An S-Parameter Based Modeling of a MIMO Channel Using Half-wave Dipole Antennas

Babu Sena Paul
Dept. of ECE
Indian Institute of Technology Guwahati
Guwahati 781039 India
babusena_paul@yahoo.com

R.Bhattacharjee
Dept. of ECE
Indian Institute of Technology Guwahati
Guwahati 781039 India
ratnajit@iitg.ernet.in

Abstract

In this paper we have introduced an S-parameter based approach for computation of MIMO channel matrix where the entire channel model is developed using half-wave dipoles. For the model under consideration, suitably terminated dipole antennas represent scatterers with different scattering coefficients. We first validate our approach by comparing results obtained by our method with the results already reported in literature for similar model evaluated using different method. Using our proposed method, we determine the variation of capacity of a MIMO link as function of separation of antennas in the mobile station for a macro-cellular scenario where the scattering environment is represented by a ring of scatterers surrounding the mobile station. We further extend our approach for modeling a dual polarized MIMO system. Simulation results on capacity match with the expected results that further corroborate the effectiveness of our approach.

Keywords-MIMO; Channel;S-parameter; Dipole antenna.

1. Introduction

Multiple Input Multiple Output (MIMO) wireless systems have demonstrated potential for increased capacity in rich multipath environments. For such systems when the channel matrix coefficients are random variables, linear increase in capacity with increase in number of antennas is possible. The capacity of MIMO system depend on the Signal to noise ratio (SNR) and correlation properties among the channel transfer functions of different pairs of transmit and receive antennas. Channel modeling plays an important role in design and performance evaluation of MIMO communication system. Among various channel modeling techniques, the geometrical channel model with a ring of scatterer around the mobile device has been extensively used for narrow band macro cellular scenarios.

In recent times understanding of MIMO channel behavior and its modeling from electromagnetic perspective has found attention from a number of researchers [1] [2]. Such modeling can take into account the effect of coupling between antenna elements. A MIMO channel modeling purely from microwave perspective by using half wave dipoles representing the transmitter and the receiver arrays, as well as the scatterers have been reported in [1]. In this modeling the impedance matrix $\mathbf{Z}$ for the MIMO system are computed. Once $\mathbf{Z}$ is computed the channel matrix $\mathbf{H}$ is determined by computing the voltage ratio between a pair of transmitter and receiver antennas with proper load condition applied to the unexcited transmitter and receiver antennas and the scatterers. When the dipole representing scatterers are short circuited, they act as perfect reflector. The unexcited transmitter and receiver antennas are kept matched terminated. By changing the termination of the dipole antennas representing scatterers different scattering coefficients can be generated to model appropriate scenarios. In [3], [4] it has been stated that use of scattering parameter (S-parameter) matrices is a more natural representation of the scattering environment for capacity formulation.

In this paper we present an S-parameter based modeling approach for computing MIMO channel capacities by representing the MIMO system as given in [1]. We employ a method of moment based package WIREMOM [5], to generate the S matrix for the MIMO system. From the S matrix the channel matrix $\mathbf{H}$ is determined. The details are given in next section.

The rest of the paper is organized as follows. Section 2 provides the system modeling using S-parameter approach. Section 3 discusses the different models and issues related to one ring model and MIMO capacity with polarization diversity. Section 4 shows the results obtained by the proposed approach and how they compare with the results published in the literature. Conclusion is drawn in Section 5.

2. S-parameter based modeling Method

Dipole Antenna as Scatterers

In MIMO system modeling, the receive and /or transmit antenna arrays are considered to be surrounded by scatterers which are responsible for producing multipath environment. Such multipath richness is exploited by MIMO systems in producing spatial diversity. An antenna depending upon its termination can produce different degree of scattering. Replacing physical scatterers by suitably terminated antenna in developing MIMO channel model was proposed in [1]. In our modeling of MIMO system we adopt the same approach in modeling scatterers. A MIMO channel consisting of n_T transmit antennas and n_R receive antennas can be represented by a $n_R \times n_T$ matrix $\mathbf{H}$ [6].

Computation of channel matrix using S-parameters

As discussed, in the MIMO model under consideration, the entire system is modeled using half-wave dipole antennas. Each dipole antenna corresponds to one port. If there are n_T transmit antennas, n_R receive antennas and n scattering antennas, then the $\mathbf{S}$ matrix is a $(n_T + n_R + n) \text{x} (n_T + n_R + n)$ matrix. We utilize WIREMOM to compute the $\mathbf{S}$-matrix. The parameters like the distance between the base station (BS) and the mobile station (MS), the radius of the ring, the inter element separation at the base station and the mobile station, number of scatterers, number of BS and MS antennas, frequency of operation, dipole length are first set. The co-ordinates of the tips (ends) of the BS, MS and the scattering antennas are found out. These coordinates are supplied to WIREMOM package to generate the wire structure of the model and the $\mathbf{S}$-matrix is computed. Once the $\mathbf{S}$-matrix is obtained from the WIREMOM, we change the terminating condition for the scatterer dipoles and reduce the scattering matrix to a $(n_T + n_R) \text{x} (n_T + n_R)$ matrix. The new scattering matrix obtained can be written of the form [3]:

$$\begin{bmatrix} \mathbf{b}_{TX} \\ \mathbf{b}_{RX} \end{bmatrix} = \begin{bmatrix} \mathbf{S}_{TX} & \mathbf{S}_{TX,RX} \\ \mathbf{S}_{RX,TX} & \mathbf{S}_{RX} \end{bmatrix} \begin{bmatrix} \mathbf{a}_{TX} \\ \mathbf{a}_{RX} \end{bmatrix} \qquad (1)$$

where $\mathbf{a}$ and $\mathbf{b}$ represents the incoming and outgoing waves respectively. Assuming proper matching of the transmitter and the receiver antennas the $n_R \mathbf{x} n_T$ channel matrix $\mathbf{H}$ can be computed from eqn. (1).

Computation of capacity

The channel matrix obtained from the previous subsection is then normalized so that the Frobenius norm becomes $n_T n_R$. The capacity is calculated as [7]

$$\text{C}=\log_2 \det \left[\mathbf{I} + \frac{\text{SNR}}{\text{N}_\text{T}} \mathbf{H}\mathbf{H}^\dagger \right] \text{ bits/s/Hz} \qquad (2)$$

where $\mathbf{H}$ is the normalized channel matrix and $\mathbf{H}^\dagger$ is its conjugate transpose.

3. Various system models

In this section we briefly describe the various models that have been considered in this paper for analysis. Fig. 1 shows a one-ring model with wire dipole scatterers. One ring model is extensively used to describe macro cellular scenario where the base station is elevated and can be considered to be devoid of surrounding scatterers. It may be noted that our model considers the coupling among the antenna elements, which is often neglected in geometrically based modeling. Fig. 2 shows the geometry of two-ring model that has been used in [1]. A polarization diversity system is shown in Fig. 3 In this case, we consider a pair of orthogonal dipole antennas at the transmitter and the receiver, the scattering dipoles are placed at random angles with respect to the vertical so as to effect both the polarization. An ideal dual polarized MIMO system can be considered as two parallel SISO channels.

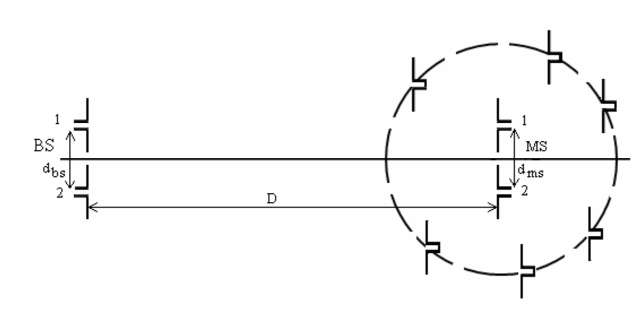

Figure 1: One Ring Model with wire dipole scatterers.

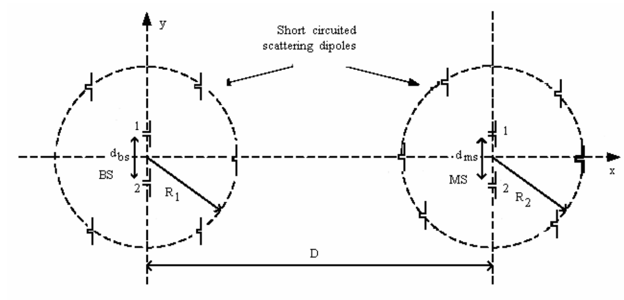

Figure 2: Two ring model with half wave length dipole antenna as scatterers [1].

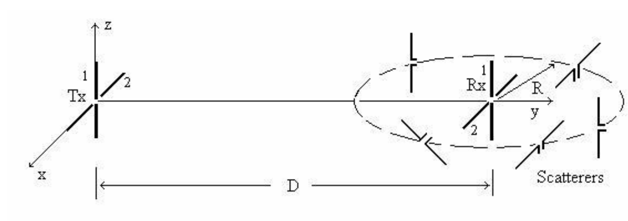

Figure 3: Dual polarized dipole antennas at the transmitter and the receiver.

4. Simlation Results

Using our proposed method described in section-II, we first compute the capacity of the two ring model having the same parameters as in [1]. Fig. 4 shows the simulation results of our approach and its comparison with the results reported in[1]. It can be seen from Fig. 4 that the results are in close agreement with those of [1].

Fig. 5 shows the plot of the capacity as a function of the inter element separation at the mobile station. It can be observed that the capacity variation at lower SNR is very small. However at higher SNR certain amount of oscillatory behavior of the capacity is observed as the separation between MS antennas varies. Table I shows the capacities for different M.S. antenna separation at an SNR of 35dB.

This variation may be attributed to mutual coupling between the mobile station antennas. Mutual coupling varies with antenna separation and modifies the cross correlation among the elements of channel matrix [8]. The channel capacity depends on such cross correlation.

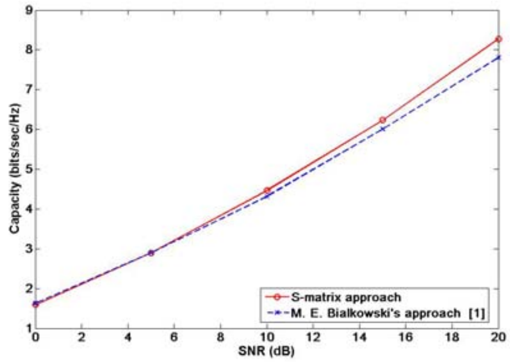

Figure 4: Plot of the capacity at different SNR using S-matrix approach and M.E. Bialkowski's [1] approach.

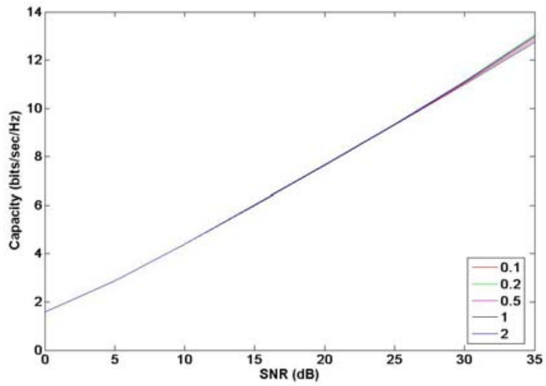

Figure 5: Plot of the capacity at different SNR for different inter element separation at the M.S.

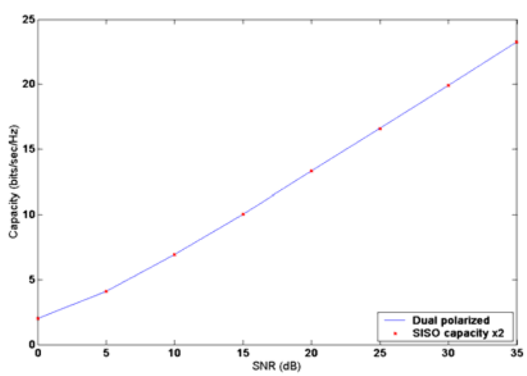

Figure 6: Plot of the capacity for dual polarized antennas both at the B.S. and M.S. and comparison with capacity of two parallel SISO channels.

Fig. 6 compares the capacities of a dual polarized MIMO channel with that of two identical parallel SISO channels. From simulation results it can be seen that a close match is obtained.

The frequency of operation for all the simulations was kept at 1 GHz. A 2 x 2 MIMO system has been considered. The inter element separation at the base station was kept fixed at 2λ where λ is the operating wavelength. The distance between the B.S. and the M.S. was kept fixed at 1000λ. The radius of the scattering circle was taken to be 35λ for both the one ring and two ring models. Twenty five basis functions were used for the MOM simulation and the CPU time for computation of the S-parameters was 10.7 seconds. The number of scatterers was taken to be twenty for two-ring model and twenty-five for the one ring model. In the dual polarized case B.S. and the M.S. consisted of two half-wave dipole antennas each, which were kept perpendicular to each other.

TABLE I. Capacity variation as a function of inter element spacing at MS at an SNR of 35 db

Antenna Separation in wavelength at M.S.	Capacity
0.1	12.96
0.2	13.06
0.5	12.84
1	12.74
1.5	12.8
2	13.02

5. Conclusion

In this paper we introduced an S-parameter based approach for computation of MIMO channel matrix where the entire channel model is developed using half-wave dipoles. We first validate our approach by comparing the results obtained following our approach with those reported in [1] for a two-ring MIMO model realized using dipole antennas. Following our method of analysis, we then evaluate the variation in capacity due to MS antenna separation for a one-ring MIMO channel modeled using dipole antennas. Finally we extend our method of analysis to compute the capacity of a dual polarized MIMO system. For this case simulation results based on our method are found close to theoretical values. The method proposed in this paper is therefore an effective means for analyzing MIMO channel models represented by using dipole antennas.

6. References

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