System-level performance of interference suppression receivers in LTE system

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***Abstract*—In wireless networks with smaller cell sizes and dense network deployments the spectral efficiency is limited by inter-cell interference. To improve signal-to-noise-plus-interference-ratio, interference can be mitigated using advanced receivers like an interference rejection combining (IRC) receiver. The performance of a practical IRC-receiver is dependent on the quality of the channel and interference covariance estimation. Interference covariance can be estimated for example by using reference signals. As the interference structure is dependent on several components, such as scheduler decisions made and precoders used by other cells, receiver evaluations are performed on system level. Because of full network system level simulations are very complex and highly computationally intensive, simplifications in modeling are needed. Typically time-frequency resolution can be reduced and only the fast-fading coefficients of the interfering links are generated. The lack of symbol samples requires a model to estimate the losses of realistic IRC receivers. In this paper, we show system level results for practical IRC algorithms.**

I. Introduction

In current wireless networks, the increasing volume of mobile data traffic is creating physical limitations to the network performance. To alleviate these limitations, networks are relying on more dense deployments and smaller cell sizes. In these networks, the performance is becoming more limited by increasing inter-cell interference. The impact of inter-cell interference can be for example reduced by coordinated multi-point transmission (CoMP) schemes or mitigated at the receiver. The 3rd Generation Partnership Project (3GPP) has put a lot of research effort in both topics [1] [2].

One approach to suppress interference in the receiver is to use interference rejection combining (IRC) algorithms. Typically these algorithms require information on the interference covariance. As shown further in the text, the performance of an ideal IRC receiver gives an upper-limit of the performance for linear IRC algorithms, but the practical implementation is hindered by the quality of channel and interference covariance estimates. On system level, many aspects have an impact on the characteristics of interference, like scheduling and precoding. Therefore, system level evaluation of IRC receivers performance is necessary. Having in mind that the modeling of a full network is complex, some compromises have to be made in order to reduce modeling complexity and calculation intensity. One typical approach is to reduce the system resolution in both frequency and time domains, that is increase the size of smallest observable block from a single OFDM symbol to one resource block. Therefore, accurate modeling of estimation losses in IRC receivers is difficult. In a companion paper [9] we are introducing a way to model such errors in system level.

In this paper, we present system performance of practical IRC algorithms. Extensive evaluations are presented in homogeneous and heterogeneous deployments, under finite and full buffer traffic conditions. Performance comparison with ideal IRC and more simplistic least minimum mean square error (LMMSE) receivers as well is provided.

The paper is organized as follows. In Section II we present the used signal model and Section III presents modeling of channel estimation and interference covariance estimation errors. In Section IV we present the modeled network topologies and the dropping of the users in the system. Section V discusses different receiver algorithms. Numerical results are presented in Section VI including the radio system model verification. Finally, our conclusions are drawn in Section VII.

II. Signal Model

In the Long Term Evolution (LTE) downlink, OFDM modulation is used together with a cyclic prefix to maintain orthogonality between sub-carriers in presence of multipath propagation. The cyclic prefix removes the time-domain inter-symbol interference if the propagation delay of the multipath components is lower than the cycle prefix length. Assuming this holds, we can consider the received signal in frequency domain. In other words, the received signal at subcarrier k of OFDM symbol j equals

$$\bar{\boldsymbol{r}}_{k,j} = \boldsymbol{H}_{k,j}\bar{\boldsymbol{s}}_{k,j} + \boldsymbol{H}_{co,k,j}\bar{\boldsymbol{s}}_{co,k,j} + \bar{\boldsymbol{n}}_{k,j} \qquad (1)$$

where the length of the vector $\bar{\boldsymbol{r}}_{k,j}$ equals the number of receive antennas, N_r, and the length of the vector $\bar{\boldsymbol{s}}_{k,j}$ equals the number of transmitted symbol streams, N_s. Vector $\bar{\boldsymbol{n}}_{k,j}$ consists of inter-cell interference and thermal noise. The matrix $\boldsymbol{H}_{k,j}$ indicates the effective channel including possible precoding. $\boldsymbol{H}_{co,k,j}$ and $\bar{\boldsymbol{s}}_{co,k,j}$ indicate the effective channel of a possible co-layer interference and interfering co-layer

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transmitted symbols only in case of multiuser transmission respectively. For other multiuser transmission specific details one can refer to [3]–[6]. Thus, assuming i.i.d. transmitted symbols from interfering cells, the spatial interference covariance $\boldsymbol{C}_{nn,k,j}$ can be written as

$$\begin{aligned}\boldsymbol{C}_{nn,k,j} &= \mathrm{E}[\bar{\boldsymbol{n}}_{k,j}\bar{\boldsymbol{n}}_{k,j}^{H}] &(2)\\ &= \sum_{i\in\mathcal{S}_I}\boldsymbol{H}_{k,j}^{(i)}\boldsymbol{H}_{k,j}^{(i)H} + \sigma_v^2\boldsymbol{I}. &(3)\end{aligned}$$

where $\mathcal{S}_I$ denotes the set of interfering cells, matrix $\boldsymbol{H}_{k,j}^{(i)}$ is the channel corresponding to interfering cell i and σ_v^2 is the thermal noise variance. It is noted that we assume that the possible precoding is embedded into the channel, i.e. matrices $\boldsymbol{H}_{k,j}$ and $\boldsymbol{H}_{k,j}^{(i)}$ in fact represent the effective radio channel taking into account precoding.

III. Estimation error models

A conventional method of using an LMMSE receiver leads to interference suppression. The interference from a modulation symbol point of view can be originating from other transmitted symbol streams in the same cell or from other cells. A general LMMSE symbol estimate

$$\begin{aligned}\hat{\boldsymbol{s}}_{k,j} = \quad & \boldsymbol{H}_{k,j}^{H}(\boldsymbol{H}_{k,j}\boldsymbol{H}_{k,j}^{H}\\ & +\boldsymbol{H}_{co,k,j}\boldsymbol{H}_{co,k,j}^{H} + \boldsymbol{C}_{nn,k,j})^{-1}\bar{\boldsymbol{r}}_{k,j} \qquad (4)\end{aligned}$$

suppresses both sources. The model can also be expressed as

$$\hat{\boldsymbol{s}}_{k,j} = \boldsymbol{H}_{k,j}^{H}(\boldsymbol{C}_{rr,k,j})^{-1}\bar{\boldsymbol{r}}_{k,j} \qquad (5)$$

with

$$\boldsymbol{C}_{rr,k,j} = \boldsymbol{H}_{k,j}\boldsymbol{H}_{k,j}^{H} + \boldsymbol{H}_{co,k,j}\boldsymbol{H}_{co,k,j}^{H} + \boldsymbol{C}_{nn,k,j}. \qquad (6)$$

In non-MIMO systems this receiver is also known as interference rejection combining (IRC). It has to be noted that the covariance of the co-layer interference $\boldsymbol{H}_{co,k,j}\boldsymbol{H}_{co,k,j}^{H}$ is only present in multiuser transmission.

In practical systems, both the channel and the received signal covariance information need to be estimated and the ideal MMSE solution is replaced by

$$\hat{\boldsymbol{s}}_{k,j} = \hat{\boldsymbol{H}}_{k,j}^{H}(\hat{\boldsymbol{C}}_{rr,k,j})^{-1}\bar{\boldsymbol{r}}_{k,j} \qquad (7)$$

using the estimates of channel and received signal covariance $\hat{\boldsymbol{H}}_{k,j}$ and $\hat{\boldsymbol{C}}_{rr,k,j}$ respectively. As mentioned, since in system-level simulations the baseband samples are typically not available, error models for $\hat{\boldsymbol{H}}_{k,j}$ and $\hat{\boldsymbol{C}}_{rr,k,j}$ are needed to be able to simulate practical IRC.

A. Channel estimation error modeling

A conventional channel estimation algorithm can be based on a LMMSE interpolator using the reference signal symbols. The channel estimate is obtained by interpolating the channel estimate samples received at reference signal locations p, where a known signal $\bar{\boldsymbol{r}}_p$ is transmitted. The channel estimation for a data symbol at (k,j) can be written as follows

$$\hat{\boldsymbol{H}}_{k,j} = \boldsymbol{C}_{(k,j),p}\boldsymbol{C}_{pp}^{-1}\bar{\boldsymbol{r}}_p = \boldsymbol{W}_{\mathrm{chest},k,j}\bar{\boldsymbol{r}}_p, \qquad (8)$$

where the $\boldsymbol{C}_{pp}$ equals to the covariance of the reference signal locations, and the $\boldsymbol{C}_{(k,j),p}$ equals to the cross correlation of the reference signal locations and the channel estimate location (k,j) of the data symbol. The covariances can be calculated based on the channel coherence bandwidth and the signal-to-noise ratio of the reference signal. Assuming that the UE is moving slowly, these parameters are relatively stable.

In the system simulator, the transmitted samples are not available which means that channel estimation error needs to be generated and added to the ideal channel state information. The channel estimator can be understood as a filter which filters the interference $\bar{\boldsymbol{n}}$. Hence, the covariance of the additive channel estimation error is expressed as

$$\boldsymbol{C}_{\epsilon\epsilon,k,j} = \mathrm{E}[(\hat{\boldsymbol{H}}_{k,j} - \boldsymbol{H}_{k,j})(\hat{\boldsymbol{H}}_{k,j} - \boldsymbol{H}_{k,j})^{H}]. \qquad (9)$$

Since the interference and noise covariance $\boldsymbol{C}_{\epsilon\epsilon,k,j}$ is known from the modeling, it may be used for generating instantaneous channel estimation error samples $\boldsymbol{\epsilon}_{k,j}$. By using a Cholesky factorization of the covariance, i.e. $\boldsymbol{C}_{\epsilon\epsilon,k,j} = \boldsymbol{F}\boldsymbol{F}^{H}$ and uncorrelated noise samples $\bar{\boldsymbol{w}}$ we generate

$$\boldsymbol{\epsilon}_{k,j} = \boldsymbol{F}\bar{\boldsymbol{w}}. \qquad (10)$$

Finally, the instantaneous estimate of the channel can be written as

$$\hat{\boldsymbol{H}}_{k,j} = \boldsymbol{H}_{(k,j)} + \boldsymbol{\epsilon}_{k,j}. \qquad (11)$$

B. Interference covariance estimation error modeling based on reference symbols

In this paper we estimate the received signal covariance matrix using the dedicated reference signal symbols. The estimated covariance matrix is modeled by taking the ideal covariance and adding an error term drawn from a certain distribution which is further discussed.

In the reference signal based estimation method, received demodulation reference signal samples are used to calculate a sample average of the interference covariance. The N_p demodulation reference signal (DMRS) positions in the set $\mathcal{S}_p$ are used for the covariance matrix estimation. These are reference symbols precoded with the same precoder as the data symbol and should also experience the same interference as the actual data symbols. The algorithm subtracts the serving cell DMRS signal before performing the covariance estimation. In other words, the inter-cell interference and noise covariance is estimated as follows:

$$\begin{aligned}\hat{\boldsymbol{C}}_{nn,p} &= \frac{1}{N_p}\sum_{(k,j)\in\mathcal{S}_p}(\bar{\boldsymbol{r}}_{k,j} - \hat{\boldsymbol{H}}_{k,j}\bar{\boldsymbol{p}}_{k,j})(\bar{\boldsymbol{r}}_{k,j} - \hat{\boldsymbol{H}}_{k,j}\bar{\boldsymbol{p}}_{k,j})^{H}\\ &= \frac{1}{N_p}\sum_{(k,j)\in\mathcal{S}_p}(\bar{\boldsymbol{r}}_{k,j} - (\boldsymbol{H}_{k,j} + \boldsymbol{\epsilon}_{k,j})\bar{\boldsymbol{p}}_{k,j})\cdot\\ &\qquad (\bar{\boldsymbol{r}}_{k,j} - (\boldsymbol{H}_{k,j} + \boldsymbol{\epsilon}_{k,j})\bar{\boldsymbol{p}}_{k,j})^{H} \qquad (12)\end{aligned}$$

where $\bar{\boldsymbol{p}}_{k,j}$ is the DMRS symbol vector. The final covariance matrix estimate is formed as a sum of Equations (11) and (12)

$$\hat{\boldsymbol{C}}_{rr,p} = \hat{\boldsymbol{H}}_{k,j}\hat{\boldsymbol{H}}_{k,j}^{H} + \hat{\boldsymbol{C}}_{nn,p}. \qquad (13)$$

From system-level simulator modeling point of view this matrix can be assumed to be a Wishart-distributed random matrix conditioned on that the channel does not change within the estimation block. In other words, $\hat{\boldsymbol{C}}_{nn,p} \sim \mathrm{W}_n(N_p, \boldsymbol{C}_{nn}+\boldsymbol{C}_{\epsilon\epsilon})$ [7] if the channel estimation error $\boldsymbol{\epsilon}$ is independent from the DMRS samples. In a conventional system simulator, this property can be exploited because in a system simulator the baseband data samples do not exist. A method of generating the Wishart-distributed random matrices can be found for example from [8].

IV. Network topology

In order to provide a wider view on receiver performance in traditional deployments and small cell deployments, following network topologies have been considered in this paper.

1) Network topology: In terms of network topology we consider both homogeneous and heterogeneous networks. The homogeneous network topology is characterized by having a hexagonal layout composed by 19 sites, each site hosting 3 Macro-eNBs (or 3 sectors). All Macro-eNBs are transmitting with the same transmission power. On the other hand, the heterogeneous network layout starts from the homogeneous topology assumption and then expands it by adding pico-eNBs uniformly distributed inside each sector. In this paper pico-eNBs are transmitting with reduced power compared with Macro-eNBs and can be also called low-power-nodes (LPN).

2) UE dropping: The way UEs are distributed also depends on network topology. In the case of homogeneous topology, we assume 10 UEs uniformly distributed inside each sector, whereas for the heterogeneous topology two UE dropping modes defined in 3GPP are considered in this paper: Configuration 1 and configuration 4b [1]. Configuration 1 is a non-clustered UE dropping mode, where 25 UEs are uniformly distributed inside a sector. In contrast, configuration 4b is a clustered UE dropping mode where 10 UEs are uniformly distributed inside a sector and 5 UEs are uniformly distribued inside each pico-eNB coverage area. The final connection between UEs and radio stations is performed by received power levels.

V. Receiver assumptions

In order to evaluate the performance gain of the DMRS sample Matrix IRC, the following baseline have been considered.

- MMSE-MRC: This receiver considers only the covariance information from the transmitted layers containing data for the intended UE. For a single user system, with rank > 1, this means the covariance matrices from all transmitted layers are estimated. In contrast, for a multiuser system, with max rank = 1, this means only the covariance matrix from a single layer is estimated. The co-layer interference covariance is considered to be diagonal

$$\boldsymbol{G}_{k,j} = \boldsymbol{H}_{k,j}^H(\boldsymbol{H}_{k,j}\boldsymbol{H}_{k,j}^H + \mathrm{diag}(\boldsymbol{H}_{co,k,j}\boldsymbol{H}_{co,k,j}^H + \boldsymbol{C}_{nn,k,j}))^{-1}. \quad (14)$$

- MMSE-MRC with co-layer interference suppression (MMSE-MRC co-layer): This receiver assumes that effective channels of the layer intended to a UE and the co-layer (multiuser interference) can be estimated. Hence, the covariance matrices from all layers transmitted by the serving-eNB can be estimated.

$$\boldsymbol{G}_{k,j} = \boldsymbol{H}_{k,j}^H(\boldsymbol{H}_{k,j}\boldsymbol{H}_{k,j}^H + \boldsymbol{H}_{co,k,j}\boldsymbol{H}_{co,k,j}^H + \mathrm{diag}(\boldsymbol{C}_{nn,k,j}))^{-1} \quad (15)$$

  Where, $\boldsymbol{H}_{co,k,j}$ indicates the interference layers effective channel.
- MMSE-IRC ideal: This is receiver possess ideally the directional information of all external-interferers. It assumes that the full covariance matrix of the sum of all external interfering equivalent channels is ideally known, this receiver shows an upper-limit of all linear receivers MMSE principle.

$$\boldsymbol{G}_{k,j} = \boldsymbol{H}_{k,j}^H(\boldsymbol{H}_{k,j}\boldsymbol{H}_{k,j}^H + \boldsymbol{H}_{co,k,j}\boldsymbol{H}_{co,k,j}^H + \boldsymbol{C}_{nn,k,j})^{-1} \quad (16)$$

- DMRS Sample Matrix IRC, Equation (16).

$$\boldsymbol{G}_{k,j} = \boldsymbol{H}_{k,j}^H(\boldsymbol{H}_{k,j}\boldsymbol{H}_{k,j}^H + \boldsymbol{H}_{co,k,j}\boldsymbol{H}_{co,k,j}^H + \hat{\boldsymbol{C}}_{nn,k,j})^{-1} \quad (17)$$

  Where, $\hat{\boldsymbol{C}}_{nn,p} \sim \mathrm{W}_n(N_p, \boldsymbol{C}_{nn} + \boldsymbol{C}_{\epsilon\epsilon})$ [7]

The assumption on the knowledge of the diagonal of the interference covariance made for MMSE-MRC and MMSE-MRC co-layer means that the interference plus noise level per receive antenna is estimated.

VI. Simulation results

To investigate the system level performance of the DMRS sample matrix IRC we show system level results for SU-MIMO and MU-MIMO with cross-polarized antenna setting and two different traffic models: a full buffer model and a finite buffer model (FTP traffic model 1 [1]). Two network topologies are used in simulations: homogenous and heterogenous. In heterogenous topology, two configurations are used: 1 and 4b [1]. Other simulation assumptions are included in I.

In this paper we present system level results for the method of emulating the estimation error by Wishart random matrices proposed in [9]. Note that the Wishart random matrix takes the number of estimation samples as a parameter, for the DM-RS Sample matrix IRC the parameter should be the number of DM-RS samples.

A. System-level performance of IRC receivers with full buffer traffic

Table II shows simulation results with full buffer in three network topologies. It can be observed that using DM-RS IRC improves the system average and coverage performance compared to the baseline. Average sector throughput for DM-RS IRC is close to MMSE-IRC ideal performance, whereas in coverage MMSE-IRC ideal is performing clearly better than

TABLE I
SIMULATION ASSUMPTIONS.

Cellular layout	Hexagonal, 19 sites, 3 sectors per site
Channel model	ITU-R UMa for Macro, ITU-R UMi for LPN
Deployment scenario	Homogenous; Heterogenous configurations 1 and 4b according to TR 36.814 with 4 LPNs / sector
Base station antenna	4 antenna elements XP 0.5λ spacing, -45^o/45^o slants
UE antenna configuration	2 antenna elements XP 0.5λ spacing, 0^o/90^o slants
MIMO scheme	SU-MIMO w/ dyn. rank adaptation MU-MIMO: Max 2 UEs, 1 layer / UE
Traffic model	Full Buffer; Finite Buffer (FTP Model 1)
Offered load	4,6,8,10,14 Mbps / sector
Number of UEs / sector	Full buffer simulation: homogenous 10 UE heterogenous conf 1: 25 UE conf 4b: 10 UE & 5 UE s per low power node
Cell selection method	Maximum RSRP
Codebook	Rel'8 4TX codebook
MU-MIMO Precoding	Zero Forcing
TD-FD scheduler	Proportional Fair - Proportional Fair
MU-MIMO scheduler	sum Proportional Fair
# of samples for Wishart	N_{dmrs}=12
Inter-cell interference model	4Tx transmission with random rank & PMI in interfering cells
Channel estimation for demod	Realistic (via AVI tables)
Channel estimation for CSI	CSI-RS Based
Reference symbol overhead	Legacy overhead: 2Tx Rel'8 CRS DRS overhead: 12 RE / PRB
Note	Other parameters according to TR 36.819

DM-RS IRC. Results show that the cell edge UEs benefit from the reduced interference and improved SINR more than average UEs in the cell. This is an natural observation as the cell edge users experience the external interference stronger than the center cell users. In multiuser transmission, the coverage gains are much higher than in single user transmission. This is probably due increased pairing probability, which is a result of the increased SINR.

Advanced receivers clearly improve the system performance with full buffer traffic. Cell edge performance benefits more from the interference suppression, and depending on network topology we get 4.2% - 11.8% coverage gains in single user MIMO.

B. *System-level performance of IRC receivers with finite buffer traffic*

Table III shows simulation results with finite buffer traffic using different offered loads in homogeneous topology. Similar behavior can be observed with finite buffer traffic as with full buffer traffic. We get moderate system average gains with both IRC receivers, but the coverage is clearly improved. As the offered load increases, i.e. call arrival rate increases, the inter-cell interference also increases. In high load cases UEs benefit from interference suppression, which is seen as a gain in coverage performance. With high loads we get 15% - 20% gains with DMRS-IRC in single user transmission.

In multiuser transmission, high performance gains are achieved compared both to baseline MMSE-MRC receiver and to MMSE-MRC co-layer receiver. The improved SINR leads to higher pairing probability and to higher number of scheduled UEs on average.

VII. CONCLUSION

In this paper we have studied the performance of IRC receivers which estimate the inferference covariance from the DM-RS symbols on system level using different network topologies. It is observed that the MMSE-IRC achieves average and cell edge gains in all evaluated scenarios. Results in Table II and Table III confirm the link level investigation [9] which shows also reliable performance of DM-RS sample based MMSE.

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TABLE II

SIMULATION RESULTS FOR FULL BUFFER

4x2 SU-MIMO XP Full Buffer

Average sector throughput in [Mbps]	MMSE-MRC	MMSE-MRC co-layer	DMRS-Wishart IRC	MMSE-IRC Ideal
Homogenous	-	23.84 (0)	24.13 (+1.2%)	24.30 (+1.9%)
Heterogenous Conf 1	-	25.88 (0)	26.24 (+1.4%)	26.35 (+1.8%)
Heterogenous Conf 4b	-	31.46 (0)	31.76 (+1.0%)	31.84 (+1.2%)
Coverage in [bits/Hz/UE]				
Homogenous	-	0.072 (0)	0.075 (+4.2%)	0.078 (+8.3%)
Heterogenous Conf 1	-	0.064 (0)	0.068 (+6.3%)	0.070 (+9.4%)
Heterogenous Conf 4b	-	0.085 (0)	0.095 (+11.8%)	0.097 (+14.1%)

4x2 MU-MIMO XP Full Buffer

Average sector throughput in [Mbps]	MMSE-MRC	MMSE-MRC co-layer	DMRS-Wishart IRC	MMSE-IRC Ideal
Homogenous	19.15 (0)	24.46 (+24.7%)	24.78 (+29.4%)	24.99 (+30.5%)
Heterogenous Conf 1	19.12 (0)	21.70 (+13.5%)	22.64 (+18.4%)	22.87 (+19.6%)
Heterogenous Conf 4b	23.44 (0)	27.91 (+19.1%)	28.62 (+22.1%)	28.78 (+22.8%)
Coverage in [bits/Hz/UE]				
Homogenous	0.074 (0)	0.077 (+4.1%)	0.084 (+13.5%)	0.085 (+14.9%)
Heterogenous Conf 1	0.063 (0)	0.069 (+9.5%)	0.075 (+19.0%)	0.077 (+22.2%)
Heterogenous Conf 4b	0.087 (0)	0.093 (+6.9%)	0.101 (+16.1%)	0.105 (+20.7%)

TABLE III

SIMULATION RESULTS FOR FINITE BUFFER WITH DIFFERENT OFFERED LOADS

4x2 SU-MIMO XP Finite Buffer

Average UE throughput in [bits/Hz/UE]	MMSE-MRC	MMSE-MRC co-layer	DMRS-Wishart IRC	MMSE-IRC Ideal
4 Mbps	-	3.632 (0)	3.644 (0.3%)	3.655 (0.6%)
6 Mbps	-	3.146 (0)	3.192 (1.5%)	3.202 (1.8%)
8 Mbps	-	2.557 (0)	2.608 (2.0%)	2.627 (2.7%)
10 Mbps	-	2.000 (0)	2.090 (2.1%)	2.126 (2.1%)
14 Mbps	-	1.022 (0)	1.167 (1.2%)	1.201 (1.2%)
Coverage in [bits/Hz/UE]				
4 Mbps	-	1.436 (0)	1.462 (1.8%)	1.472 (2.5%)
6 Mbps	-	1.061 (0)	1.129 (6.4%)	1.145 (7.9%)
8 Mbps	-	0.673 (0)	0.741 (10.1%)	0.756 (12.3%)
10 Mbps	-	0.456 (0)	0.524 (14.9%)	0.542 (18.6%)
14 Mbps	-	0.180 (0)	0.216 (20.0%)	0.227 (26.1%)

4x2 MU-MIMO XP Finite Buffer

Average UE throughput in [bits/Hz/UE]	MMSE-MRC	MMSE-MRC co-layer	DMRS-Wishart IRC	MMSE-IRC Ideal
4 Mbps	2.181 (0)	2.305 (5.7%)	2.366 (8.5%)	2.387 (9.5%)
6 Mbps	1.856 (0)	2.033 (9.5%)	2.126 (14.5%)	2.156 (16.6%)
8 Mbps	1.485 (0)	1.700 (14.5%)	1.810 (21.9%)	1.841 (24.0%)
10 Mbps	1.197 (0)	1.420 (18.6%)	1.543 (28.9%)	1.579 (31.9%)
14 Mbps	0.620 (0)	0.817 (31.8%)	0.946 (52.6%)	0.991 (59.8%)
Coverage in [bits/Hz/UE]				
4 Mbps	0.977 (0)	1.148 (17.5%)	1.249 (27.8%)	1.289 (31.9%)
6 Mbps	0.642 (0)	0.816 (27.1%)	0.915 (42.5%)	0.939 (46.3%)
8 Mbps	0.408 (0)	0.553 (35.5%)	0.631 (56.7%)	0.660 (61.8%)
10 Mbps	0.288 (0)	0.375 (30.2%)	0.443 (53.8%)	0.197 (65.3%)
14 Mbps	0.126 (0)	0.164 (30.2%)	0.197 (56.4%)	0.211 (67.5%)