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Empirical Differences in LTE Open- and Closed-Loop Power Control

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***Abstract*—We present the empirical Physical Uplink Shared Channel radiated power of a User Equipment in a commercial Long-Term Evolution Frequency Division Duplex system in open- and closed-Loop power control. We present new insights, targeted on power control, from the data taken by NASCTN Report-7, which presents measured radiated PUSCH channel power, while varying 28 different system factors. The NASCTN experiment was performed to examine the impact of each of the 28 factors on the radiated emissions of LTE UEs. Here, we address how the choice of power control algorithm impacts the radiated UE emissions. We examine the results of two cases: Reference Signals Received Power equal to -78 dBm and -98 dBm. We show significant differences in UE emissions using an open- or closed-loop power control algorithm in a stable RF environment. We discuss the difference in detail and note that the UE is not precisely following the power control equation as expected in all cases. This work is performed on a commonly used UE model in North America. The results can have implications for those looking to model or control 4G LTE UE emissions and designing accurate power control algorithms for emerging cellular systems such as 5G New Radio.**

I. Introduction

The User Equipment (UE) uplink power is an important aspect of the Long-Term Evolution (LTE) cellular wireless communications systems. Without precise power control, a high power UE can lead to shorter UE battery life which degrades the user experience, RF interference to other UEs in the same area, and a saturated signal at the E-UTRAN Node B's (eNB's) receiver. In contrast, a low UE power can cause a low Signal to Interference plus Noise Ratio (SINR) at the eNB's receiver. This can lead to improper signal detection by the eNB and result in low data throughput for the user [1].

The two main power control algorithms in LTE, open- and closed-loop, function by increasing the UE's output power in poor RF conditions (e.g., high path loss) and decreasing the power in good RF conditions (e.g., low path loss).

Although LTE uses a different equation for each major LTE logical channel, there are many similarity between them. In this paper we focus on the most resource demanding channel power control algorithm: Physical Uplink Shared Channel (PUSCH) [2].

The expected UE transmit power value in both open and closed-loop circumstances is defined in [2]. This value obtained by the UEs follow the power control equation specified in [2]. This equation is seen in equation (1) and its parameters seen in table (I).

TABLE I
Power Control Equation parameters

(i)	An instance of power in a LTE subframe
$(P_{c,max})$	The maximum UE transmit power is +23 dBm
$(P_{0,PUSCH})$	The nominal UE power present at the eNB
$(M_{PUSCH}(i))$	The physical resource blocks (PRBs) granted
(PL)	The path loss between UE and eNB
$(\alpha(i))$	Fractional power control
(Δ_{TF})	Delta Modulation and Coding Scheme MCS
$(f(i))$	eNB closed-loop correction function

$$P_{\text{PUSCH}} = \min[P_{cMax}, 10\log_{10}(M_{\text{PUSCH}}(i)) + P_{0\ \text{PUSCH}}(i) + \text{PL}\,\alpha(i) + \Delta_{TF} + f(i)][dBm]. \quad (1)$$

In close-loop power control, the power adjustment value, $(f(i))$, is provided by eNBs. In the open-loop power control this factor is zero [2].

II. Experiment Setup

The experiment setup [3] used to determine the impacts of 28 different factors of eNB and non-eNB parameters on radiated UE power transmission is shown in figure 1. This setup utilizes two adjacent LTE cells for creating inter-cell interference, a UE Traffic Generator (UTG) to generate traffic at the eNB, and a Vector Signal Analyzer (VSA) to monitor the radiating power of a Commercial Off-The-Shelf (COTS) UE in a small RF shielded chamber.

III. Measurements

As a part of the NASCTN Report 7 [3] statistical factor screening, we examined the effect of the two different power control algorithms, by measuring the DUT UE power while loading different eNB configurations and cycling through combinations of non-eNB configurations. In [3] we ran 32 eNB configurations permuted with 32 non-eNB configurations through four rounds of testing and examined the data from these 4,096 individual configurations.

IV. Discussion

Looking at the results from figures 3 and 2 in light of the LTE power control equation raises some questions. First, the results in the figures show that the UE radiated power does not

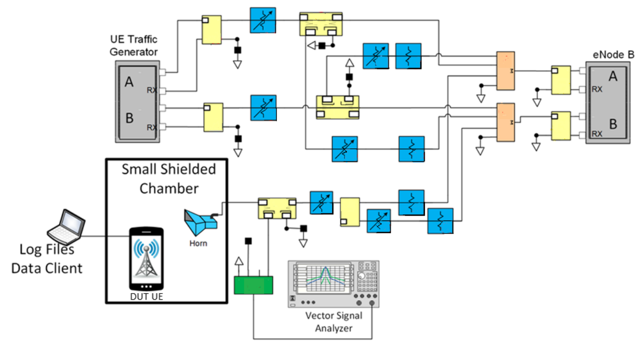

Fig. 1. Laboratory experimental setup used in experiments. NASCTN Report 7 [3]. The eNB is shown on the right side of the diagram, and the UTG on the left side. The parts specifications are given in [3].

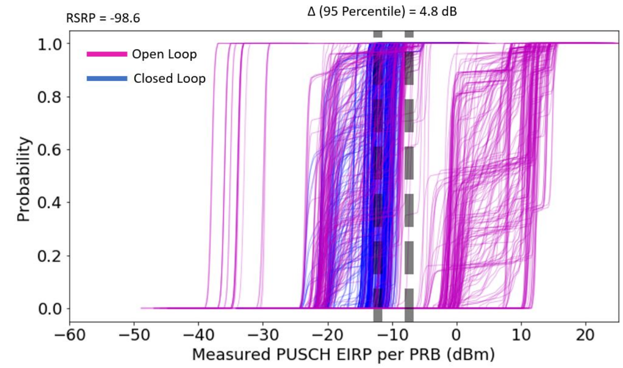

Fig. 2. Comparison of all open- and closed-loop CDFs when RSRP is -98 dBm. The dashed lines indicate the 95^{th} percentile of the mean CDF.

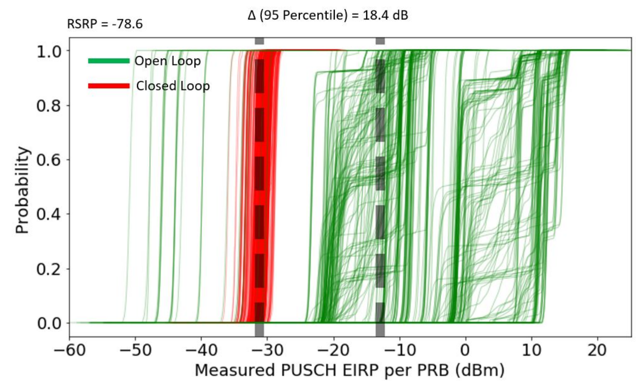

Fig. 3. Comparison of all open-loop CDFs when RSRP is -78 dBm. The dashed lines indicate the 95^{th} percentile of the mean CDF.

converge in open-loop as it does in the closed-loop cases when UE is placed at RF far condition, RSRP -98 dBm, or RF mid condition, RSRP -78 dBm. The RF conditions of system stay stable during the log collections. However, in both cases, it appears as though the eNB may be using power control to drive the UE into negative power headroom situations. This applies to the cases appearing on the left side of the Cumulative Distribution Function (CDF) spread. Regardless of the type of power control that we used, the mathematical calculation of the power control equation was different from the measured power transmitted by the UE [2].

The second - and more significant observation - pertains to the open-loop data in figures 3 and 2. In these cases, it is hard to see how the power control equation, with relatively few deterministic terms, could produce variability on the scale shown in the plots. It is apparent that other factors have an impact on the UE power transmission. From a statistical sense, it would be difficult to fit a model to data with such large variation. Attempts to fit a model to the open-loop data will produce an equation (or set of equations) markedly different from the power control equation defined by 3GPP [2].

This variation poses a challenge for those seeking to design power control algorithms or model emissions from LTE UEs. UE emissions in open-loop scenarios may not be entirely unpredictable, but the results indicate that a variety of factors not shown in the power control equation may be impacting the actual radiated power including manufacture of eNBs' scheduler.

V. Conclusion

We show measurements taken from a large statistical factor screening measurement involving the impact of different factors on the radiated emissions of a COTS UE [3]. Here, we examine those results specifically for the impacts of open- and closed-loop power control on the radiated power from a UE. The data indicate substantial differences between open- and closed-loop power control. In cases where the RSRP is -78 dBm, the difference is about 18 dB. This difference shrinks down to about 5 dB as the RSRP decreases to -98 dBm. These results indicate modeling UE transmit power based on 3GPP power control equation (1) may not be sufficient and there is no advantage of using open-loop power control in RF mid (-78 dBm) or RF far (-98 dBm) conditions.

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