Large Scale MIMO performance analysis over Cascaded $\alpha$-$\mu$ MIMO channel for M2M Communication

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Abstract— Large scale multiple-input multiple-output (LS-MIMO) is a relatively new concept which can be used to increase the data rate and throughput of wireless networks. In this paper, performance analysis for LS-MIMO has been carried out for mobile-to-mobile (M2M) communication network over N-\(\alpha\)-\(\mu\) fading channels. The orthogonality condition for LS-MIMO over cascaded independent and identically distributed (iid) \(\alpha\)-\(\mu\) MIMO fading channels has been verified extensively. Using this property, we have analyzed for the first time LS-MIMO M2M communication over cascaded iid \(\alpha\)-\(\mu\) MIMO fading channels. The analytical results have been verified through Monte Carlo simulations.

Keywords — LS-MIMO, M2M communication, N-\(\alpha\)-\(\mu\) channel, orthogonality conditions.

I. INTRODUCTION

LS-MIMO or Massive MIMO [1], [2] holds the promise to offer higher data rates and good quality of service in M2M communication without increasing the power consumption or bandwidth requirements. In M2M communication, scatterers are located both at the transmitter and receiver ends while in cellular communication, base station is free from local scatterers due to its greater elevation. Due to the presence of multiple scattering groups, conventional channel models fail for M2M communication. Many channel models are available in past literature ranging from 2D models to 3D models [3]-[6]. But a majority of them consider only a single or double scattering group, whereas in reality multiple scattering groups exist. So cascaded model is more suitable for this purpose.

The \(\alpha\)-\(\mu\) fading model is a generalized physical fading model comprising of propagation of clusters of multipath waves in a non–homogeneous environment [7]. It is expressed in terms of two parameters generally- \(\alpha\) and \(\mu\). \(\alpha\) depicts the non-linearity factor of the propagation medium whereas \(\mu\) represents the number of multipath clusters.

In this paper, the channel vectors of the cascaded \(\alpha\)-\(\mu\) channel have been found to be pairwise orthogonal when the number of antennas becomes very large. It decouples the signals from each transmit antenna at the receiver which simplifies the ML decoder significantly. The symbol error rate (SER) of LS-MIMO over cascaded \(\alpha\)-\(\mu\) MIMO channel for M2M communication has been evaluated analytically which has been validated by Monte Carlo simulations. The expressions for probability distribution function (PDF) and cumulative distribution function (CDF) of cascaded \(\alpha\)-\(\mu\) channel have been shown in [8].

II. LS-MIMO M2M COMMUNICATION MODEL

The orthogonality conditions which need to be satisfied for LS-MIMO are:

\[
\begin{align*}
\mathbf{H}^H \mathbf{H} \xrightarrow[N_T \to \infty]{N_R} \mathbf{I}_{N_T} \\
\mathbf{H} \mathbf{H}^H \xrightarrow[N_T \to \infty]{N_R} \mathbf{I}_{N_R}
\end{align*}
\]

Here \(\mathbf{H}\) represents the cascaded iid \(\alpha\)-\(\mu\) MIMO channel matrix whereas \(N_T\) and \(N_R\) are the number of transmit and receive antennas respectively. These conditions are obtained using law of large numbers and absolute convergence theorem as shown in [2]. If the above two conditions are satisfied then the decoding complexity can be reduced as the system equation

\[
y = \mathbf{H}\mathbf{x} + \mathbf{n}
\]

can be reduced to a simpler form by means of precoding. If we multiply our input matrix, \(\mathbf{x}\) by \(\mathbf{H}^H\) in the precoder, then the input matrix becomes \(\mathbf{H}^H\mathbf{x}\). By using (5) we can write

\[
y = \mathbf{H}\mathbf{H}^H\mathbf{x} + \mathbf{n} = N_T \mathbf{I}_{N_R}\mathbf{x} + \mathbf{n} = N_T \mathbf{x} + \mathbf{n}
\]

Thus we see that the complexity of the equation has decreased to that of a SISO model. We know that the decoding complexity in case of maximum likelihood (ML) decoding increases exponentially as \(M^{N_T}\) with the number of transmit antennas and constellation size \((M)\). For LS-MIMO M2M communication case the computational complexity will tend to be infinity as \(N_T\) is very large. Hence this reduction technique using orthogonality condition reduces the computational complexity to \(N_R \times M\) (since \(y\) is a \(N_R \times 1\) vector) which is of the linear form.
III. RESULTS AND ANALYSIS

We have verified the orthogonality conditions for cascaded $\alpha$-$\mu$ fading channels (considering iid case). The effect of various parameters like $\alpha_1$ (signifying $\alpha$ for first channel of the cascaded channel), $\mu$, number of cascaded components ($N$), $N_T$ and $N_R$ have been studied and put forth in this paper. For verification of the above conditions, mean square error has been taken as the performance metric.

The effect of the variation in the number of cascaded components ($N$), fading parameter $\mu$ and $\alpha_1$ has been shown in Fig. 1. For smaller number of receive antennas, higher $N$ values give more error, but for higher number of receive antennas, the variation in $N$ does not have any influence on the resultant error. The error also decreases with an increase in $N_R$. It can be observed that the difference in fading parameter $\mu$ does not impact the error much. For larger values of $\alpha_1$, the errors are larger, indicating optimum value of $\alpha_1$ is 2. Fig. 2 shows the influence of variation in the number of transmit antennas ($N_T$). When the number of receiving antennas are large, then the variation in $N_T$ does not have any effect on the error performance. The other parameters are kept fixed as $\alpha_1=2$, $\mu = \{2, 2\}$, $N=2$. Similar analysis has been done for large number of transmit antennas to verify the second orthogonality condition. The variation of the different parameters have a similar influence on the orthogonality condition for LS-MIMO M2M model. The results have been skipped due to lack of space. These results prove that irrespective of the channel conditions and fading severity, the orthogonality condition is satisfied for large number of antennas.

![Fig. 1. Effect of variation of different parameters on the orthogonality condition for cascaded iid $\alpha$-$\mu$ LS-MIMO channel](image1)

![Fig. 2. Effect of the number of transmit antennas, $N_T$ on the orthogonality condition for cascaded iid $\alpha$-$\mu$ LS-MIMO channel](image2)

The error performance analysis of LS-MIMO system has been done for binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), 16-quadrature amplitude modulation (QAM) and 16- phase shift keying (PSK) modulation schemes, and the analytical results have been verified by means of Monte Carlo simulations. It has been observed that the SER value decreases with an increase in signal to noise ratio (SNR) as expected. It can be seen from Fig. 3 that the simulation and analytical results match thereby confirming the validity of our approach. For SER analysis we have considered cascaded $\alpha$-$\mu$ channel and $N_T=10000$, $N_R=5$, $\alpha_1=2$, $\mu = \{2, 2\}$, $N=3$.

IV. CONCLUSION

In this paper, we have analyzed SER of LS-MIMO M2M communication over cascaded $\alpha$-$\mu$ fading channels. It has been verified using Monte Carlo simulation results. The analysis is simplified by applying the orthogonality condition of the cascaded iid $\alpha$-$\mu$ MIMO fading channels which is extensively verified. It has been also observed that this orthogonality condition is satisfied for cascaded $\alpha$-$\mu$ Kronecker MIMO channels for correlation coefficients $0 \leq \rho \leq 0.2$. This model can also be used for vehicle to fixed infrastructure (V2I) communication.

REFERENCES