Comparison of LTE Performance Indicators and Throughput in Indoor and Outdoor Scenarios at 700 MHz

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***Abstract*—This paper compares indoor and outdoor LTE network performance at 700 MHz. We collect data using commercial test equipment on a commercially deployed 2×2 MIMO LTE network in a campus environment. The purpose of the study is to determine performance of LTE MIMO for indoor users from transmit antennas that are outdoors as compared to performance from transmit antennas that are indoors. To characterize performance, the typical method is to compare throughput and common LTE key performance indicators. In this study, we also study the relationship of these performance indicators to throughput performance. In this way, the value of performance indicators can be estimated. The conclusion of this study is that most of the key performance indicators show a positive correlation to throughput.**

***Index Terms*— LTE, MIMO, Indoor, Outdoor, 700MHz, Key Performance Indicators.**

I. Introduction

Long Term Evolution (LTE) has been adopted as the fourth-generation (4G) broadband wireless air interface. Both orthogonal frequency division multiplexing (OFDM) and multiple-input and multiple-output (MIMO) are employed within the LTE networks in order to increase data rates and enhance link robustness. Recently, both indoor and outdoor network elements have been deployed by major cellular service providers in the U.S.. An indoor network user will be served either by an indoor cell site or by outdoor cell sites.

This paper compares indoor and outdoor performance when the signals originate from outdoor cells. To determine the performance, the basic method is to compare the throughput of each condition.

There are many factors that affect performance. In previous work [1], the authors give the basic performance results for an indoor user comparing the outdoor-to-indoor and indoor-to-indoor signals on a 5.66 GHz 2×2 MIMO system in a campus scenario. They conclude that the indoor and outdoor performance is similar. However, the paper only compares the results of conventional bit error rate (BER) verses signal noise ratio (SNR). Additional parameters verses throughput are presented in our paper using a commercial LTE network.

Similar measurements comparing performance of indoor and outdoor users have been addressed by other papers. The scenario comparing outdoor-to-indoor and indoor-to-outdoor measurements on a 32×18 and 50×18 MIMO system at 5.25 GHz is discussed in [2]. The main focus is a discussion of the concept of reciprocity. Other scenarios of indoor-and-outdoor measurement have been brought out in [3] and [4], measuring a 2.4 GHz system and a 1.7666 GHz 4×4 MIMO system respectively. These papers make studies using custom measurement equipment. Again, the previous work only focuses on a few performance factors.

In this paper, the study is unique in two ways. First, we use a commercial network and environment in order to get practical results. A commercial 2x2 MIMO 700MHz LTE network was tested on University of Colorado, Boulder campus. Second, we examine many performance metrics, comparing throughput relative to these common LTE key performance indicators (KPI).

To avoid oversimplifying the conclusion and have diverse results, we made two families measurements at different locations. Both sets of measurement were measured in the evening on different days. All measurements were made by using commercial test equipment, systems, and network.

The remainder of this paper is organized as follows. The setting and environment of the measurements are described in Section II. The analysis of the measurements is presented in Section III. In Section IV, a comparison and conclusion are discussed.

II. Measurement Overview

A. Measurement Setup

In all measurements a commercial LTE data device, an LG LTE VL600, is used to collect LTE over the air performance metrics. The LG LTE device connects to a laptop and the OTA metrics are logged and displayed by JDSU E7464A, a commercial wireless network optimization test equipment product. Further data analysis is conducted by importing collected data into MatLab.

For testing throughput in the downlink, we download files from public File Transport Protocol (FTP) sites. These sites provide limited throughput, up to 5 Mbps, when downloading a file whereas we expect the maximum download rate will be around 30 Mbps. In order to reach the maximum throughput of

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The authors acknowledge the commercial test equipment contribution and assistance by the JDS Uniphase Corporation.

978-1-4673-1881-5/12/$31.00 ©2012 IEEE

the downlink, the E7464A software permits nine different files from public FTP sites to be downloaded simultaneously. Five-minute data collects are made at each test location. Both families of measurements were made between 7 pm to 11 pm on different days.

B. Engineering Building Locations

The first set of measurements were made in and around the Engineering Building (ENG) as shown in Fig. 1. The location of LTE cells around the main campus is also shown in Fig. 1 along with their cell IDs in blue.

Fig. 1. Campus map and cell sites distribution

Fig. 2 is a close-up view of the measurement locations around the set of engineering building measurements. Five indoor and outdoor measurement locations are shown. At each location, several independent five-minute data collections were made for a total of 25 measurements.

Location A is the first floor of engineering building. Location B and C are in an outdoor courtyard. Two to eight story buildings are located around both these two locations. From these locations are eight outdoor measurements that are non-line-of-sight (NLOS) to any cell. Two measurements are in location D. This location is an outdoor measurement at the front door of the Engineering building, which has line-of-sight (LOS) view to cell 229. Location E is inside the Engineering building. Five measurements are made in this location.

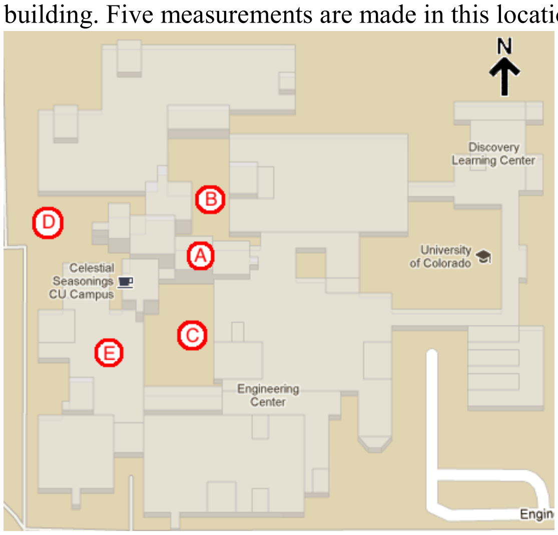

Fig. 2. Engineering building.

C. Fleming Building Locations

A second family of measurements was made in and around the Fleming Building on the University of Colorado at Boulder campus. This is shown in Fig. 1as FLEM.

Fig. 3 is a map of the first floor (ground floor) of the Fleming building. Eleven outdoor measurements are made, No. 1 to No. 11. Five indoor measurements, No. 12 to No. 16, were also made. Fig. 4 shows the first basement of the Fleming building. Seven indoor measurements, No. 17 to No. 23, were made here.

Fig. 3. Outdoor and indoor measurement at the first floor of Fleming building. No. 1 to No. 11 are outdoor measurements; No. 12 to No. 16 are indoor measurements.

Fig. 4. Indoor measurement at the first basement of Fleming building.

III. Measurement Analysis

A. Engineering Building Measurement Result

1) General Information

Table I shows the basic measurement information from the Engineering Building. There are ten outdoor measurements and fifteen indoor measurements. The primary serving sector of each location is recorded in the serving cell site column. The number of detected cell sites for each measurement is also shown. The last column shows the average downlink throughput during the measurement. In order to have an accurate result, the first forty seconds during which the connection is setting up, is deducted from the original five minutes. Therefore, the valid measurement during is approximately 260 seconds.

2) Throughput vs. Other Parameters

From a user perspective, the parameter of interest is the throughput of the network. From an engineering perspective, it is useful to correlate other parameters to the throughput when a network needs to be adjusted and expanded. In this section, the analysis and comparison of throughput to each parameter will be presented.

a) Indoor vs. Outdoor

Both indoor and outdoor measurements at the same area are made in this study. We use cumulative distribution function (CDF) to compare the throughput in different locations. Fifteen different indoor measurement CDF are shown in Fig. 5. Ten outdoor measurements CDF are shown in Fig. 6.

In Fig. 5, the ten measurements in location A have been divided into two groups, A1 to A5 and A6 to A10, which indicated two different areas in location A. In first group, A1 to A5, there are obvious variances of the throughput whereas the second group, A6 to A10, has stable transmission. In Location E, both stable transmissions and variances of the throughput can be seen.

TABLE I
ENGINEERING BUILDING GENERAL INFORMATION

Location	Number	Indoor /Outdoor	Total number of detected cell sites	Average Throughput (Mbps)
Location A (lobby)	1	Indoor	3	17.8295
	2	Indoor	3	21.7785
	3	Indoor	1	28.5853
	4	Indoor	3	23.5005
	5	Indoor	3	26.7661
	6	Indoor	3	15.8778
	7	Indoor	3	17.6617
	8	Indoor	2	27.7525
	9	Indoor	1	19.5173
	10	Indoor	3	18.0133
Location B (plaza)	1	Outdoor	5	14.3482
	2	Outdoor	4	10.4165
	3	Outdoor	4	11.6636
	4	Outdoor	4	17.0030
Location C (plaza)	5	Outdoor	2	10.0199
	6	Outdoor	2	13.9107
	7	Outdoor	4	16.3765
	8	Outdoor	4	11.9414
Location D	9	Outdoor	2	27.2746
	10	Outdoor	1	27.6682
Location E	1	Indoor	2	22.4128
	2	Indoor	1	28.8132
	3	Indoor	3	12.8804
	4	Indoor	2	28.4068
	5	Indoor	2	18.6894

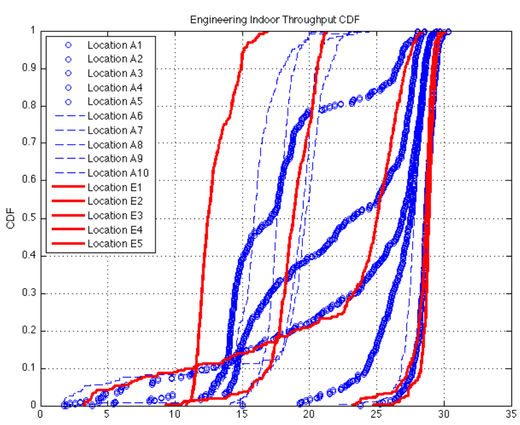

Fig. 5. Engineering CDF of the Indoor Throughput.

In Fig. 6, ten different outdoor measurements are collected. Both Location B and Location C are plaza areas whereas Location D is at the front door of the Engineering Building. While the plaza area is outside the building and without LOS to a cell. Unlike the indoor locations, the outdoor measurements can simply divide into two groups LOS and NLOS. The first group is the NLOS plaza area, Location B and Location C, which has low throughput and some variance. The second group, LOS, at the front door has high and stable throughput.

We might conclude that indoor User Equipment (UE) served from outdoors will experience more variance than a UE in an outdoor location. In indoor cases, it is hard to classify the data without carefully considering the detail of environment. In outdoor locations, the environment is more easily categorized into LOS and NLOS conditions.

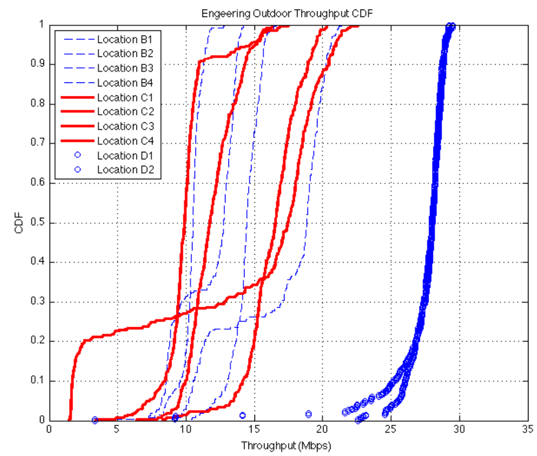

Fig. 6. Engineering CDF of the Outdoor Throughput.

b) Throughput vs. SNR

Signal to noise ratio (SNR) is one of the main factors that will affect the capacity in LTE system. In Fig. 7, the distribution of the SNR and the throughput of the measurements are presented. This figure shows that the SNR is directly proportional to the throughput. Other phenomenon can be observed in this figure. The first is that with low SNR (< 10 dB), low throughput will always occur. Second, even with high SNR (>20 dB), the transmission can still have low throughput, lower than 20 Mbps in average.

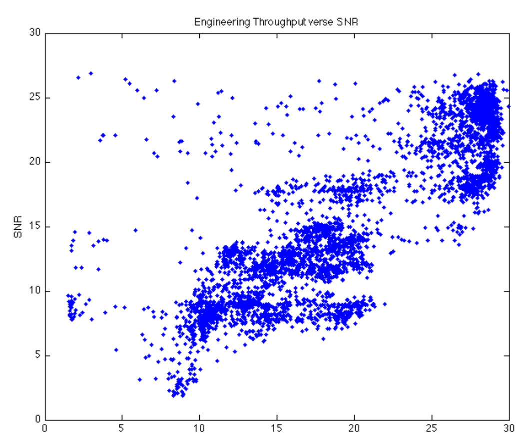

Fig. 7. Engineering building: Throughput vs. SNR.

c) Throughput vs. RSSI

Received Signal Strength Indicator (RSSI) indicates the total received power including noise and interference. In Fig. 8, the RSSI and the throughput are presented. There is no obvious trend that can be seen by this figure. However, there are some trends to be observed. Like SNR, even with strong RSSI low throughput can still occur. It is true that for high throughput, the reception will typically have a high RSSI (> -75 dBm) but high SINR is not a guarantee of good throughput. Managing interference is then a key to providing good throughput.

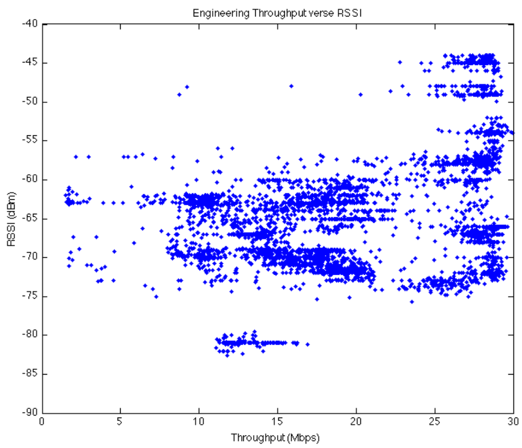

Fig. 8. Engineering building: Throughput vs. RSSI.

d) Throughput vs. Number of Detected Cell Sites

More detected cell sites will typically cause more interference for UEs. In Fig. 9, the number of detected cell sites and the throughput are presented. In general, less detected cell sites yeild higher throughput. With three or four cell sites detected, the throughput cannot reach the highest levels.

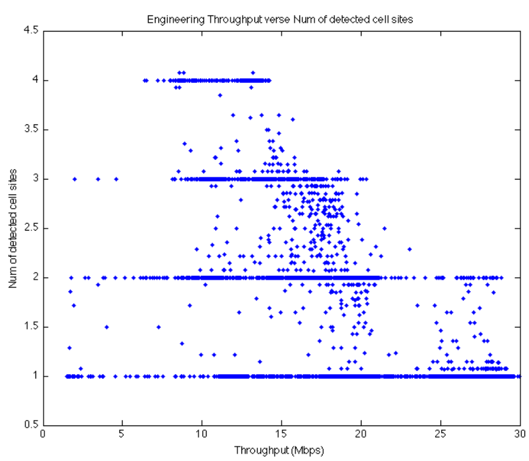

Fig. 9. Engineering building: Throughput vs. Number of detected cell

B. Fleming Building Measurement Results

1) General Information

Table II shows the basic measurement information from each location at the Fleming building. There are eleven outdoor measurements and twelve indoor measurements. The measurement method and settings are the same as used in the Engineering Building measurements.

2) Throughput vs. Other Parameters

a) Indoor vs. Outdoor

The CDF for the twelve indoor measurements are shown in Fig. 10. Eleven outdoor measurement CDFs are shown in Fig. 11.

Unlike the Engineering building set, the Fleming building indoor measurements can be divided into two groups: seven first basement measurements and five first floor measurements. In the basement, we can see that the throughputs are distributed between 7 Mbps and 21 Mbps. The throughput in the first floor is generally above 18 Mbps, except one throughput is 11 Mbps.

TABLE II
FLEMING BUILDING GENERAL INFORMATION

Location	Number	Indoor /Outdoor	Total number of detected cell sites	Average Throughput (Mbps)
Outdoors	1	Outdoor	2	19.2217
	2	Outdoor	3	15.1467
	3	Outdoor	2	10.8263
	4	Outdoor	3	17.0596
	5	Outdoor	3	18.6758
	6	Outdoor	3	21.7375
	7	Outdoor	1	23.0104
	8	Outdoor	2	21.8145
	9	Outdoor	3	13.6614
	10	Outdoor	2	18.5343
	11	Outdoor	2	18.3567
First Floor	12	Indoor	2	11.7289
	13	Indoor	2	19.4773
	14	Indoor	2	18.4040
	15	Indoor	1	24.0514
	16	Indoor	3	21.4927
First Basement	17	Indoor	3	13.0210
	18	Indoor	2	11.2848
	19	Indoor	2	19.8803
	20	Indoor	2	13.5909
	21	Indoor	3	11.3443
	22	Indoor	3	7.2423
	23	Indoor	2	20.3418

In Fig. 11, the eleven outdoor measurements are divided into four groups, the south side, west side, north side and east side of the Fleming building. The south side measurements, No.1 to 6, are distributed between 14 Mbps to 19 Mbps. The west side measurement, No.7, is 11 Mbps. The north side measurements, No.8 to 9, are around 16 Mbps and 17 Mbps. The east side measurements, No.10 to 11, are 23 Mbps and 24 Mbps. From the figure, we can observe that different sides have different performance.

From Fig. 10 and 11, outdoor locations can still have poor performance. In the basement area, the performance is inconsistent whereas it is much more consistent in the first floor area. Although both indoor and outdoor measurements can have periods of low throughput and high throughput, the outdoor performance is more consistent.

b) Throughput vs. SNR

In Fig. 12, the distribution of the SNR and the throughput presented. As before, it shows that throughput is proportional to SNR. With Low SNR (< 10 dB), low throughput will be observed. Even with high SNR (>20 dB), the transmission can still have low throughput, lower than 20 Mbps in average.

c) Throughput vs. RSSI

In Fig. 13, the RSSI and the throughput are presented. As before, there is no obvious trend to be observed.

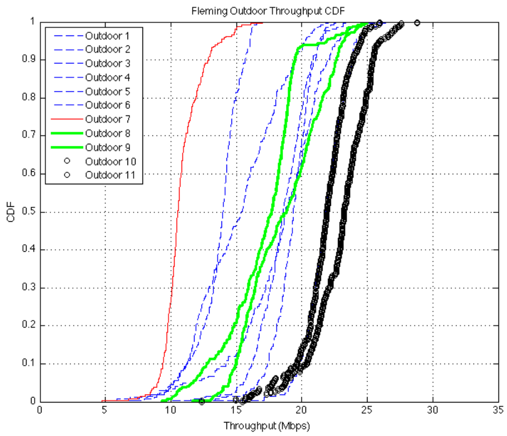

Fig. 10. Fleming CDF of the Outdoor Throughput.

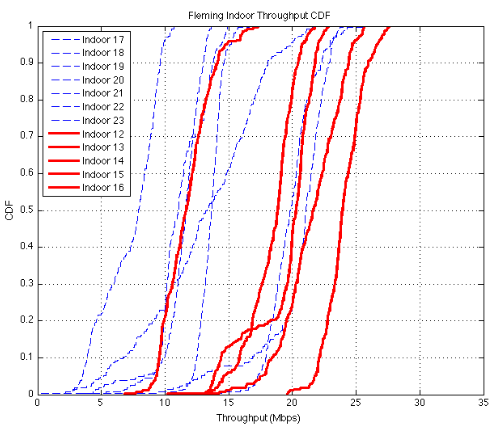

Fig. 11. Fleming CDF of the Outdoor Throughput.

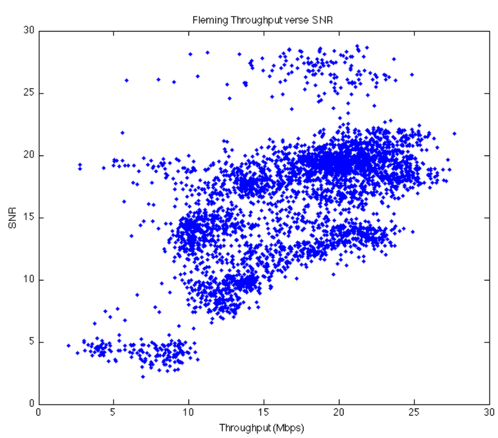

Fig. 12. Fleming Throughput vs. SNR

IV. Conclusion

In the indoor environments, the lower average throughput is observed. The variation of throughput indoors seems to be larger than outdoors. For outdoor locations, the variation in performance is strongly related to the LOS to NLOS condition.

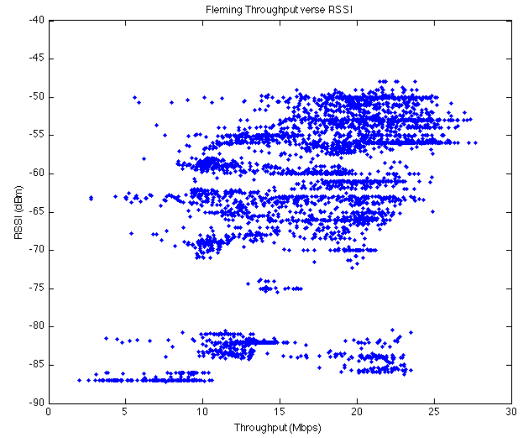

Fig. 13. Fleming Throughput vs. RSSI

a) Throughput vs. Number of Detected Cell Sites

Data from the Fleming buildings measurements also showed that less detected cell sites are associated with higher throughput, similar to Fig. 9. This indicates that the management of interference is key to higher LTE throughput performance

B. Comparison of the two location

Both sets of measurements have similar results as mentioned above. However, even with the same system and strong signal strength, the highest average throughputs that can be achieved are different in the two locations. In the Fleming building, the highest three average throughputs are 24.05 Mbps, 23.01 Mbps and 21.81 Mbps, compared to 28.81 Mbps, 28.58 Mbps, and 28.40 Mbps in the Engineering building. There is about 4.8-6.4 Mbps difference.

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