White Paper

Impact of Reciprocal Path Loss on Uplink Power Control for LTE

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1 Disclaimer

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2 Executive Summary

Traditional testing that operators and their vendors do for LTE performance has been largely focused on downlink performance. However as LTE matures, the focus for LTE-Advanced is now shifting towards algorithms and applications such as SC-FDMA clustering and simultaneous PUCCH/PUSCH for improving the efficiency of the uplink channel as well. One of the key challenges in testing the uplink is factoring the dynamically changing power being transmitted by the device to compensate for changes in the channel. The Azimuth Reciprocal Path Loss (RPL) solution is the first purpose built solution in the market that is specifically designed to allow the user to test such dynamic variations while providing a channel environment for testing such algorithms. This case study shows the impact of testing LTE PUCCH power control of the device under truly reciprocal channel conditions that factor the downlink and uplink variations.

3 Introduction

The focus of typical pre-deployment performance and conformance testing that operators and device vendors do in the lab is usually on the overall downlink performance of the device. The use of a diverse set of Over-the-Top (OTT) services and applications such as video conferencing requires the performance of the uplink to be robust as well. A key part of LTE-Advanced includes uplink access enhancements such as clustered SC-FDMA and simultaneous PUCCH/PUSCH access to improve the efficiency of uplink transmissions. These transmissions on the uplink have a direct impact on the Transmit (Tx) power of the User Equipment (UE) and have to be balanced with the ever-increasing need to support more LTE users per cell on a limited radio channel on the uplink.

Uplink power control algorithms help the UE achieve the optimal power to reach the eNB at the right power level without causing excessive interference to other transmissions in the same or other cells [1]. These algorithms have a direct impact on throughput performance, mobility, signaling and scheduling performance of the UE and the network. Hence for a more complete performance assessment, one must also consider the impairments that a wireless environment may provide on the uplink.

Traditional lab testing for LTE has been done with a focus on downlink throughput performance by keeping a static channel on the uplink. This is typically due to complexity in building a true bi-directional channel in a lab environment that accurately mimics the dynamically changing real world while factoring these changes in the transmit power of the UE. As a result these uplink algorithms are not exercised and hence users may only get a partial picture of the overall performance of devices.

In this case study we analyze the impact of both downlink and uplink path loss variations on the transmit power of an LTE UE. In order to do this, we leverage the fact that the link (downlink and uplink) is typically reciprocal in nature. Using this property of the air interface along with device measurements collect in the downlink, we can recreate the uplink environment in a lab environment using the Reciprocal Path Loss (RPL) feature available in the ACE RNX channel emulator. RPL adds a new dimension to traditional downlink tests by dynamically computing and applying the uplink path loss based on data collected by the UE.

4 Power Control in LTE

In LTE, the main purpose of power control is to compensate for the variations in power due to slow fading i.e. shadowing or variations due to path loss. This is done through a combination of open loop and closed loop power schemes. Closed loop schemes allow the eNB to leverage power measurements from the UE in addition to estimates to control the power. These are described and implemented using the PUSCH, PUCCH and SRS transmit power as per [2]. As per [2], the Power control in LTE for PUSCH is defined as shown below:

$$P_{PUSCH} = minimum\ (P_{cmax}, 10 * Log_{10}(M_{PUSCH} + P_{OPUSCH} + \propto *\ PL + \Delta_{TF} + f(i))$$

,

Where,

- P_{cmax} is the configured UE maximum power
- M_{PUSCH} is the bandwidth of the resource block allocation for PUSCH
- P_{OPUSCH} is the nominal PUSCH power provided by higher layers
- $\propto$ determines how much of the path loss component needs to be taken into consideration. It ranges from 0 to 1 where 1 indicates that all the path loss needs to be considered into the formula.
- $PL\ is\ the\ pathloss$
- Δ_{TF} is a parameter that is calculated using a UE specific parameter deltaMCS-Enabled that is provided by higher layers
- f(i) is the closed look feedback parameter that is provided by the eNB

The power control in LTE for PUCCH is defined as shown below:

$$P_{PUCCH} = minimum\ (P_{cmax}, P_{OPUCCH} + PL + \Delta_{F\_PUCCH} + (i))$$

Where,

- P_{cmax} is the configured UE maximum power
- P_{OPUCCH} is the nominal PUCCH power provided by higher layers
- $PL\ is\ the\ pathloss$
- Δ_{TF_PUCCH} is a parameter that is provided by higher layers and corresponds to a specific PUCCH Format
- $g(i)$ is the closed loop feedback, also referred to as the Transmit Power Control (TPC) command

When we compare PUSCH and PUCCH power, we notice that the major difference is the impact of Resource Block (RB) allocation on the PUSCH power control algorithm. This is due to the fact that PUSCH carries the user information or data on the uplink along with control information related to MIMO parameters. Depending on the resources requested by the UE and the Quality of Service (QoS) requirements of the operator, the P_{PUSCH} may hit maximum power faster and it will be difficult to isolate the specific impact of path loss variations. We also notice that for P_{PUCCH} the parameter of $\propto$ is equal to 1. This indicates that PUCCH power depends quite a bit on the path loss variations. Hence to examine the specific impact of path loss in this study we specifically examine the PUCCH power control scheme. We specifically look at the impact of changing the path loss in the downlink as well as the uplink on the PUCCH Tx power.

5 Test Setup and Configuration

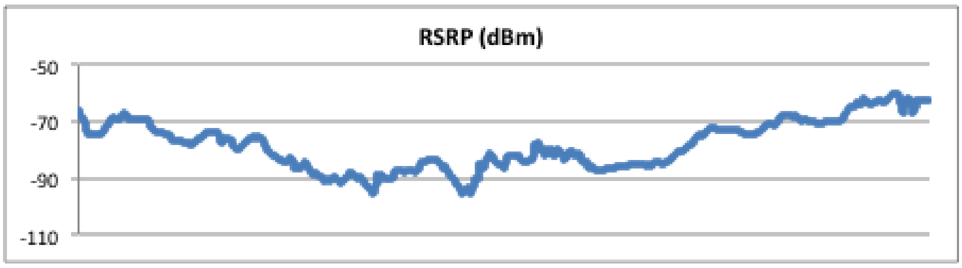
The exercise was performed with in a Tier-1 US operator's lab with the UE connected to the live network through the ACE RNX as shown in Figure 1 below. The ACE RNX was used to recreate the field RF conditions. This was done through Azimuth's Field-to-Lab (FTL) solution that recreates field conditions for a drive test (extracted from a scanner/diagnostic monitor log) in the lab on the ACE RNX. FTL also provides the user the flexibility to override some parameters during playback with values different from what was seen on the field.

Figure 1. Setup Configuration

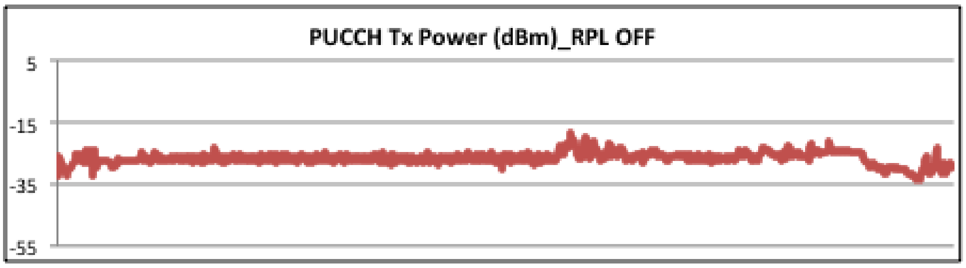
UDP traffic was used to ensure that there were no bursts of traffic impacting the resource block allocation. The same diagnostic monitor as what was used in the field was used to capture the log during the test in the lab.

6 Results

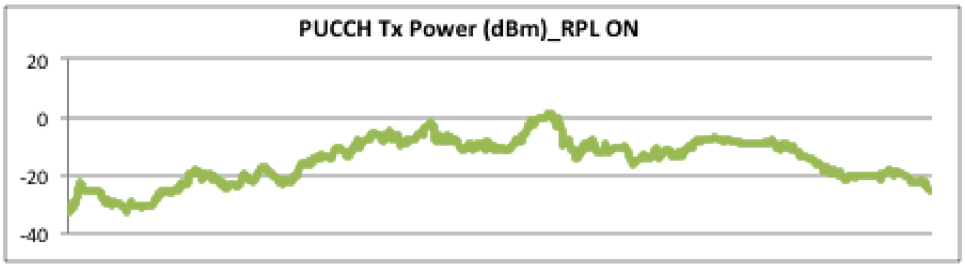
Graph 1 shows the path loss variations captured as a function of Reference Signal Received Power (RSRP). RSRP is the average reference power of reference signals and can be considered as a good indicator of the power received by the UE due to the downlink path loss since it does not factor the impact of noise and interference. In Graph 2 we first run the test without changing the path loss on the uplink with the same RSRP variations as Graph 1 i.e. with a fixed channel on the uplink. Even though there are variations on the downlink path loss, we see that the power being received to at the eNB is fairly constant. This is due to the fact that the target power on the eNB is being received easily with a static link on the uplink, thus resulting in the eNB not requesting for more or less power.



Graph 1. RSRP variations



Graph 2. PUCCH power without Uplink pathloss variations



Graph 3. PUCCH power with Reciprocal Path Loss (RPL) Enabled

We then turn on the RPL feature on the ACE RNX, which ensures that the RSRP variations in graph 1 are converted to a path loss parameter and applied on the uplink. From the perspective of a channel we also apply the reciprocal channel to mimic the reciprocity of the air interface. We notice that in Graph 3 the Tx power for the UE starts tracking the path loss variations and we see that it is almost a mirror image of the RSRP. This is due to the fact that the UE power being received by the eNB on the uplink may be less or more depending on the path loss being applied. Since the uplink is shared among different users, the eNB needs to ensure that the UE will not saturate other users by transmitting at a very high power. The eNB sends Transmit Power Control (TPC) commands to the

UE to reduce or increase its power level to compensate for these path loss variations. The goal is to try to overcome the interference and the reach the nominal power i.e. Po as communicated by the eNB. Thus we see that the UE behavior is very different when compared to doing a test only in the downlink versus doing a test that is truly bi-directional and mimics the channel environment.

In order to create a scenario that is representative of the real world we need to ensure that the UE undergoes similar power transitions as seen in the real world. The uplink power control impacts the throughput, interference received at the eNB, battery life, response of the eNB to measurement reports and overall performance of the UE. Field validation of such algorithms is difficult since we cannot isolate aspects of the channel environment such as path loss in a controlled and repeatable way. 3GPP R10 has specified the possibility of using multiple PUSCH being transmitted on multiple carriers resulting in more complicated power control algorithms when used in conjunction with Carrier Aggregation. With the Azimuth solution it is possible to take field conditions, isolate and create RF conditions that allow the user to test such algorithms and determine whether it is working as per expectations.

7 Conclusion

As we see from the test results, the path loss variations in the uplink have a significant impact on the UE power control behavior specifically on PUCCH Tx power control. Uplink power control algorithms are a key part of LTE and LTE-Advanced technologies. These algorithms need to quickly adapt to the complex channel environment and leverage it in order to optimize transmit power, uplink throughput, battery etc.

Traditional testing that uses a static uplink channels with a focus on downlink performance doesn’t exercise these UE power control algorithms sufficiently. The ACE RNX solution with its RPL feature is the first solution in the market that is purpose built to create a truly bi-directional channel environment for testing uplink LTE and LTE-Advanced power control algorithms.

8 References

[1] 4G LTE / LTE-Advanced for Mobile Broadband, Second Edition, Erik Dahlman, Stefan Parkvall and Johan Sköld

[2] LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Layer Procedures; 3GPP TS 36.213 version 8.8.0 Release 8.

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• United States
Anritsu Company
1155 East Collins Blvd., Suite 100, Richardson,
TX 75081, U.S.A.
Toll Free: 1-800-267-4878
Phone: +1-972-644-1777
Fax: +1-972-671-1877

• Canada
Anritsu Electronics Ltd.
700 Silver Seven Road, Suite 120, Kanata,
Ontario K2V 1C3, Canada
Phone: +1-613-591-2003
Fax: +1-613-591-1006

• Brazil
Anritsu Eletronica Ltda.
Praça Amadeu Amaral, 27 - 1 Andar
01327-010 - Bela Vista - Sao Paulo - SP
Brazil
Phone: +55-11-3283-2511
Fax: +55-11-3288-6940

• Mexico
Anritsu Company, S.A. de C.V.
Av. Ejército Nacional No. 579 Piso 9, Col. Granada
11520 México, D.F., México
Phone: +52-55-1101-2370
Fax: +52-55-5254-3147

• United Kingdom
Anritsu EMEA Ltd.
200 Capability Green, Luton, Bedfordshire, LU1 3LU, U.K.
Phone: +44-1582-433200
Fax: +44-1582-731303

• France
Anritsu S.A.
12 avenue du Québec, Bâtiment Iris 1- Silic 612,
91140 VILLEBON SUR YVETTE, France
Phone: +33-1-60-92-15-50
Fax: +33-1-64-46-10-65

• Germany
Anritsu GmbH
Nemetschek Haus, Konrad-Zuse-Platz 1
81829 München, Germany
Phone: +49-89-442308-0
Fax: +49-89-442308-55

• Italy
Anritsu S.r.l.
Via Elio Vittorini 129, 00144 Roma, Italy
Phone: +39-6-509-9711
Fax: +39-6-502-2425

• Sweden
Anritsu AB
Kistagången 20B, 164 40 KISTA, Sweden
Phone: +46-8-534-707-00
Fax: +46-8-534-707-30

• Finland
Anritsu AB
Teknobulevardi 3-5, FI-01530 VANTAA, Finland
Phone: +358-20-741-8100
Fax: +358-20-741-8111

• Denmark
Anritsu A/S
Torveporten 2, 2500 Valby, Denmark
Phone: +45-7211-2200
Fax: +45-7211-2210

• Russia
Anritsu EMEA Ltd.
Representation Office in Russia
Tverskaya str. 16/2, bld. 1, 7th floor.
Moscow, 125009, Russia
Phone: +7-495-363-1694
Fax: +7-495-935-8962

• Spain
Anritsu EMEA Ltd.
Representation Office in Spain
Edificio Cuzco IV, Po. de la Castellana, 141, Pta. 5
28046, Madrid, Spain
Phone: +34-915-726-761
Fax: +34-915-726-621

• United Arab Emirates
Anritsu EMEA Ltd.
Dubai Liaison Office
902, Aurora Tower,
P O Box: 500311- Dubai Internet City
Dubai, United Arab Emirates
Phone: +971-4-3758479
Fax: +971-4-4249036

• India
Anritsu India Private Limited
2nd & 3rd Floor, #837/1, Binnamangla 1st Stage,
Indiranagar, 100ft Road, Bangalore - 560038, India
Phone: +91-80-4058-1300
Fax: +91-80-4058-1301

• Singapore
Anritsu Pte. Ltd.
11 Chang Charn Road, #04-01, Shriro House
Singapore 159640
Phone: +65-6282-2400
Fax: +65-6282-2533

• P.R. China (Shanghai)
Anritsu (China) Co., Ltd.
Room 2701-2705, Tower A,
New Caohejing International Business Center
No. 391 Gui Ping Road Shanghai, 200233, P.R. China
Phone: +86-21-6237-0898
Fax: +86-21-6237-0899

• P.R. China (Hong Kong)
Anritsu Company Ltd.
Unit 1006-7, 10/F., Greenfield Tower, Concordia Plaza,
No. 1 Science Museum Road, Tsim Sha Tsui East,
Kowloon, Hong Kong, P.R. China
Phone: +852-2301-4980
Fax: +852-2301-3545

• Japan
Anritsu Corporation
8-5, Tamura-cho, Atsugi-shi, Kanagawa, 243-0016 Japan
Phone: +81-46-296-1208
Fax: +81-46-296-1248

• Korea
Anritsu Corporation, Ltd.
5FL, 235 Pangyoyeok-ro, Bundang-gu, Seongnam-si,
Gyeonggi-do, 13494 Korea
Phone: +82-31-696-7750
Fax: +82-31-696-7751

• Australia
Anritsu Pty. Ltd.
Unit 20, 21-35 Ricketts Road,
Mount Waverley, Victoria 3149, Australia
Phone: +61-3-9558-8177
Fax: +61-3-9558-8255

• Taiwan
Anritsu Company Inc.
7F, No. 316, Sec. 1, NeiHu Rd., Taipei 114, Taiwan
Phone: +886-2-8751-1816
Fax: +886-2-8751-1817

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