Practical Multi-Antenna Terminals in LTE System Performance Simulations

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Abstract

In cellular radio network simulations the modeling of terminal antennas is often extremely simplified. In this paper the results from a study on the impact of using realistic terminal antennas in LTE system simulations are presented. Results from downlink simulations using measured radiation patterns of a number of typical multi-antenna terminals have been compared with results using an ideal antenna model. The results showed that the impact was weak in a scenario with high intercell interference while a substantial performance degradation could be observed in a scenario with low interference. Cell-edge throughput was found to be the most sensitive performance metric which in the worst case suffered a 53% throughput reduction compared to the ideal model. An analysis of the relation between antenna properties and system performance is also presented. It was observed that the geometric mean of the eigenvalues of the pattern covariance matrix has a distinct connection to system performance. It was also found that efficiency is important for cell-edge throughput and that the pattern correlation has impact on peak throughput.

1 Introduction

A key enabler for meeting the demands from recent years' explosive development of mobile broadband usage is to exploit the spatial domain by using multiple antennas at the radio base stations and the user equipment (UE). Multi-antenna techniques such as spatial multiplexing, beamforming, interference rejection, and diversity, offer increased data rates and capacity as well as improved coverage and link reliability. Several of these multi-antenna techniques have been specified in the 3GPP standards HSPA and LTE [1] and also in the IEEE 802.11 and 802.16 standards [2] (WLAN and WiMAX).

In order to facilitate comparison between different technology proposals to standardization bodies, a set of reference simulation scenarios has been specified. In such simulation specifications, the model of the user terminal antennas is often extremely simplified, usually only specified as an isotropic radiation pattern [3,4]. A practical terminal antenna is far from being isotropic and there is a lot of variability in terminal antenna characteristics. There is also a lot of variability in how a terminal is used, which may affect its radiation characteristics, e.g. radiation pattern disturbances caused by the user's hand and head. One approach is to model the antenna statistically as proposed in [5]. Furthermore, with the advent of multi-antenna terminals, the radiation characteristics become more difficult to model in a concise manner since it is no longer sufficient to characterize the antenna by the radiation pattern of a single isolated antenna element. Multi-antenna characteristics such as mutual coupling and correlation are additional aspects that need to be taken into account. In this study, these aspects have been captured by using embedded radiation patterns.

The purpose of the work presented in this paper is to investigate the impact of using a more realistic characterization of multi-antenna terminals in system-level simulations of a wireless cellular network. A fairly detailed radio network simulator that models a 3GPP LTE system has been used to compare performance with an ideal antenna model and using measured antennas of some typical multi-antenna terminals.

In [6] link-level performance was evaluated using measured embedded radiation patterns of two-antenna terminals. Basic metrics such as diversity gain and Shannon capacity were used to evaluate the performance in noise limited scenarios. In this paper, results are presented from system-level evaluations in scenarios with low and high intercell interference using a multi-cell radio network simulator and measured embedded radiation patterns of two- and four-antenna terminals. Only downlink results are reported in this paper.

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2 Antennas and System Model

In order to evaluate the impact of using realistic terminal antennas in system performance evaluations, simulation results obtained when using an ideal antenna model are compared with results using measured antenna radiation patterns. The ideal antenna model is simply an isotropic radiation pattern for each antenna, which is also assumed to have 0 dBi gain. In the case of two-antenna evaluations the two antennas are assumed to have the same phase center and to have $\pm 45^\circ$ polarization for all angles. In the case of four-antenna terminals two such antenna pairs displaced half a wavelength are assumed.

The set of measured devices consists of one four-antenna and eight two-antenna terminals, both commercial devices and mock-ups. The four-antenna terminal has been measured at five different frequencies and, in order to limit the amount of simulations, only one frequency has been selected for each two-antenna terminal. Most devices have been measured in free-space but for two phones also measurements with the phone mounted in a hand phantom have been made. One of the phones is an intentionally bad design, which was designed for high correlation in order to evaluate the impact of signal correlation on performance. This phone will not belong to the set of terminals which is later on referred to as "realistic antennas".

Table 1 lists the measured two-antenna terminals with a brief description, frequency at which the measurements were made, mean efficiency, and pattern correlation. Mean efficiency is simply the average efficiency of the two antenna ports. The efficiency has been calculated as the ratio between realized gain and directivity, and pattern correlation has been calculated from the embedded radiation patterns assuming a uniform 3-D power spectrum of the incident field [6].

Description	Frequency (MHz)	Mean efficiency (dB)	Pattern correlation
Commercial notebook 1	2140	-5.7	0.12
Commercial notebook 2	2170	-4.7	0.01
PDA mock-up	2170	-6.6	0.09
Phone mock-up 1	1960	-3.0	0.09
Phone mock-up 2	1960	-2.8	0.10
Phone mock-up 3	1960	-2.9	0.14
Phone mock-up 4	750	-2.9	0.24
Phone mock-up 4 mounted in hand	750	-6.6	0.51
Bad phone mock-up	750	-5.2	0.97
Bad phone mock-up mounted in hand	750	-6.2	0.96

Table 1: Measured two-antenna terminals and their properties.

The system simulations were performed with a fairly detailed LTE radio network simulator which includes models of, e.g., adaptive coding and modulation, UE mobility, and delays in channel quality reports. It also contains an implementation of the 3GPP spatial channel model [3] and the mutual information based link-to-system interface described in [7].

The antennas have been evaluated for two different scenarios; one with high and one with low intercell interference, respectively. These are based on the 3GPP cases 1 and 3 as specified in [8]. The high-interference scenario is based on 3GPP case 1 with on average 5 UEs/cell and the low-interference scenario is based on 3GPP case 3 with on average 0.1 UEs/cell. The network consists of 19 three-sector sites placed on a hexagonal grid with 500 m site-to-site distance for case 1 and 1732 m for case 3.

3 Simulation Results

Table 2 summarizes the simulation results for the two scenarios. The left table shows results for two-antenna terminals and the right for four-antenna terminals. In the simulations, the base station had two antennas with $\pm 45^\circ$ polarization when two-antenna terminals were evaluated and two such pairs separated 0.7 wavelengths when four-antenna terminals were evaluated. The radiation pattern of each base station antenna was modeled as in [9].

The metrics used are system, cell-edge, and peak throughput. System throughput is defined as the total number of correctly received bits of all UEs divided by the simulated time. Cell-edge and peak throughput are defined as the 5% and 95% level, respectively, in the user throughput CDF. All throughput values have been normalized so that 100 corresponds to the throughput obtained when using the ideal antenna model. Each entry in a table cell shows the lowest and highest relative throughput of the measured antenna patterns. The results for the bad phone are shown separately from the realistic (all other measured terminals).

The results show that the largest impact of using realistic antennas is on cell-edge throughput in the low-interference scenario, in which only 47% of the throughput of the ideal antenna is retained for the worst realistic terminal (excluding the "bad phone"). However, the spread among different terminals is quite large. The impact in the high-interference scenario is weak for the realistic terminals, while the bad phone still shows severe throughput degradation. In the four-antenna case some terminals even show slightly higher throughput than the ideal. The spread among the throughput values for the four-antenna patterns is less than for the two-antenna patterns. This could be explained by that these patterns are measurements on the same device at different frequencies.

2x2	3GPP case 1, high load		3GPP case 3, low load	
	Realistic	Bad phone	Realistic	Bad phone
System throughput	93–98	71–71	70–89	61–64
Cell-edge throughput	87–98	66–66	47–79	45–49
Peak throughput	96–101	71–72	79–96	54–54

4x4	3GPP case 1 high load	3GPP case 3 low load
System throughput	98–102	87–94
Cell-edge throughput	97–104	71–86
Peak throughput	97–100	94–98

Table 2: Throughput of realistic antennas and bad phone relative to the ideal antenna model.

In an attempt to find relations between performance and antenna properties, Figure 1 shows scatter plots of throughput vs antenna properties for the low-interference scenario. Each marker in a plot corresponds to the throughput obtained with a particular measured two-antenna terminal. Cell-edge, peak, and system throughput are plotted vs mean efficiency, pattern correlation, and the geometric mean of the eigenvalues of the pattern covariance matrix. The latter metric was found to have a close connection to diversity gain and Shannon capacity in noise-limited scenarios in [6]. By visual inspection of these scatter plots it can be observed that there is a clear relation between the geometric mean of the eigenvalues and all throughput metrics. A high geometric mean is obtained if the eigenvalues are high and similar, properties that are known to be beneficial for channel capacity. Further relations that can be observed are between efficiency/cell-edge and correlation/peak throughput. These are expected results since UEs at the cell-edge benefit from high received signal power while low correlation is important for achieving high throughput by spatial multiplexing.

4 Conclusions

In this paper the results from a study on the impact of using realistic terminal antennas in LTE system simulations have been presented. System simulation results using measured radiation patterns of a number of typical user devices have been compared with the results obtained with an ideal antenna model. The results showed that the impact of using realistic antennas is scenario dependent with the strongest impact being observed in a scenario with low intercell interference. Cell-edge throughput is the most sensitive metric for which up to 53% throughput reduction compared to the ideal model was observed for the worst realistic antenna. In a scenario with high intercell interference the impact is weaker, typically less than 10% throughput reduction. The relation between multi-antenna properties and system performance has also been investigated for the scenario with low intercell interference. The geometric mean of the eigenvalues of the pattern covariance matrix was found to have a distinct relation to system, cell-edge and peak throughput. It was also observed that efficiency is important for cell-edge throughput and that there is a relation between pattern correlation and peak throughput.

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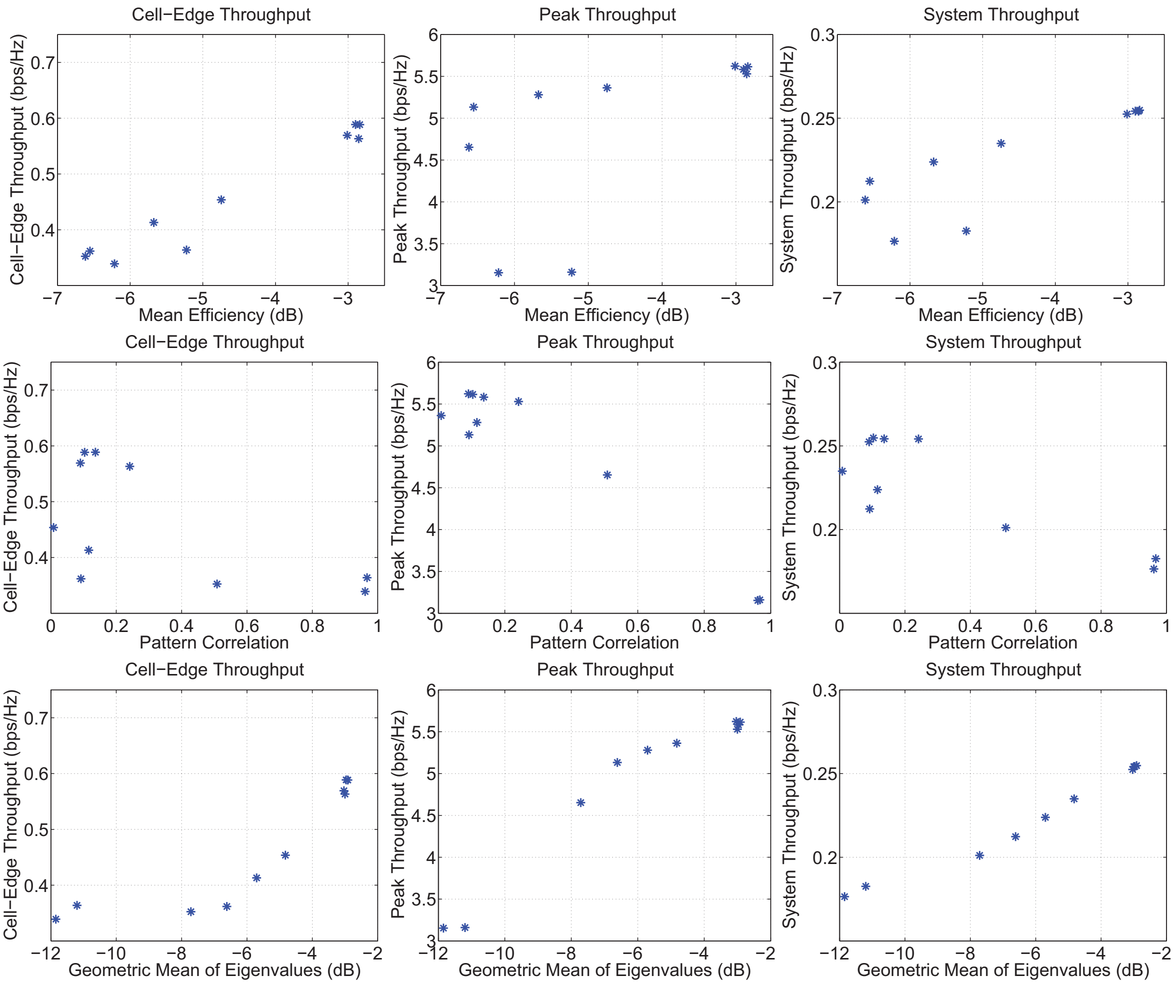

Figure 1: Performance vs radiation pattern properties for 3GPP case 3 with low load.

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