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FDD LTE MIMO CLOSED-LOOP VS OPEN-LOOP PERFORMANCE EVALUATION IN COMMERCIAL NETWORK

Darius CHMIELIAUSKAS *

Vilnius Gediminas Technical University, Vilnius, Lithuania

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Abstract. With a growing network traffic Mobile Network Operators (MNO) looking for ways to increase network capacity and improve customer experience. One of the ways is to find the best parameters from the set defined by 3GPP. In the study, closed-loop MIMO was compared to open-loop MIMO on the LTE FDD network. Network performance was evaluated in 3 different scenarios: slow and fast-moving UE under different SINR levels and large scale on 2T2R and 4T4R cells. The result shows gains of using closed-loop and it is recommended to use it commercial LTE networks.

Keywords: closed-loop MIMO, LTE FDD, mobile network capacity.

Introduction

All over the world, mobile network data traffic is continuously growing. Moreover, the Covid-19 pandemic caused the increase of mobile network data traffic by a big leap. Also, it was observed shift of traffic in Mobile Network Operators (MNO) networks out of business districts to dwelling neighborhoods. The base stations in the business district are usually prepared to transfer huge traffic amounts, while other locations may lack resources. All this set increased requirements of mobile traffic delivery that should be reflected by improvements of mobile networks such as LTE or 5G New Radio (NR).

Even 5G roll-outs started globally counting 166 5G operators in May 2021 according to *Ookla 5G Map*, LTE will remain the dominant mobile access technology by subscriptions at least until 2026 (Cerwall et al., 2020). As LTE remains the primary mobile data carrier it is important for MNO and equipment vendors to investigate and evaluate methods of increasing network capacity and efficiency.

Methods for expanding mobile network capacity divide into three general categories: the deployment of more radio spectrum; more intensive geographic reuse of spectrum; and increasing the throughput capacity of each MHz of spectrum within a given geographic area (Clarke, 2014). To increase the throughput capacity of each MHz of spectrum a.k.a Spectral Efficiency (SE), MNOs should search for optimal parameter set within the 3GPP standard limits. Based on standard (European Telecommunications Standards Institute [ETSI], 2014) LTE networks may be configured to use different Multiple-input multiple-output (MIMO) modes. The most common choices are Transmission Mode 3 (TM3) or Transmission Mode 4 (TM4), known as open-loop and closed-loop respectively. Setting the most suitable MIMO mode for the mobile network can improve SE and overall network capacity. Additionally, it is important to quantify differences for different base station types and client scenarios such as different coverage levels and moving speeds. In this paper, we compare the performance of open-loop versus closed-loop MIMO in LTE Frequency Division Duplex (FDD) in the city driving, walking tests, and large-scale network-level scenarios.

The paper is structured into 5 sections. Section 1 gives an overview of mobile radio network capacity increase methods. In section 2 provided a description of the factors impacting LTE cell capacity Single-User MIMO Transmission Modes used in LTE described in section 3. Evaluation scenarios presented in section 4. Section 5 presents achieved results. Finally, the conclusions are reported in the last section.

*Corresponding author. E-mail: *darius.chmieliauskas@vilniustech.lt*

1. MNO capacity increase methods

Mobile network capacity measured in bit/s/km^2 and can be modeled as follows (Van Chien & Björnson, 2017):

$$Area\,throughput = Bandwith \times Cell\,density \times Spectral\,efficiency. \tag{1}$$

As seen in Equation (1) first method to increase mobile network capacity is to increase used bandwidth. Typically band 20 (800 MHz), band 3 (1800 MHz), band 7 (2600 MHz), band 1 (2100 MHz) frequency bands used for LTE networks. In Lithuania, each MNO owns 10 MHz, 25 MHz, 20 MHz, 20 MHz respectively (Lietuvos Respublikos ryšių reguliavimo tarnyba, 2018). Additionally, in the hot-spot locations where all available spectrum resources already in use, the industry focuses on the spectrum below 6 GHz with 3400–4200 MHz as the primary selection for 5G (Wang et al., 2017).

Due to the lowest frequency and the best propagation LTE cells operating on band 20 used for deep indoor and wide rural coverage. To increase bandwidth in the base station serving area higher frequency cells can be added. Adding new cells to the base station can increase network capacity and user achievable bit rates proportionally to newly available bandwidth. The negative side of adding new cells is hardware and software license costs. Also in some locations base station is already equipped with cells from all bands. Besides, if MNO clients are far away from the base station or inside a building with insulating walls, higher frequency bands may not reach UE due to poor propagation.

The second term of Equation (1) is cell density. Increasing cell density is done by adding new base stations. Building new base stations have higher costs compared to other means due to active and passive hardware and new location lease. Additionally, in some places (e.g. old town), civil construction works feasibility may be limited by strict visual pollution or heritage requirements. One more method to increase cell density is the LTE base station sectors antenna split. In the sector split instead of a typical 3 sector site with 65-degree antennas, 6 sectors with 30-degree antennas must be used. Using a sector split solution the network throughput can be improved if customers are located on the center lobes of new cells. If customers are between sectors, inter-cell interference would reduce benefits.

The last part of area throughput Equation (1) is spectral efficiency. Improving spectral efficiency may be achieved by wireless network standards such as LTE and 5G NR evolution. Standardization organizations and equipment vendors introducing new functions such as higher-order modulation (256QAM), Carrier Aggregation (CA), and more spatial multiplexing known as MIMO layers (Wannstrom, 2013). To utilize gains of these functions not only the network side should be ready, but also support is required from the UE side. Even if UE is capable to support it, using higher-order modulation be limited by Signal-to-interference-plus-noise ratio (SINR) requirements. Referring to Table 7.2.3-2: 4-bit CQI Table 2 of (ETSI, 2014) we can see requirements to report Channel Quality Indicator above 12 for 256QAM usage. To use higher order MIMO (e.g from 2×2 to 4×4) number of transmit antennas in the base station and receive antennas in the UE must increase from 2 to 4. CA is beneficial only for UE with such function support and located in the coverage area with multiple frequency bands coverage.

On top of introducing new functions, MNO can improve SE by setting optimally designed parameters based on their clients' UE capabilities and base station infrastructure. One of the choices how to increase LTE cell capacity to find the most suitable MIMO mode. In the next section factors related to single LTE cell capacity is described.

2. LTE single cell capacity components

Overall LTE network capacity can be considered as a sum of single-cell capacities. The single LTE cell capacity or the throughput which can be achieved by the user in the coverage area depends on 3 major components:

- A number of scheduled physical resource blocks (PRB) from LTE time-frequency radio resources grid. PRB allocation and downlink scheduling described in (Capozzi et al., 2013);
- SINR, which is reported by UE as Channel Quality Indicator (CQI). The UE determines CQI such that it corresponds to the highest Modulation and Coding Scheme (MCS) allowing the UE to decode the transport block with error rate probability not exceeding 10% (Kawser et al., 2012);
- Multiple-input multiple-output (MIMO) usage performance.

Efficient utilization of multiple antennas can further improve spectral efficiency. In the LTE technology multiple MIMO techniques are defined. Differences of typically used MIMO modes are highlighted in the next section.

3. Single-User MIMO transmission modes in LTE

MIMO systems use more than one transmitting antenna (Tx) to send a signal on the same frequency to more than one receiving antenna (Rx). If multiple antennas are located in the same UE, it is called Single-User (SU) MIMO, in contrast to base station equipped with multiple antennas communicates with several UEs at the same time-frequency resources, it is referred to as Multi-User MIMO (Zheng et al., 2015). In the industry, downlink SU MIMO realized using 2 or 4 Tx antennas at the base station. UEs are equipped with 2 or 4 Rx antennas, with penetration of 4 Rx terminals is up to 20% in Baltic States networks.

Having multiple Tx and Rx antennas, two major operations used under SU-MIMO: transmit diversity and spatial multiplexing. Spatial multiplexing is used to improve UE's spectral efficiency at cell center users and transmit diversity to improve the reliability of cell edge UEs (Liu

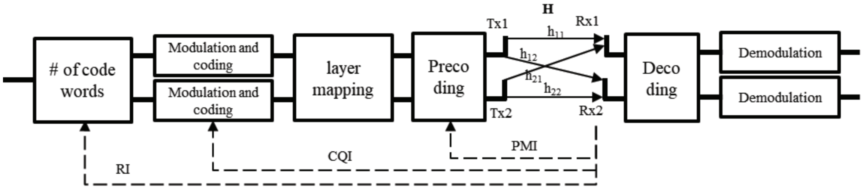

Figure 1. MIMO channel model (2Tx 2Rx). PMI is reported only in closed-loop spatial multiplexing mode

et al., 2012). LTE network may be configured to use transmission modes from 1 to 10 as defined in the standard (ETSI, 2014), but typical choices are TM3 (Open-loop spatial multiplexing with cyclic delay diversity) or TM4 (Closed-loop spatial multiplexing).

Figure 1 shows LTE physical layer block diagram for the MIMO 2×2 scenario, which is the most common cell type in commercial networks. The main difference, looking from the receiver side, between TM3 and TM4 is feedback from UE. In the open-loop transmission mode, UE reports Rank Indicator (RI) and CQI values but does not report precoding matrix indicator (PMI). In the TM4 (closed-loop) UE report RI, CQI, and PMI values. From the transmitter side in TM3 the signal is supplied to every antenna with a specific delay (cyclic delay diversity), thus artificially creating frequency diversity. It requires less UE feedback regarding the channel and is used when channel information is missing or when the channel rapidly changes, e.g. for UEs moving with high velocity (Rohde & Schwarz, 2015). TM3 can deliver better performance not only to fast-moving UE but also if the PMI values reported by UEs are unreliable or the demodulation capability of UEs is low. For the UEs in static scenarios or moving in walk speed, TM4 increases the downlink throughput compared with TM3. If UE is located in the high SINR region, TM3 and TM4 should provide similar throughput capability, as UE can decode two code-words. For the lower SINR, it is expected that TM4 may have an advantage if the channel matrix is correctly reported. The gains of TM4 are expected to grow with a larger number of Tx antennas. In the LTE cell with two transmitters, UE may choose preferred precoding from the defined codebook with 4 options, in the case of four transmit antennas there are 16 options to encode the channel. In details precoding process for TM3 and TM4 is described in (ETSI, 2017). For the live mobile network performance following points should be considered: evaluation current state of UE PMI reporting capabilities, the proportion of 2 Tx and 4 Tx cells, and typical UE moving speeds.

4. Evaluation scenarios

LTE network performance was compared using TM3 versus TM4. Three different scenarios were constructed to reflect customer experience under various coverage levels and mobility. These testing scenarios are trying to cover different cases: slow and fast-moving UE, different SINR levels, and large-scale roll-out. In all scenarios, the main performance metric was user achievable downlink throughput.

The first scenario is designed to measure user achievable throughput in driving speed. Drive test measurements are widely used for MNO benchmarking tests. So it is important to evaluate the impact of closed-loop MIMO for UE moving at high speed. According to (Adhikari, 2011; Rohde & Schwarz, 2015) closed-loop MIMO is expected to perform worse in drive tests compared to open-loop due to rapid changes of the channel and reported PMI outdating.

Figure 2 shows the selected cluster for the driving test. The location is an urban dwelling neighborhood.

The Drive test cluster consisted of 6 base stations. These base stations (marked yellow in Figure 2) containing 24 4T4R and 46 2T2R cells. Test scenario designed to be similar to commercial clients. Test UE was not locked to a specific frequency or cell, it camped freely on any of the carriers based on network mobility settings. To evaluate achievable downlink throughput using TM3 and TM4 large file download was done to the test UE. To avoid the impact of fluctuating traffic from other clients, the test was performed on the same cluster with live network background traffic on the same weekday and same hour.

Figure 3 shows UE moving speed during testing. For the single UE, it is expected to have a lower downlink throughput using closed-loop transmission mode due to

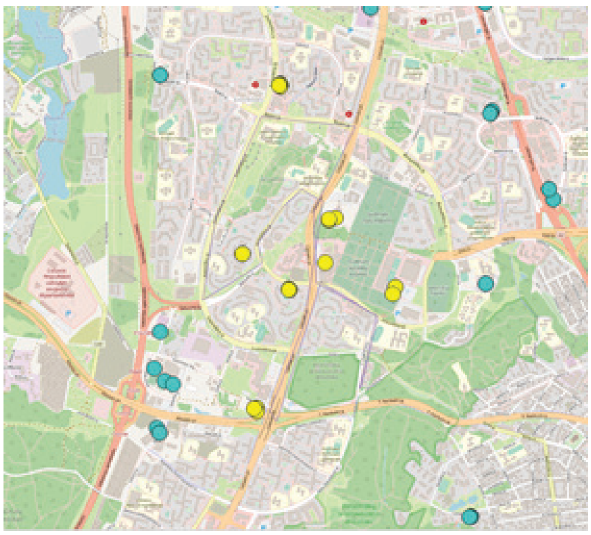

Figure 2. Base stations of the test cluster used for MIMO modes evaluation

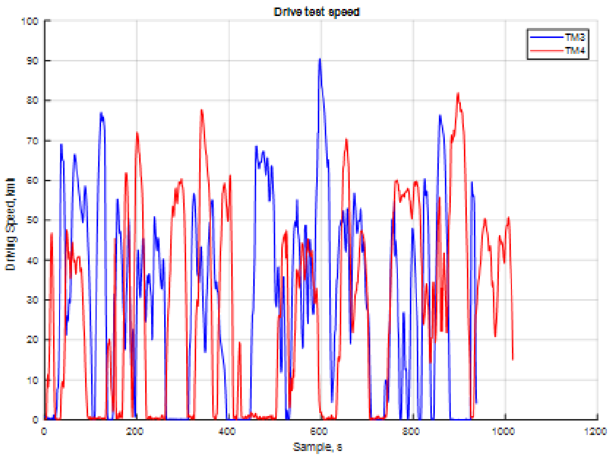

Figure 3. UE moving speed during evaluation

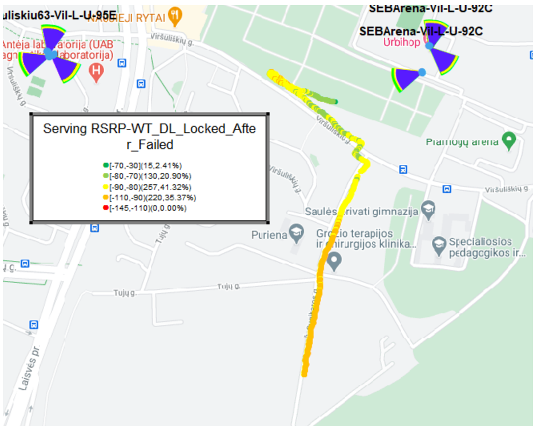

Figure 4. Walk test route and RSRP values of UE locked to single cell

PMI outdate moving at high speed. But if we consider the live network, where most of the other clients are stationary, we expect that other clients will consume less PRB for the same amount of downlink data and a larger amount of PRBs will be allocated to test UE.

To show no negative impact for the drive test scenario, UE moving speed was reaching up to 60–90 km/h.

The second scenario was constructed to compare downlink throughput under different Reference Signal Received Power (RSRP) and SINR levels at walking speed. Collecting throughput measurement samples at a wide range of SINR can reflect the benefits of closed-loop MIMO for customers in different coverage areas. Figure 4 shows the RSRP level at the walk test route.

For the walk test scenario test UE with a capability of locking to the specific cell was used. UE was locked to the single E-UTRA operating band 3 cell with 20 MHz bandwidth. Without locking UE to the cell, it could perform handover to neighboring cells and it would be difficult to perform measurements in a wide RSRP/SINR range. With UE lock to the cell measurements made in the cell center and moving away to the cell edge.

A comparison of MIMO TM3 with TM4 was done in the live network with other customers using the cell. It may lead to large fluctuations of time-frequency resources scheduled for the test UE. To avoid the impact of different cell load during measurement achievable throughput was recalculated using Equation (2):

$$FullUtilizationThroughput = TotalPRB \times \frac{RLCDLthroughput}{PDSCHRBnumber / s}. \quad (2)$$

In Equation (2), the *FullUtilizationThroughput* is the downlink throughput that could be achieved if all PRB would be allocated to test UE. It reflects LTE cell capacity. *TotalPRB* is all PRB configured in the cell. In our case, the cell with 20 MHz bandwidth contains 100 PRB in the frequency domain and the measurement sampling interval is 1000 ms. Total in 1s interval 100000 PRBs available. *RLCDLthroughput* is measured downlink throughput at Radio Link Control (RLC) layer and *PDSCHRBnumber/s* is measured number of PRBs scheduled to the UE. All these values are collected using special LTE network measurement equipment at a wide SINR range.

The third scenario is the large-scale roll-out. Large-scale roll-out shows the impact of parameter setting on all the MNO customers. It does not provide a fine-grained understanding of TM4 and TM3 evaluation on a single UE, but statistically shows the impact on overall network performance and capacity. A large number of 2 Tx and 4 Tx cells were included. The main metric was UE throughput calculation as defined by 3GPP (ETSI, 2011):

$$AvgUEThp = \frac{TotPDCPVolDataExclLastTTs}{ToTEffectiveTimeExclLastTTIs}. \quad (3)$$

In Equation (3) *AvgUEThp* is average user downlink throughput, *TotPDCPVolDataExclLastTTs* is transferred data volume without last Transmission Time Interval (TTI) and *ToTEffectiveTimeExclLastTTIs* is the time used for transmission. The last data unit TTI shall always be removed from calculations since it can be impacted by packet size.

5. Results

LTE network performance in terms of downlink user throughput was compared with MIMO TM3 and MIMO TM4 configurations in the previously described scenarios.

The drive test results show improvements in the average values and all percentile ranges. Table 1 shows an increase of average throughput in the cluster from 105 Mbps to 128 Mbps after the change from TM3 to TM4.

Table 1. Measured downlink throughput in the drive test

	Measured downlink throughput, Mbps			
MIMO mode	Mean	Median	25th percentile	75th percentile
TM3	105	96	61	142
TM4	128	110	66	188
Increase, %	22%	15%	8%	32%

Figure 5 shows probability density function (PDF) function of measured downlink throughput. The shift towards higher throughput ranges is visible.

Measured downlink throughput increased even for fast-moving UE in opposite to expectations. The single fast-moving UE in the empty cell is expected to have higher throughput using open-loop MIMO, but in the live network, closed-loop MIMO outperforms open-loop even for fast-moving UE. The throughput increase caused by both increased MIMO utilization and the possibility to get more PRB as other clients need less PRB to transfer the same data amount.

Figure 6 showing the measurements scatter plot with the approximating curve. The presented results were obtained from the walk test scenario. Here measurement made moving at slow speed and includes wide SINR range. The closed-loop MIMO configuration proves its advantage. It improves downlink throughput compared to open-loop for slow-moving UE in both low and high SINR regions.

The last results were obtained from the large-scale comparison. It includes thousands of 2T2R and 4T4R cells and hundreds of thousands of UEs. As MIMO modes compared in the commercial network it contains 2 Rx and 4 Rx UE moving at slow and fast speeds. Such a comparison shows average throughput difference for specific commercial network, but similar behavior is expected on any LTE MNO. To discard impacts of traffic fluctuations one week with TM3 in use was compared to one week with TM4. Figure 7 shows daily average user downlink throughput calculated using Equation (3) for cells with 2 transmitters.

Even for standard legacy configuration cell with two transmit antennas, large scale TM4 activation show improvements. As seen in Figure 7 average user downlink throughput increase by 13.5% on 2T2R cells.

Figure 8 shows daily average user downlink throughput calculated using Equation (3) for cells with 4 transmitters.

As expected the gains are even larger for 4T4R after the change to TM4 from TM3. As seen in Figure 8 average user downlink throughput increased by 29% on 4T4R cells. The large-scale roll-out shows the benefit of closed-loop MIMO selection for both sides: customer experience improvement and for MNO network capacity increase.

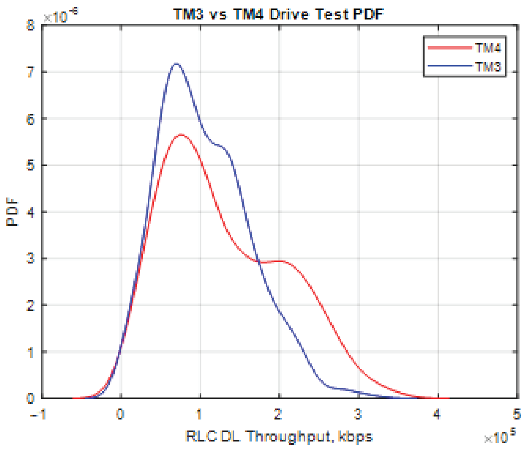

Figure 5. PDF function of throughput measurements during drive test

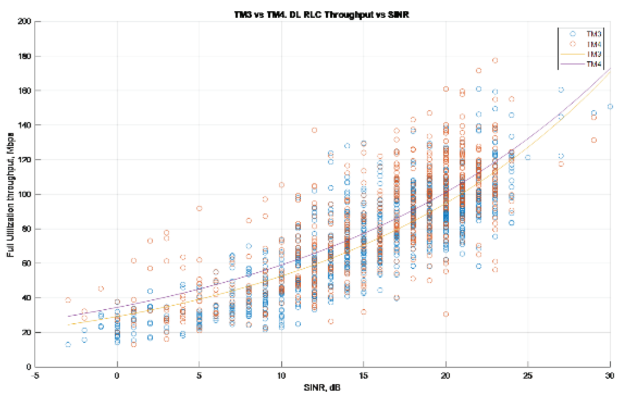

Figure 6. Calculated full utilization throughput in different SINR levels

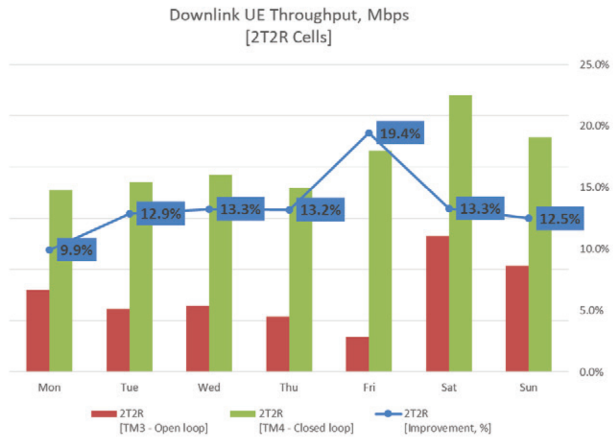

Figure 7. Downlink UE throughput calculated from network statistics for 2T2R cells

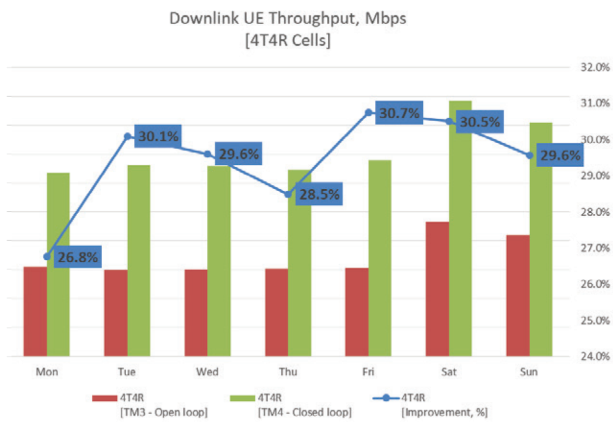

Figure 8. Downlink UE throughput calculated from network statistics for 4T4R cells

Conclusions

The study presents closed-loop LTE FDD closed-loop MIMO (TM4) and open-loop MIMO performance compassion in terms of downlink throughput. The measurements were performed in three different scenarios: drive test for fast-moving UE, walk test to see gains under different SINR levels, and large scale test on 2T2R and 4T4R cells. All scenarios were evaluated in the live commercial network.

Closed-loop MIMO improves downlink throughput compared to open-loop in the driving test on average 22%. From statistical performance monitoring the gain are 13% and 29% 2T2R and 4T4R cells respectively. As the result using closed-loop MIMO in FDD LTE suggested in all scenarios.

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LTE MIMO ATVIROJO IR UŽDAROJO MIMO CIKLO PALYGINIMAS KOMERCINIAME TINKLE

D. Chmieliauskas

Santrauka

Didėjant mobiliojo ryšio tinkle perduodamam duomenų srautui, mobiliojo ryšio operatoriai (MNO) ieško būdų, kaip padidinti tinklo pajėgumą ir pagerinti klientų patirtį. Vienas iš būdų yra rasti geriausius parametrus iš 3GPP apibrėžto rinkinio. Tyrimo metu uždarojo ciklo MIMO buvo lyginamas su atvirojo ciklo MIMO LTE FDD tinkle. Tinklo našumas buvo vertinamas pagal 3 skirtingus scenarijus: lėtai ir greitai judantis klientas. Taip pat palyginta pagal skirtingą signalo ir triukšmo santykio vertę. Taip pat atliktas masinis palyginimas 2T2R ir 4T4R tipo ląstelėse. Rezultatas rodo uždarojo ciklo naudojimo pranašumus. Todėl uždarojo ciklo MIMO rekomenduojama naudoti komerciniuose LTE tinkluose.

Reikšminiai žodžiai: atvirojo ir uždarojo ciklo MIMO, LTE tinklo talpa, mobiliojo ryšio kokybė.