Experimental Investigation of WCDMA Uplink Transmit Power for Practical Usage Scenarios

Jeong Heon Lee, Arjun Bhupathi Raju, and R. Michael Buehrer
Mobile and Portable Radio Research Group (MPRG), Wireless @ Virginia Tech
Blacksburg, VA 24060, USA
Email: {jeonghel, arjunb, buehrer}@vt.edu

***Abstract*—This paper presents an empirical investigation into WCDMA uplink (UL) transmit power for various indoor/outdoor locations. Specifically, the statistics of UL transmit power measured in different locations over a commercial UMTS network are provided and compared. Similar locations are then grouped to form four practical mobile usage scenarios, and their empirical probability distribution functions are analyzed. Further, we investigate the impact of typical handset positions (next to the ear and using a Bluetooth headset) on the UL transmit power levels. The results presented in this paper can be useful for not only optimizing a WCDMA handset design for the UMTS network, but also predicting battery life and examining WCDMA coverage.**

I. Introduction

WCDMA has been proven to be a technology that provides unique features such as high speed transmission and accurate power control for mobile communications. Many aspects of its physical features have been studied and are now well understood. Nevertheless, uplink (UL) transmit power profiles are not yet fully characterized, which could facilitate an improvement of the power consumption of user equipment (UE). For example, the efficiency of a power amplifier (PA), which is known to be the most power consuming device in the UE, is typically calculated at maximum output power. While this method has evolved into the de-facto figure of merit, it ignores the system effects on average output power, and cannot generally provide an accurate estimate of the PA impact on handset talk time [1]. A more meaningful efficiency estimate is the overall PA efficiency, which is based on the distribution of the transmit power levels. Thus, in order to optimize the overall PA efficiency and thus increase the talk time, it is vital to know the UL transmit power profile.

The UL transmit power distribution commonly used in literature for CDMA-based mobile phones is based on drive test data collected by the CDMA Development Group (CDG) in 1995 [2]. The CDG collected the transmit power data in urban and suburban environments and presented the corresponding empirical distribution curves for IS-95 networks. Besides the fact that the data is dated, one of the primary concerns regarding the original measurement methodology is that it relied on drive-testing using roof-mounted antennas and thus may not reflect actual mobile phone transmit power when considering common usage patterns and environmental factors. Thus, the primary objective of this experimental study is to characterize the UE transmit power statistics in WCDMA networks based on current network data and realistic mobile phone usage scenarios.

In this measurement campaign, more than 300 separate measurements and 1600 minutes of UE transmit power data from dozens of different locations were collected from December, 2007 through February 4, 2008. The measurements were performed in the Northern Virginia, Washington D.C. and Baltimore areas, where similar measurement location types are grouped according to the following four typical mobile usage scenarios:

1) **Indoor Public** - Mall (S|W), Office (S), University (S|W), Restaurant (S), Airport (S|W), Hotel (S)
2) **Outdoor Public** - Downtown (S|W), Street (S|W), Metro station (S), Park (S|W)
3) **Home** - Apartment (S), House (S)
4) **Transit** - Car, Metro, Walking for Street & Downtown

where ‘S’ and ‘W’ denote a mobility factor of stationary and walking, respectively. The equipment used for collecting the transmit power data is the SwissQual Qualipoc handset which is essentially a Nokia N75 smart phone loaded with post-processing software provided by SwissQual [3]. It allows us to measure transmit power levels of an actual mobile handset used in realistic situations. Before starting the measurement, the phone was forced to operate on the WCDMA network over the 1900 MHz band only. During the measurement, the voice activity was kept at approximately 40%.

The rest of this paper is organized as follows. Section II presents the empirical statistics of WCDMA UL transmit power for different locations and scenarios. Also, the impact of using a Bluetooth headset on the transmit power is investigated. In Section III, we compare our measurement results with those reported by the CDG group for IS-95. We conclude with a summary of our measurement results in Section IV.

II. Statistics of UL Transmit Power for Different Locations and Usage Scenarios

A. Empirical PDF for Each Location and Usage Scenario

In this section, the statistics of WCDMA UL transmit power in different types of locations are presented. Then, we provide the empirical probability distribution functions (PDFs) of four typical phone usage scenarios. Each set of statistics is the result of many measurements including both mobile and stationary cases in a similar environment. For

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TABLE I: Uplink Transmit Power Statistics for Each Location Type and Usage Scenario

Meas. Location	Mean Transmit Power (dBm)	Standard Deviation (dBm)	No. of Meas.	Total Meas. Time (mins)
Car	2.1	9.5	40	315
Metro	1.1	9.7	12	60
Airport	-0.6	5.6	24	120
Hotel	4.0	7.1	28	140
Mall	7.4	12.9	28	135
Office	10.4	12.6	12	60
Restaurant	13.1	15.4	14	70
University	8.9	13.6	24	125
Downtown	-1.8	3.3	24	116
Metro Station	-14.1	-6.2	12	60
Park	-13.6	0.5	24	120
Street	-18.1	-12.9	24	120
Apartment	-4.1	0.8	12	60
House	7.2	9.5	24	120
Total	5.7	11.5	302	1621
Indoor Public	8.2	12.9	130	650
Outdoor Public	-6.3	1.4	84	416
Home	6	9.1	36	180
Transit	1.1	9	80	600

example, the statistics for the 'Park' location are based on all of the data taken in several parks including both mobile and stationary measurements and both handset positions (phone by the ear & using a Bluetooth headset). On the other hand, for location types of 'Car' and 'Metro', only dynamic measurements (including both handset positions) over the entire measurement area are considered. A summary of the transmit power statistics at each location type is included in Table I.

From Table I, it can be observed that the transmit power levels in indoor locations are considerably higher than those in outdoor locations. The mean transmit power values in the outdoor locations were typically in the range of -18 to -13 dBm, while those in the indoor locations were in the range of 4 to 10 dBm. The highest power variation from the mean value occurred in indoor locations as well as the two 'Transit' cases (*i.e.*, while traveling in a car and on the metro). This is because of the high mean transmit power levels and dynamically varying channel conditions. The lowest mean transmit power value observed was -18.1 dBm in the 'Street' location (see Fig. 1), while the highest value was 13.1 dBm in the 'Restaurant' location (see Fig. 2).

Next, the individual locations are grouped into four usage scenarios (Transit, Indoor Public, Outdoor Public, and Home) as introduced in Section I, and shown in Table I. The resulting empirical PDFs are presented in Fig. 3. The high mean transmit power and standard deviation were observed in the 'Indoor Public' scenario. It is inferred that the worse coverage and high multipath effects in indoor cases resulted in the most varying UL transmit power levels with highest mean. It is also noted that the 'Home' case shows the second highest mean and deviation of transmit power. These observations are consistent with results presented in [4] which shows that the transmit power levels for GSM networks are consistently higher indoors than outdoors and that indoor/outdoor differentiation is one of the most important factors affecting transmit power. This observation indicates that it is desirable to deploy more UMTS base stations in the suburban area (or femtocells at home), and employ micro cells in public indoor places to increase UE talk time, while satisfying high throughput requirements for future mobile data applications.

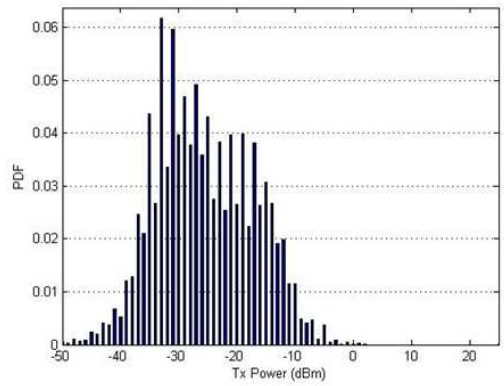

Fig. 1: Empirical PDF for 'Street' location (mean = -18.1, std = -12.9) (dBm).

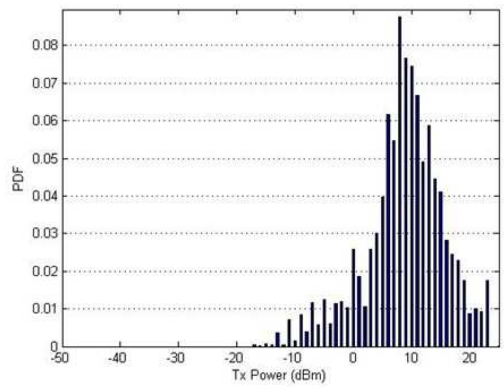

Fig. 2: Empirical PDF for 'Restaurant' location (mean = 13.1, std = 15.4) (dBm).

B. Impact of Using a Bluetooth Headset on UL Transmit Power

During the last few years, the number of Bluetooth hands-free device users has been steadily increasing. As a result, in the context of UL transmit power for practical situations, it is important to address the impact of using the Bluetooth headset away from the head. For this investigation, two identical (to the degree possible) measurements were taken at each exact location: first holding the handset next to the ear and second using the headset with the handset held away from the head.

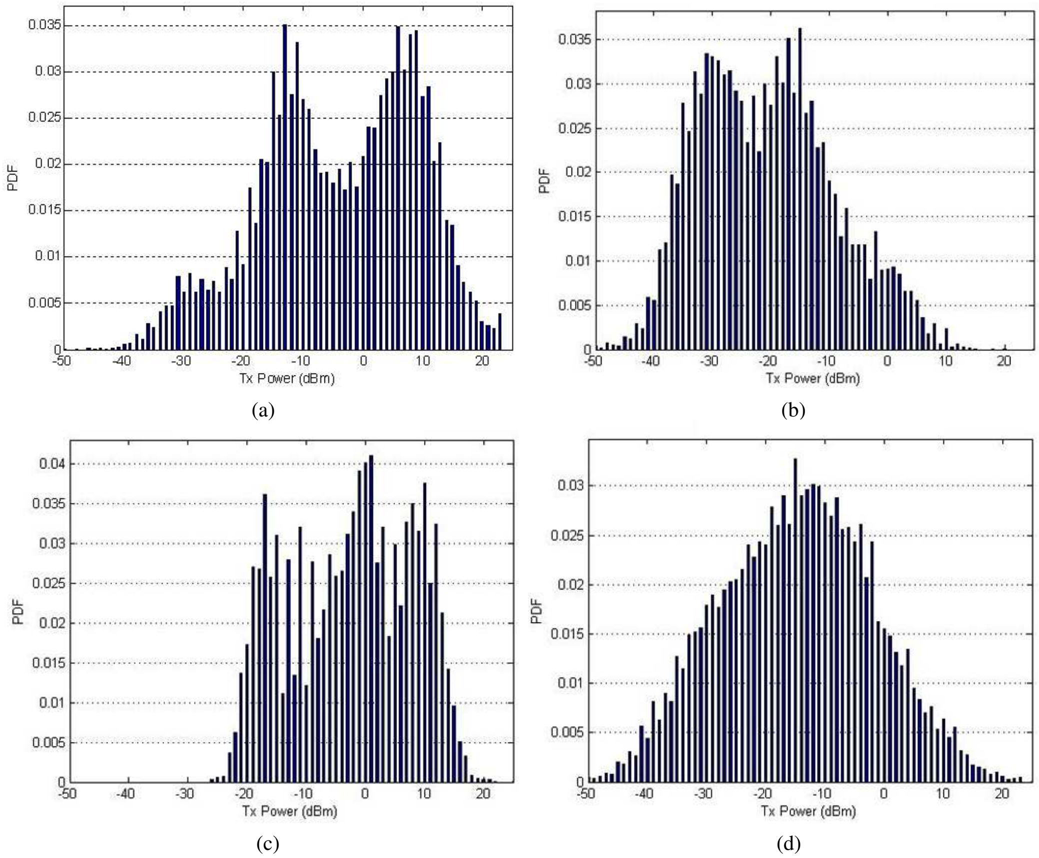

Fig. 3: Empirical PDFs for different usage scenarios: (a) Indoor Public (mean: 8.2, std: 12.9), (b) Outdoor Public (mean: -6.3, std: 1.4), (c) Home (mean: 6, std: 9.1), (d) Transit (mean: 1.1, std: 9) (all dBm).

As can be seen from Table II, the absolute difference in transmit power between the two cases is around 1$\sim$5 dB in most of the locations. In some cases, the mean transmit power was higher when using the headset, while it was lower in the other cases. Thus, a definitive conclusion cannot be reached about which of the two handset positions results in higher UL transmit power. However, the results demonstrate the range of difference in transmit power possible between the two handset positions.

Another possible conclusion from these results is that the difference in transmit power depends heavily on the orientation of the body relative to the direction of arrival of the signal. For example, if the body is shadowing the phone from the main receive path, using the hands-free headset may demand higher transmit power [5], [6]. The signal transmitted from the UE experiences different fading effects caused by reflection, diffraction and scattering in different positions. Thus, depending on the UE position, the user's body will affect the transmitted signal propagating to the base station in different ways. Thus, in different positions the UE will receive different transmit power command (TPC) sequences from the associated base station(s) to counteract these channel effects [7].

Due to the limited space, the transmit power distributions obtained using the two handset positions are not included in this paper. Instead, we summarize our findings here that there is little impact of the handset position on the shape of the empirical PDF. To explore the effect of more various handset positions relative to the body, additional measurements changing the specific handset position around the body are needed. The results of this study are presented in [8].

III. Comparison with CDG Results for IS-95

This section presents a comparison of transmit power distributions from our experimental data and the CDG report [2]. As shown in Fig 4, the overall mean transmit power value from all of our collected data[1] is found to be 5.7 dBm, whereas the mean values given in [2] are 10.6 dBm and 5.4 dBm for suburban and urban topographies, respectively. Thus, our statistical results are consistent with the CDG urban case, but differ from the CDG suburban result. It is noted that the shapes of the three PDFs are very different from each other. In fact, the PDF of the CDG urban profile exhibits a similar shape as the 'Transit' PDF shown in Fig 3d, thus inferring that the CDG data were collected while in transit. Taking into account the PDF shape of measured UL transmit power data is

[1]A more accurate characterization would include weighing the data collected at each location / usage scenario according to the actual mobile usage patterns, although we do not consider it in this paper.

TABLE II: Comparison of Uplink Mean Transmit Power for Two Different Handset Positions (Next to the Ear vs. Using a Bluetooth Headset (BH))

Meas. Location	Mean Transmit Power (dBm) – Ear	Mean Transmit Power (dBm) – BH	Additional Power Required for Phone Near Ear
Car	1.2	3.4	-2.2
Metro	-6.1	3.8	-9.9
Airport	-3.4	1.2	-4.64
Hotel	0.9	5.7	-4.8
Mall	8.2	5.8	2.4
Office	9.6	11.1	-1.5
Restaurant	12.0	13.8	-1.8
University	8.7	9.1	-0.4
Downtown	-3.9	-0.2	-3.7
Metro Station	-12.6	-16.3	3.7
Park	-15.1	-12.5	-2.6
Street	-18.4	-17.6	-0.8
Apartment	-2.6	-6.8	4.2
House	7.6	6.8	0.8
Indoor Public	7.8	8.5	-0.7
Outdoor Public	-8.3	-4.6	-3.7
Home	6.3	5.5	0.8
Transit	-1.0	1.5	-2.5

important to accurately estimate the UE talk time. Further, this consideration helps to optimize the efficiency of a new handset design (particularly, power amplifier), thus maximizing its talk time.

It should be noted that the transmit power levels reported in this paper are also generally consistent with those given in [9]. However, a couple of caveats are in order. It was shown in [10] that the most important impact factor on transmit power was network location (specifically New Jersey vs. New York). Since all of our measurements were taken in the Northern Virginia/D.C./Baltimore area, it is possible that higher or lower transmit powers could be found in other areas. Further, it was shown in [4] that rural networks had substantially higher transmit powers than suburban or urban areas. However, in our measurements of this paper, all of our results could be characterized as suburban/urban.

IV. Conclusion

In this paper, we have presented the statistics of WCDMA UL transmit power for different locations and practical usage scenarios. In particular, the empirical PDFs of transmit power were provided. It was found that the mean transmit power values in outdoor locations were typically in the range of -18 to -13 dBm, whereas those in indoor locations were in the range of 4 to 10 dBm. The highest deviation of transmit power levels from the mean value was noticed in the indoor locations, where considerably higher mean transmit power was observed compared to the outdoor locations (maximum 26.7 dB difference). Also, such a high variation occurred for the two 'Transit' scenarios (*i.e.*, traveling in a car and on the metro).

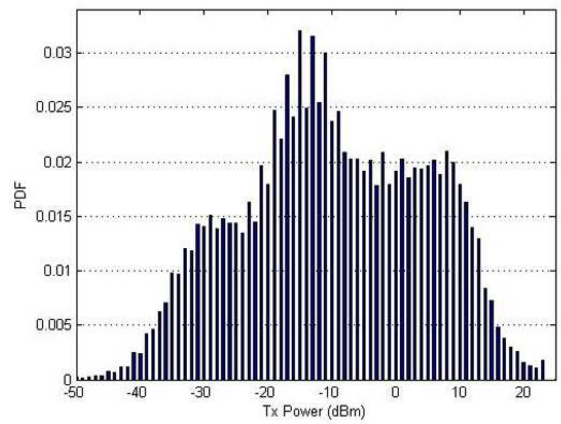

Fig. 4: PDF of all of the uplink transmit power measurement data (mean = 5.7, std = 11.5) (dBm).

Since many people use a Bluetooth hands-free device these days, the impact of the two primary handset positions (*i.e.*, next to the ear and using the Bluetooth headset) on the transmit power was analyzed. For the case of the Bluetooth usage, the handset held away from the head was placed in a natural way. We found that there were 1$\sim$5 dB differences of transmit power between the two cases with no consistent pattern. Finally, the total empirical PDF from all of the measured data was presented and compared with CDG results. Despite similar transmit power statistics compared with the CDG urban case, we observed a substantial difference in the shape of the PDFs.

Our results reported in this paper can be beneficial for optimization of a WCDMA handset design for UMTS networks and characterization of the talk time of a WCDMA handset.

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