Effect of Imperfect Channel Estimation on Spectrum Sharing Between the Massive MIMO System and MIMO Radar

Ture Peken, Mohammed Hirzallah, and Tamal Bose
Dept. of Electrical and Computer Engineering
University of Arizona
Tucson, Arizona 85719
Email: {turepeken, hirzallah, tbose}@email.arizona.edu

***Abstract*—Massive MIMO has been introduced to improve the spectral efficiency. With massive MIMO, the systems having a much larger number of antennas per site than today are considered. Massive MIMO has several benefits which makes this technology an active research area for next generation wireless systems such as 5G. Perfect channel estimation becomes a big challenge since the maximum number of orthogonal training sequences for channel estimation are upper bounded by either the channel coherence time or the interference from the users in neighboring cells. This paper presents the problem of spectrum sharing between a communication system with a massive MIMO capability and MIMO radar. If the interference channels are assumed to be perfectly estimated by the communication users and fed back to the radar without an error, the interference at the communication receivers can be eliminated. We study how the results would change in spectrum sharing between the massive MIMO system and MIMO radar when the interference channels are estimated with linear squares (LS) and linear minimum mean squared error (LMMSE) channel estimation techniques. According to our simulation results, we get worse performance with LMMSE but nearly same performance with LS compared with using the perfect channel. Therefore, we can eliminate interference from MIMO radar even if the channel is not perfectly estimated by LS channel estimation.**

Keywords—Massive MIMO, 5G, Channel Estimation, Spectrum Sharing, MIMO Radar, LS, LMMSE

I. Introduction

Today, Multiple Input Multiple Output (MIMO) is the integral technology in several WiFi and cellular systems. Implementing MIMO systems with large antenna arrays have drawn interest recently since this technology provides significant benefits. These benefits make massive MIMO an important research area for next generation wireless systems.

Massive MIMO can increase the capacity 10 times or more and simultaneously improve the radiated energy efficiency on the order of 100 times [1]. The capacity increase results from the aggressive spatial multiplexing used in massive MIMO. The fundamental principle that makes the dramatic increase in energy efficiency possible is that with a large number of antennas, energy can be focused with extreme sharpness into small regions in space [2]. Moreover, Massive MIMO can be built with inexpensive, low-power components. By using extremely low power at the each antenna unit, the energy consumption of the cellular base units can be decreased significantly. Furthermore, massive MIMO can be built very robust compared with typical MIMO systems in terms of tolerating more failure.

However, massive MIMO requires various challenges. One of the most important challenges is the pilot contamination which is the effect of reusing pilots from one cell to another and the associated negative consequences [2]. There is also a challenge of low-cost hardware because building hundreds of RF chains, converters, and so forth, will require economy of scale in manufacturing comparable to what we have seen for mobile handsets [2]. Fast and distributed coherent signal processing is required if massive MIMO arrays generate vast amounts of baseband data that must be processed in real time. In reality, massive MIMO must be built with low-cost components [2]. This is likely to mean that hardware imperfections are larger. Moreover, it is necessary to have channel models that reflect the true behavior of the radio channel to facilitate a realistic performance assessment of massive MIMO systems [2].

We start from well known channel estimation methods which are linear squares (LS) and linear minimum mean squared error (LMMSE). We apply this channel estimation methods to estimate the channel of the massive MIMO system. Then, we propose a spectrum sharing between a massive MIMO system and a MIMO radar. We study how the interference at the massive MIMO system would have been affected when the interference channels are estimated with linear squares (LS) and linear minimum mean squared error (LMMSE) channel estimation techniques. Simulations show that when LMMSE is used for channel estimation interference cannot be eliminated as good as in the case that we know the channel perfectly. On the other hand, interference can be eliminated well if LS is used for channel estimation. The main contribution of this paper is that it shows imperfect channel knowledge still allows to eliminate the interference from MIMO radar.

The rest of the paper is organized as follows. In Section II, we summarize the related work on channel estimation problem of massive MIMO and MIMO radar. In Section III, we give a brief introduction on our system model. In Section IV, we describe the channel estimation methods we consider in our system. Then in Section V we propose a spectrum sharing between a massive MIMO system and a MIMO radar in which LS and LMMSE channel estimation methods are applied to estimate the interference channels. In Section VI, we give our simulation results which are obtained in MATLAB. Finally we summarize our work in Section VII.

II. RELATED WORK

So far in the literature, both blind and non-blind channel estimation techniques have been proposed to solve the channel estimation problem in massive MIMO and to improve the performance of massive MIMO systems. Compressive sensing based channel estimation, polynomial expansion based channel estimation, composite channel estimation, minimum mean squared error (MMSE) channel estimation, linear squares (LS) and multi-dimension Wiener filter channel estimation have been proposed [3]-[5].

Spectrum sharing between communication systems and radar has been studied [6]-[7]. A communication system modeled as MIMO IFC which coexists and shares the spectrum with MIMO radar, i.e., radar with multiple antennas at both transmit and receive mode is considered [8]. It is shown that by projecting the radar signal onto an expanded subspace, which encompasses the aforementioned null space, the radar performance will be improved while the interference at the communication users will increase. Two approaches are proposed for this problem. First one is to increase the number of radar transmit antennas which will incur additional burden on the radar side. The second one is to increase the nullity of $\tilde{H}$ by reducing the requested degrees of freedom of one or several of the communication user. It is shown in [9] that while the precoder null steers the radar interference to communication users it degrades the radar performance by introducing correlation to the probing signals and this performance loss can be compensated for by increasing the number of radar antennas.

III. SYSTEM MODEL

We consider a communication system with massive MIMO capability and operate in the geographical neighborhood of a collocated MIMO radar (See Fig. 1).

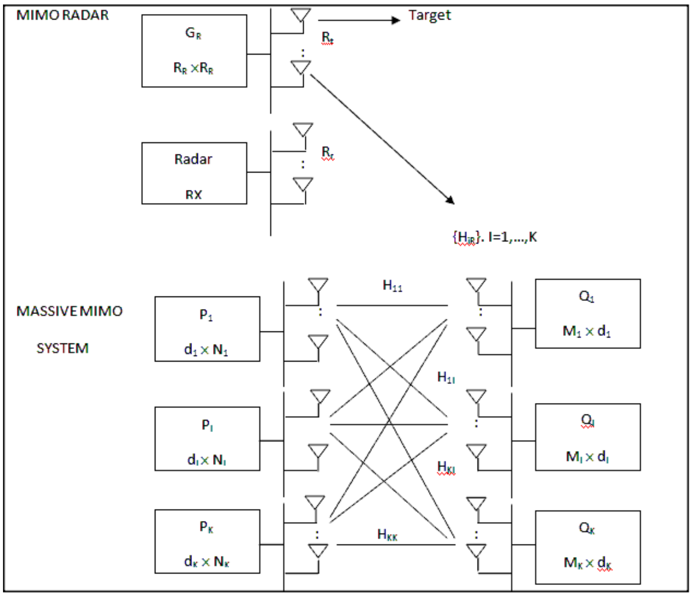

Fig. 1: System Model

The massive MIMO system and the radar system share the spectrum. Since high-power radio frequency (RF) pulses with low duty-cycle are sent from radars, the massive MIMO system is negatively affected by the interference. The massive MIMO system also causes interference to the MIMO radar.

Even though, the interference caused by the massive MIMO system to the MIMO radar needs to be eliminated, we study the interference from the radar to the communication system in this paper. The system and channel models used in this work for the massive MIMO and the MIMO radar are explained in the following.

A. Massive MIMO System Model

The massive MIMO system consists of K transmitter and receiver pairs. The *k*th transmitter and receiver pair have N_k and M_k antennas where $N_k >> M_k$ respectively. The signal transmitted from *k*-th transmitter to *k*-th receiver is given by,

$$Y_k = X_k H_{kk} + W_k \tag{1}$$

where X_k is the $1 \times N_k$ transmitted symbol vector, H_{kk} is the $N_k \times M_k$ MIMO channel vector, and W_k is a zero-mean independent and identically distributed (i.i.d.) complex Gaussian noise with covariance σ_W^2.

The transmitter *k* and receiver *k* communicates using d_k independent streams of information which is equal to the degrees of freedom (DoF). DoF of the channel between the transmitter *k* and receiver *k* is determined by the minimum of the numbers of transmitter and receiver antennas (i.e., $d_k \leq \min\{ N_k, M_k \}$ [7]. The transmitter *k* transmits the d_k information messages over N_k transmit antennas which employs a $d_k \times N_k$ precoding matrix (denoted by P_k in Fig. 1). The receiver *k* uses a $M_k \times d_k$ post-processing matrix (denoted by Q_k in Fig. 1). The pre-coding and post-processing matrices employed by the communication users are determined by using the SU-MIMO based strategy.

B. MIMO Radar Model

The MIMO radar has R_t transmit and R_r receive antennas. Denoting the R_t - dimensional radar transmitted signals as $\{x(\mathrm{n})\}_{n=1}^{N}$ the spatial covariance matrix is [9]

$$R_s = \frac{1}{N}\sum_{n=1}^{N} x(n)x^*(n) = \begin{bmatrix} 1 & \varphi_{12} & \dots & \varphi_{1R_r} \\ \varphi_{21} & 1 & \dots & \varphi_{1R_r} \\ \vdots & \vdots & \vdots & \vdots \\ \varphi_{R_r 1} & \varphi_{R_r 2} & \dots & 1 \end{bmatrix} \quad (2)$$

where n is the time index, φ_{ij} is the correlation coefficient between ith and jth signals and N is the time duration.

Let's consider a single target at direction θ. The received signal by kth receive element is [9]

$$y_k(n) = \delta\sum_{i=1}^{R_r} G_{ik} x_i(n) + w_k(n)\,,\ k = 1, \dots, R_t \quad (3)$$

where G_{ik} is the phase delay, δ is the complex path loss and $w_k(n)$ is the additive noise received at the kth receive element. The phase delay $G_{ik}(\theta)$ is formulated as [9]

$$G_{ik}(\theta) = \exp(-jw_c(\tau_{t,i}(\theta) + \tau_{r,k}(\theta))) = \alpha_{t,i}(\theta)\alpha_{r,k}(\theta) \quad (4)$$

where

$$\alpha_{t,i}(\theta) = \exp(-jw_c\tau_{t,i}(\theta)), \quad (5)$$

$$\alpha_{r,k}(\theta) = \exp(-jw_c\tau_{r,k}(\theta)).$$

In (5), $\tau_{t,i}(\theta)$ and $\tau_{r,k}(\theta)$ are the delays between ith transmit element and target and target and kth receive element, respectively.

C. Channel Model

Unlike conventional MIMO with small and compact antenna arrays, massive MIMO with a large number of antennas can have antenna arrays that span tens to hundreds of wavelengths in space. Over this type of large arrays, the propagation channel cannot be seen as wide-sense stationary (WSS) as is usually the case for conventional small MIMO. In massive MIMO, when we resolve the propagation channel into scatterers, we observe that some scatterers are not visible over the whole array, and for scatterers being visible over the whole array, their power contribution may vary considerably [10].

The COST 2100 MIMO channel model is a geometry-based stochastic channel model (GSCM) that can reproduce the stochastic properties of MIMO channels over time, frequency, and space [11]. The COST 2100 is currently the most sophisticated GSCM. It characterizes and models the radio channel in delay and directional domains, through the geometric distribution of scatterers, or clusters, i.e., groups of multipath components (MPCs), in the propagation environment which is the case in massive MIMO [11]. Therefore, channel between the massive MIMO system and MIMO radar is modeled with COST 2100 channel model in this paper.

IV. CHANNEL ESTIMATION

Clever channel estimation algorithms may mitigate or eliminate the effects of pilot contamination. Pilot signals based, semi-blind and blind channel estimation methods have been proposed for the conventional MIMO systems so far.

LS and LMMSE are the most typical pilot signals based channel estimation methods that are implemented in conventional MIMO systems. Therefore, we focus on these channel estimation methods.

A. Linear Squares (LS) Channel Estimation

The goal of the least square channel estimator is to minimize the squared distance between the received signal and the original signal.

The received pilot signal can be written as [12],

$$Y_p = X_p H_p + W_p \quad (6)$$

where X_p is the $1\times N_t$ transmitted pilot symbol vector, H_p is the $N_t \times N_r$ MIMO channel vector seen by the pilot symbol vector, and W_p is a zero-mean independent and identically distributed (i.i.d.) complex Gaussian noise with covariance σ_W^2.

The least square estimates of the channel at the pilot subcarriers can be obtained by the following equation,

$$\hat{H}_p = (X_p)^{-1} Y_p \quad (7)$$

B. Linear Minimum Mean Squared Error (LMMSE) Channel Estimation

The LMMSE based channel estimator utilizes the second-order statistics of the channel conditions to minimize the mean-square error of the channel estimates. LMMSE estimate of the channel at the pilot subcarriers is given as [12]

$$H_p^{LMMSE} = R_{HH_p}(R_{H_pH_p} + \sigma_W^2 (X_p X_p{}^H)^{-1})\hat{H}_p^{LS} \quad (8)$$

where $R_{H_pH_p}$ represents the cross correlation matrix between all subcarriers and the subcarriers with reference signals and $R_{H_pH_p}$ represents the autocorrelation matrix of the subcarriers with reference signals.

V. THE PROPOSED SPECTRUM SHARING MODEL BETWEEN THE MASSIVE MIMO SYSTEM AND THE MIMO RADAR

If the interference from a MIMO radar to a massive MIMO system increases, target localization performance decreases. In this paper, we allow some interference at the massive MIMO system to enhance the MIMO radar performance.

We consider the set C = {1, 2, …, K} as the set of massive MIMO transmitter-receiver pairs. The interference from radar to receiver k of massive MIMO system across its degrees of freedom after post-processing is given as [9]

$$s_R = G_R \tilde{s}_R \,,\; k \in C \tag{9}$$

where s_R is the radar transmitted signal vector. We denote the radar probing signals by $\tilde{s}_R$ which are transmitted through a spatial precoder. We denote this spatial precoder as G_R which is shown in Fig. 1. The radar transmitted signal vector is given as $s_R = G_R \tilde{s}_R$ [9]. We increase interference at the massive MIMO system by choosing the precoder as projection matrix onto an expanded subspace.

The nullity of the matrix $\tilde{H}$ is $R_t - \sum_{k=1}^{K} d_k$ [9]. One way of increasing the nullity of $\tilde{H}$ is to increase the number of radar transmit antennas. However, it will cause an additional overhead on the radar side. It is also possible to increase the nullity of $\tilde{H}$ by decreasing the degrees of freedom of communication users. The communication user k takes into account only the d_k largest singular values of H_{kk}. By only considering the largest singular values we can increase the nullity of $\tilde{H}$. Consequently, we can improve the radar performance.

VI. NUMERICAL AND SIMULATION RESULTS

First of all, we investigate the performance of LS and LMMSE channel estimation techniques on massive MIMO communication system. The cost 2100 channel model is considered. A dipole antenna array is implemented. In Fig. 2, the MSE of LS and LMMSE estimates of the channel when the number of transmit and receive antennas at the massive MIMO communication system are 50 and 10 respectively are shown for the different SNR values. It can be seen from the figure that LMMSE achieves significantly better performance than LS as expected. The MSE of LMMSE is less than 1% of the MSE of LS.

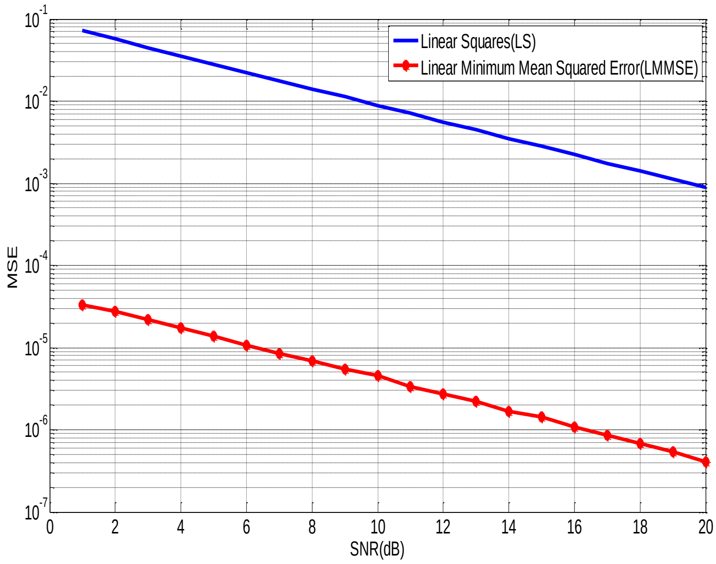

Fig. 2: MSE of LS and LMMSE vs SNR (N_t = 50, N_r = 10)

In Fig. 3, we consider the interference performance in terms of the metric $\|Q_1 H_{1R} G_R\|_F$ .We can see the interference levels from MIMO radar to massive MIMO system for perfect channel, LS and LMMSE channel estimates when SNR equals to 20 dB. The diThe number of transmit and receive antennas at the massive MIMO communication system are 50 and 10 respectively. The MIMO radar have 10 transmit and receive antennas. The distance from radar array to target equals to 5000 m and operation frequency of the channel is 3.5 GHz. We assume the target is at direction of 0° and the radar inter-element spacing is 3λ/4. We can observe that the interference from MIMO radar to massive MIMO is almost same when LS channel estimation is used and channel is known perfectly. On the other hand, interference level becomes worse when LMMSE channel estimation method is used. In this case, interference level becomes nearly two times of the case when LS channel estimation is used.

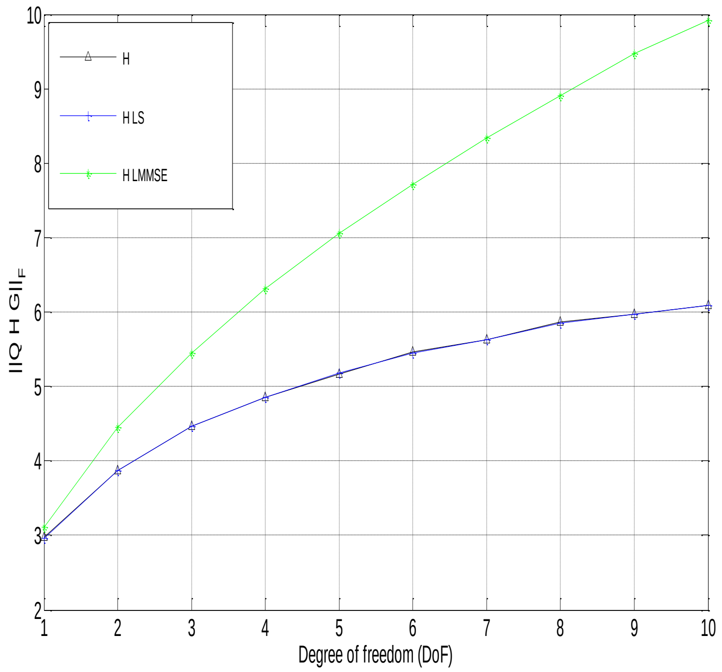

Fig. 3: Interference Levels for Perfect Channel, LS Channel Estimate and LMMSE Channel Estimate (N_t = 50, N_r = 10, R_t = 10, R_r = 10)

VII. CONCLUSIONS

In this paper, we study the effects of imperfect channel estimation on interference elimination between MIMO radar and massive MIMO system. We compare the performance of LS and LMMSE channel estimation methods when they are applied to massive MIMO system. We show that LMMSE has better performance than LS. We assume non-zero interference at massive MIMO system to improve the target estimation of MIMO radar. In our simulation which shows the interference levels from MIMO radar to massive MIMO, we observe that the interference level when LS channel estimation is used and the channel is perfectly known are almost same. This means that interference elimination from MIMO radar to massive MIMO can be done with LS channel estimation as good as in the case channel is perfectly known. However, LMMSE channel estimation decreases the performance of interference elimination. In the future, we aim to study other channel estimation methods to compare their performances with LS channel estimation.

REFERENCES

[1] V. Jungnickel, K. Manolakis, W. Zirwas, B. Panzner, V. Braun, M. Lossow, R. Apelfröjd, M. Sternad, T. Svensson, “The role of small cells, coordinated multi-point and massive MIMO in 5G”, IEEE Communications Magazine, vol. 52, no. 5, May 2014.

[2] Larsson, Erik G., et al. ”Massive MIMO for Next Generation Wireless Systems.” arXiv preprint arXiv:1304.6690 (2014).

[3] Nguyen, Sinh Le Hong; Ghrayeb, Ali, "Compressive sensing-based channel estimation for massive multiuser MIMO systems," *Wireless Communications and Networking Conference (WCNC), 2013 IEEE* , vol., no., pp.2890,2895, 7-10 April 2013.

[4] Ko-Feng Chen; Yen-Cheng Liu; Su, Y.T., "On composite channel estimation in wireless massive MIMO systems," *Globecom Workshops (GC Wkshps), 2013 IEEE* , vol., no., pp.135,139, 9-13 Dec. 2013.

[5] Shariati, N.; Bjornson, E.; Bengtsson, M.; Debbah, M., "Low-complexity channel estimation in large-scale MIMO using polynomial expansion," *Personal Indoor and Mobile Radio Communications (PIMRC), 2013 IEEE 24th International Symposium on* , vol., no., pp.1157,1162, 8-11 Sept. 2013.

[6] Communication Signals in the 2.6 GHz Band and Maritime Radar, Technical Assessment of Interference, Ofcom Technica Report, 2011.

[7] Radar/Wimax Network Interference Mitigation Best Practices, WiMAX Forum White Paper, WMF-M14-002-v01

[8] Babaei, A; Tranter, W.H.; Bose, T., "A practical precoding approach for radar/communications spectrum sharing," Cognitive Radio Oriented Wireless Networks (CROWNCOM), 2013 8th International Conference on , vol., no., pp.13,18, 8-10 July 2013.

[9] Babaei, A.; Tranter, W.H.; Bose, T., "A nullspace-based precoder with subspace expansion for radar/communications coexistence," *Global Communications Conference (GLOBECOM), 2013 IEEE* , vol., no., pp.3487,3492, 9-13 Dec. 2013.

[10] X. Gao, F. Tufvesson, and O. Edfors, “Massive MIMO channels - Measurements and models,” 47th Annual Asilomar Conference on Signals, Systems, and Computers, Nov. 2013.

[11] J. Poutanen, Geometry-based radio channel modeling: propagation analysis and concept development. Ph.D. dissertation, Aalto University (2011).

[12] O. Longoria-Gandara and R. Parra-Michel. “Estimation of Correlated MIMO Channels using Partial Channel State Information and DPSS”, IEEE Transactions on Wireless Communications, vol. 10, no. 11, pp. 3711-3719, Nov. 2011.