# Modelling Polarimetric Power Delay Spectrum for Indoor Wireless Channels via Propagation Graph Formalism

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# Modelling Polarimetric Power Delay Spectrum for Indoor Wireless Channels via Propagation Graph Formalism

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## Abstract

This paper presents approximate expressions for polarimetric power delay spectrum and cross-polar power ratio via propagation graph modelling formalism. The expressions are derived considering average signal propagation in a graph. The models relate co- and cross-polar power and the power ratio to model parameters (number of scatterers, probability of visibility, reflection gain and polarization coupling parameter) thereby providing a useful approach to investigate the averaged effect of these parameters on the channel statistics. Simulation results show statistics obtained using the model and the approximate expressions match very closely.

## 1 Introduction

Propagation graphs (PGs) offer a flexible structure for modelling multlink channels with account for multiple scattering. PGs describe the channel as a directed graph with the transmitters, receivers and scatterers as vertices and interactions between vertices defined as a time-invariant transfer function. Based on the graph description, closed-form expressions for the channel transfer function is given in [1]. The graph may be generated deterministically or following a stochastic procedure as done in the example model in [1].

Several applications of the graph based model have been studied in the literature. Recently, a generalization of the model to polarized channels was presented in [2]. The authors showed via simulations that the co- and cross-polar channels exhibit different decay rates for early arrivals.

In this paper, we derive approximate expressions for predicting the polarimetric power delay spectrum (PDS) and power ratios based on average propagation on a PG. The expressions provide a simpler alternative for studying the effects of model parameters (i.e., number of scatterers, probability of visibility, reflection gain and coupling parameter) on the power delay spectrum of polarimetric channels without implementing the model.

## 2 Propagation Graph for Polarized Channels

Referring to [1] the vertices of a PG models transmitters, receivers and scatterers, and the edges model the propagation

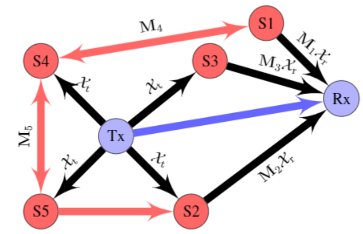


**Figure 1.** PG for a polarized channel.

conditions between the vertices. Signals propagate along the edges and thus to each edge is associated a transfer function to account for propagation delay, phase shifts and frequency dependent attenuation etc. The scatterers sum signals on incoming edges and redistributes a scaled version of the signal on the outgoing edges. See [1] for details. In the generalization of PG based modelling to polarized channels [2] illustrated in Fig. 1, the depolarization effects is modelled via the polarimetric antenna responses, $\mathcal{X}_{t/r}$, in the direction of the edges and a unit norm $2\times 2$ coupling matrix, $\mathbf{M}_n$. The matrix, $\mathbf{M}_n$, accounts for power leakage between the polarization states due to interaction with a scatterer. These polarimetric effects are combined with other propagation mechanisms to model the edge transfer function and hence, the channel transfer function in [2]. A procedure for stochastically generating the polarimetric impulse response and hence, the PDS is presented and used for simulating polarimetric channels in [2]. An approximate expression for the PDS and XPR is described in the next section.

## 3 Polarimetric PDS Model

We approximate the full propagation graph by a much simpler graphs as depicted in Fig. 2. On average, each vertex in a PG is connected to $(N_s-1)P_{vis}$ scatterer vertices, where $N_s$ and $P_{vis}$ denote the number of scatterers and the probability of visibility, respectively. To ensure power balance at a vertex, the signal on each outgoing edge of a vertex is the input scaled by $\sqrt{(N_s-1)P_{vis}}$. The received signal power after $K$ inter-scatterer interactions can be approximated as

$$P_r(k) = \frac{1}{(N_s-1)P_{vis}} \mathcal{G}_t^T \left[g^2\mathbf{M}\right]^k \mathbf{M}\mathcal{G}_r P_t, \qquad (1)$$

where $g$ denotes the average reflection gain. $P_r$ and $P_t$ are the output and input power vector, respectively. The terms

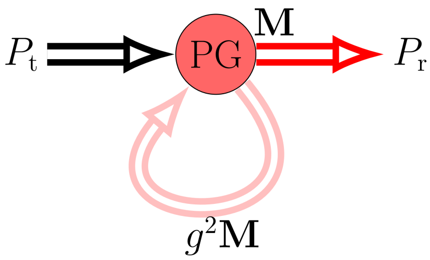


**Figure 2.** Power transfer in the PGM

$[g^2\mathbf{M}]^k$ and $\mathbf{M}$ in (1) result from recursive inter-scatterer interactions and depolarization due to scatterer to receiver edges in the PG. For simplicity, we ignore the delay spread due to different edge lengths in the original PG and consider only the mean delay $\mu_\tau$. Then the power received at delay, $\tau$, after $k = \tau/\mu_\tau$ interactions reads

$$P_r(\tau) = \frac{g^{(2\tau/\mu_\tau)}}{\mathrm{PL}(N_s - 1)P_{vis}} \mathcal{G}_t^T \mathbf{M}^{(1+\tau/\mu_\tau)} \mathcal{G}_r P_t, \qquad (2)$$

where $\mathcal{G}_{t/r}$ denotes the transmitter/receiver antenna response averaged over all possible edge directions. PL is a normalization factor accounting for the average power decay on the transmitter to scatterer and scatterer to receiver edges. Approximating this arrival time by $2\mu_\tau$, PL is obtained from Friis's law as

$$\mathrm{PL} = \frac{8\pi\mu_\tau c}{\lambda} \qquad (3)$$

where $c \approx 3 \cdot 10^8$ m/s and $\lambda$ are the free space wave velocity and wavelength, respectively.

## 4 Results

This section presents results comparing the PDS and cross-polar ratio from the graph and approximate expression in (1) for a dual polarized channel in the frequency band, 58 GHz to 62 GHz, $N_s = 10$, $P_{vis} = 0.9$, and $g = 0.6$. The polarization power coupling matrix is modelled as

$$\mathbf{M} = \frac{1}{1+\gamma}\begin{bmatrix} 1 & \gamma \\ \gamma & 1 \end{bmatrix}; \quad 0 \leq \gamma \leq 1. \qquad (4)$$

Details of the procedure for computing PDS from the PG can be found in [2]. We consider ideal dual polarized omnidirectional antenna with no antenna polarization coupling as in [2]. We therefore, represent the averaged transmit antenna response as $\mathcal{G}_t = [1 \quad 0]^T$ and the averaged receiver response as $\mathcal{G}_r = [1 \quad 0]^T$ and $\mathcal{G}_r = [0 \quad 1]^T$ for co- and cross-polar channels, respectively. As shown in Fig. 3, the predictions from (1) agree closely with those generated from the model. In particular, the co-polar PDS decays nearly exponentially with constant rate of decay. In the cross-polar case, the rate of decay is different. It can be seen that that ratio of the co- and cross polar PDS also follow the approximation very well. In Fig. 4, we illustrate the effects of the model parameters on the PDS and

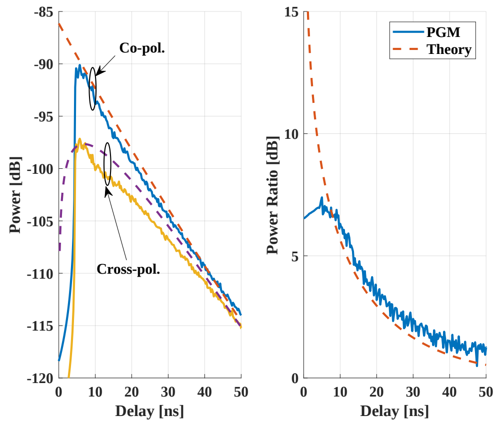


**Figure 3.** Polarimetric power and power ratio from propagation graph and approximate expressions.

XPR. We observed that a change in the value of $g$ results in a change in the tail decay rate of the PDS. An increase in $\gamma$ causes a decrease in the polarization ratio. This is intuitive since the model in (4) implies that an increase in $\gamma$ increases the power in the cross-polar channel for every interaction. Another interesting observation from Fig. 4 is that, with constant value of $(N_s - 1)P_{vis}$, the polarimetric PDS is not affected by changes in the values of $P_{vis}$ and $N_s$.

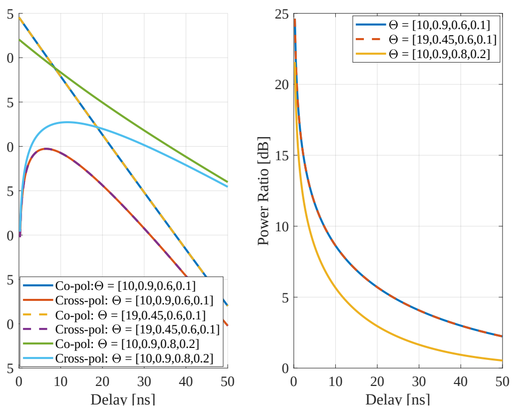


**Figure 4.** Polarimetric power and power ratio with different parameters. $\Theta$ denotes the parameter set $[N_s, P_{vis}, g, \gamma]$.

## 5 Conclusion

This paper summarizes a theoretical framework for predicting the polarimetric power delay spectrum and cross-polarization ratios based on average signal propagation in a propagation graph. The expressions provide a way to study the effects of model parameters on the statistics without Monte Carlo simulations involved in generating the statistics from the model. Results show that the predictions agree closely with the simulated spectrum and power ratio obtained from the model.

## 6 Acknowledgements

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