*

Time-averaging over 6 min as stipulated in most RF exposure guidelines is not feasible in uplink since the length of calls often is shorter. Instead, an averaging time of 2 s was used, corresponding to the shortest possible sampling period. This was done in order to obtain the best possible statistics including calls of short durations. If 6 min time averaging had been possible, even lower output power levels would have been obtained.

An estimate of the changed usage pattern with the growing number of smartphone users during last years may be obtained by comparing the total amount of service hours for the "data" and "voice" services. According to Table I, the total amount of service hours for "data" is about 63% more than for "voice". For the measurements taken in 2008 and reported in [18], the amount of service hours for "data" was about 24% less than for "voice". Given that the bitrates are much higher for data, already in the Swedish 2008 study the amount of data traffic was significant. Since then the amount of data traffic has continued to increase which is illustrated by the current measurements taken in 2014.

Among the tested applications, the user device output power levels were found to be lowest for voice and highest for video, with data located in between. This was also observed in [18]. The user device output power levels obtained in this paper were found to be somewhat higher than those reported in [18] and [13]. This may be explained by an increased interference in uplink due to the higher population density in India compared with Sweden. It is important to remember, however, that the mean output power values obtained are only about 1%, 3%, and 4% of the maximum available power of user devices for voice, data, and video, respectively.

The highest user device output power values were obtained in rural environments which also is in agreement with the findings in [18]. This is explained by the larger separation distance between the base station and an average user in rural environments.

Fast power control mechanism is one of the reasons for low output power of WCDMA-based user devices. LTE also implements power control mechanism to reduce user device output power consumption. The power control rate in LTE is slower than in WCDMA, because it makes use of orthogonal frequency resources in the uplink, which avoids the near-far problem that required fast power control in WCDMA [24]. Similar to downlink, LTE user devices also tend to maximize the throughput by utilizing all available resource blocks resulting in short transmission times where the device momentarily might transmit at or close to the maximum power, while maintaining the average output power values on a low level. In a terminal-based drive and walk test study conducted in Stockholm in 2012, the mean output power of an LTE device for an application with a data rate comparable to voice call was found to be 0.3% of the maximum available power [25]. This may be compared with the corresponding power levels for WCDMA of <1% reported in [18] and 1% obtained in this study.

## V. Conclusions

Output power measurements for radio base stations and user devices were conducted in a WCDMA-based 3G network in India. In downlink, mean, median, 90$^{th}$ percentile, and 95$^{th}$ percentile power levels of 24%, 21%, 42%, and 53% of the maximum were obtained, respectively. Since the exposure is proportional to the transmitted power, these numbers also represent realistic exposure levels with respect to the maximum possible exposure in downlink. In uplink, measurements of user device output power levels were conducted for voice, data, voice + data, and video applications. The mean output power for the mentioned applications were found to be around 1%, 3%, 2%, and 4%, respectively, of the maximum available power. As for downlink, these numbers also represent an estimate of realistic uplink exposure levels with respect to the maximum possible exposure. In both downlink and uplink, the impact of different environments on the output power levels has been found to be quite low.

Despite the fact that the current study included some noticeable differences, such as a different operator, a larger population density, a larger amount of collected data and a larger number of smart phones users implying a larger proportion of data traffic, the obtained results are found to be consistent with outcomes of previous studies and similar conclusions may be drawn. In general, it is demonstrated that the actual power levels in both uplink and downlink may be significantly below the theoretical maximum normally used for EMF compliance assessment purposes.

## References


[1] International Commission on Non-Ionizing Radiation Protection, "Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)," *Health Phys.*, vol. 74, no. 4, pp. 494–522, Apr. 1998.

[2] *Human Exposure to Radio Frequency Fields from Hand-Held and Body-Mounted Wireless Communication Devices—Human Models, Instrumentation, and Procedures—Part 1: Procedure to Determine the Specific Absorption Rate (SAR) for Hand-Held Devices Used in Close*

*Proximity to the Ear (Frequency Range of 300 MHz to 3 GHz)*, IEC Std. 62209-1, 2005.

[3] *Human Exposure to Radio Frequency Fields from Hand-Held and Body-Mounted Wireless Communication Devices—Human Models, Instrumentation, and Procedures—Part 2: Procedure to Determine the Specific Absorption Rate (SAR) for Wireless Communication Devices Used in Close Proximity to the Human Body (Frequency Range of 300 MHz to 3 GHz)*, IEC Std. 62209-2, 2010.

[4] *Determination of RF Field Strength and SAR in the Vicinity of Radio Communication Base Stations for the Purpose of Evaluating Human Exposure*, IEC Std. 62232, 2011.

[5] *Basic Standard to Demonstrate the Compliance of Fixed Equipment for Radio Transmission (110 MHz - 40 GHz) Intended for Use in Wireless Telecommunication Networks With the Basic Restrictions or the Reference Levels Related to General Public Exposure to Radio Frequency Electromagnetic Fields, When Put into Service*, CENELEC Std. EN 50400, 2006.

[6] *Basic Standard for Calculation and Measurement of Electromagnetic Field Strength and SAR Related to Human Exposure from Radio Base Stations and Fixed Terminal Stations for Wireless Telecommunication Systems (110 MHz - 40 GHz)*, CENELEC Std. EN 50383, 2010.

[7] H. Holma and A. Toskala, *WCDMA for UMTS—Radio Access for Third Generation Mobile Communications*, 3rd ed. Chichester, England: John Wiley & Sons, 2004, pp. 11–60.

[8] W. Joseph, L. Verloock, E. Tanghe, and L. Martens, "In-situ measurement procedures for temporal RF electromagnetic field exposure of the general public," *Health Phys.*, vol. 96, no. 5, pp. 529–542, May 2009.

[9] W. Joseph, L. Verloock, F. Goeminne, G. Vermeeren, and L. Marteens, "Assessment of general public exposure to LTE and RF sources present in an urban environment," *Bioelecromagnetics*, vol. 31, no. 7, pp. 576–579, Oct. 2010.

[10] Z. Mahfouz, A. Gati, D. Lautru, M. F. Wong, J. Wiart, and V. F. Hanna, "Influence of traffic variations on exposure to wireless signals in realistic environments," *Bioelecromagnetics*, vol. 33, no. 4, pp. 288–297, May 2012.

[11] J. Wiart, C. Dale, A. Bosisio, and A. Le Cornec, "Analysis of the influence of the power control and discontinuous transmission on RF exposure with GSM mobile phones," *IEEE Transactions on Electromagnetic Compatibility*, vol. 42, no. 4, pp. 376–385, Nov. 2000.

[12] M. Vrijheid, S. Mann, P. Vecchia, J. Wiart, M. Taki, L. Ardoino, B. K. Armstrong, A. Auvinen, D. Bédard, G. Berg-Beckhoff, J. Brown, A. Chetrit, H. Collatz-Christensen, E. Combalot, A. Cook, I. Deltour, M. Feychting, G. G. Giles, S. J. Hepworth, M. Hours, I. Iavarone, C. Johansen, D. Krewski, P. Kurttio, S. Lagorio, S. Lönn, M. McBride, L. Montestrucq, R. C. Parslow, S. Sadetzki, J. Schüz, T. Tynes, A. Woodward, and E. Cardis, "Determinants of mobile phone output power in a multinational study: implications for exposure assessment," *Occup. Environ. Med.*, vol. 66, no. 10, pp. 664–671, Oct. 2009.

[13] A. Gati, A. Hadjem, M.-F. Wong, and J. Wiart, "Exposure induced by WCDMA mobiles phones in operating networks," *IEEE Trans. Wireless Commun.*, vol. 8, no. 12, pp. 5723–5727, Dec. 2009.

[14] D. Colombi, B. Thors, T. Persson, N. Wirén, L.-E. Larsson, M. Jonsson, and C. Törnevik, "Downlink power distributions for 2G and 3G mobile communication networks," *Radiat. Prot. Dosimetry*, vol. 157, no. 4, pp. 477–487, Dec. 2013.

[15] D. Colombi, B. Thors, N. Wirén, L.-E. Larsson, and C. Törnevik, "Measurements of downlink power level distributions in LTE networks," in *Electromagnetics in Advanced Applications (ICEAA), 2013 International Conference on*, Torino, Italy, 9–13 Sep. 2013, pp. 98–101.

[16] A. Bürgi, D. Scanferla, and H. Lehmann, "Time averaged transmitter power and exposure to electromagnetic fields from mobile phone base stations," *Int. J. Environ. Res. Public Health*, vol. 11, no. 8, pp. 8025–8037, Aug. 2014.

[17] A. Gati, E. Conil, Man-Fai¨, Wong, and J. Wiart, "Duality between uplink local and downlink whole-body exposures in operating networks," *IEEE Trans. Electromagn. Compat.*, vol. 52, no. 4, pp. 829 – 836, Nov. 2010.

[18] T. Persson, C. Törnevik, L.-E. Larsson, and J. Lovén, "Output power distributions of terminals in a 3G mobile communication network," *Bioelectromagnetics*, vol. 33, no. 4, pp. 320–325, May 2012.

[19] J. Baumann, F. Landstorfer, L. Geisbusch, and R. Georg, "Evaluation of radiation exposure by UMTS mobile phones," *Electron. Lett.*, vol. 42, no. 4, pp. 225 – 226, Feb. 2006.

[20] H. Kaaranen, A. Ahtiainen, L. Laitinen, S. Naghian, and V. Niemi, *UMTS Networks—Architecture, Mobility and Services*, 2nd ed. Chichester, England: John Wiley & Sons, 2005, pp. 119–120.

[21] *Basic Standard for the In-Situ Measurement of Electromagnetic Field Strength Related to Human Exposure in the Vicinity of Base Stations*, CENELEC Std. EN 50492, 2008.

[22] W. Joseph and L. Verloock, "Influence of mobile phone traffic on base station exposure of the general public," *Health Phys.*, vol. 99, no. 5, pp. 631–638, Nov. 2010.

[23] *Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields*, FCC Std. OET Bulletin 65, 1997.

[24] H. Holma and A. Toskala, *LTE for UMTS—Evolution to LTE-Advanced*, 2nd ed. Chichester, England: John Wiley & Sons, 2011, pp. 123–124.

[25] P. Joshi, "Assessment of realistic output power levels for LTE devices," Master's thesis, Lund University, Lund, Sweden, 2012.

**Paramananda Joshi** received the M.Sc. degree in wireless communication from Lund University, Sweden, in 2012.

Since 2012, he has been with Ericsson Research, Stockholm, Sweden. His research interest and current research include assessment of realistic exposure to radio frequency (RF) electromagnetic fields (EMF) from radio base stations and user devices.

**Mukesh Agrawal** received the B.Engg degree in electronics and communication from NIT Jaipur, India in 1998 and Masters in Business Administration from University of Bradford, United Kingdom in 2008.

He currently works for Ericsson and manages delivery of Global mobile network projects of Latin America. He has been in the wireless telecom industry since 1998 and has extensive experience in mobile network strategy, design and planning, optimization and performance management across different technologies such as GSM, WCDMA and LTE. His interest includes the initial designing and optimization of the mobile networks. He has worked in the early mobile networks of India and Europe in both Greenfield and existing networks. He is currently located in India.

**Björn Thors** received the M.Sc. degree in engineering physics from Uppsala University, Sweden, in 1996 and the Ph.D. degree in electromagnetic theory from the Royal Institute of Technology (KTH), Stockholm, Sweden, in 2003.

He spent the 2001 to 2002 academic year with The ElectroScience Laboratory, The Ohio State University, Columbus, as a Visiting Scholar, working with development of high-frequency methods for conformal antennas. From 2003 to 2005, he was a Research Associate at KTH. Since 2005 he has been with Ericsson Research, Stockholm, Sweden, working with research and standardization related to radio frequency exposure from wireless communication equipment.

**Davide Colombi** received the M.Sc. degree in telecommunication engineering (summa cum laude) from Politecnico di Milano, Italy, in 2009.

Since 2009 he has been with Ericsson Research, Stockholm, Sweden, working with research and standardization related to radio frequency exposure from wireless communication equipment.

**Ashwani Kumar** received the B. Tech. degree in Electronics & Communication engineering in 1990 and M. Tech. in Micro-Electronics from Indian Institute of Technology, Roorkee (India) in 1991.

He has been with Ericsson since 2008 responsible for developing technology roadmap, spectrum standardization for IMT technologies for WRC-15, and driving technology standardization in 3GPP LTE Radio & Core, M2M/IoT, NFV/SDN domains, and standardization related to Energy Efficiency in cellular networks & Radio Frequency exposure from wireless communication equipment in Indian SDO (TSDSI) and global SDOs.

He has been extensively engaged in standardization activities with key SDOs (ITU, IEEE, MEF, TMN Forum, ITU-APT etc.) as a state representative from India for 6 years during 2001-2006. He has been active in SDH, Optical/DWDM, Carrier Ethernet & IP/MPLS Transport and DSL/GPON standardization domains as Editor and Correspondence Group leader in ITU-T Study Group 15. His work has received warm recognition by ITU Vice Chairman and Government of India.

He has been in the telecom industry since 1992 with diverse experience in solution design, project planning & system integration, telecom security & regulatory affairs in both wireline & wireless industry in India and abroad.

**Christer Törnevik** (M'98) received the M.Sc. degree in applied physics from the Linköping University, Linköping, Sweden, in 1986, and the Lic. (Tech.) degree in materials science from the Royal Institute of Technology, Stockholm, Sweden, in 1991. He joined Ericsson in 1991, and has, since 1993, been involved in research activities related to radio frequency exposure from wireless communication equipment. He is currently head of sustainability research within Ericsson Research and responsible for electromagnetic fields and health within the Ericsson Group. Between 2003 and 2005, he was the Chairman of the Board of the Mobile Manufacturers Forum (MMF), and he is currently the Secretary of the Board. Since 2006, he is the chairman of the technical committee on electromagnetic fields within the Swedish Electrotechnical Standardization organization, SEK, and he has as an expert contributed to the development of several CENELEC, IEC and IEEE standards on the assessment of RF exposure from wireless equipment.