Abstract— This thesis faces the problem of radio channel modeling when multiple antenna arrays both at the Transmitter (Tx) and the Receiver (Rx) are used (Multiple Input – Multiple Output, MIMO). The complexity of the modeling comes from the fact that between each transmitter–receiver antenna pairs it is established a wideband channel which is correlated to each other. The proposed solution comes from the orthogonalization principle applied to the time delay and spatial domains, simplifying the problem and allowing an error predefinition of the channel simulation realization.

I. INTRODUCTION

In the channel modeling process it is necessary to count on models that truly represents what is happening at the channel, i.e., phase and amplitude changes to every signal components, in order to propose techniques that mitigate those effects and allow reliable communication links. It is also needed channel simulator to prove those techniques before the communication system is built. The results given by the simulator will validate the system feasibility.

For channel modeling purposes, it is assumed that the channel can be described by its impulse response function (Channel Impulse Response, CIR) of by its transfer one, as it is done with every linear system as in circuit theory, e.g., let us consider an RC circuit as the one in Fig. 1.

\[ h(t) = \frac{1}{RC} e^{-\frac{t}{RC}}. \]  

(1)

where \( \tau \) represents the time delay and RC is the time constant of the circuit.

It can be seen from (1) that the system is completely deterministic, as R and C are both fixed. Let us assume that one of them can change in time by some rule, i.e., \( R = R(t) \); with this, the SIR changes both in \( t \) and \( \tau \) domains as,

\[ h_s(t,\tau) = 1 - e^{-\frac{t}{RC}}. \]  

(2)

II. PROBLEM DEFINITION

The idea behind this thesis is to provide a wideband channel simulator able to give MIMO channel realizations with predefined propagation statistics. A channel realization is a random process which fulfill with some desired statistics. The channel statistics can be taken from measurement campaigns, geometrical models [1] or standards [2–3] used in the systems’ operation definitions.

At the radio channel we have a full analogy. Let us consider the scenario shown at Fig. 2 to explain it. In its propagation trajectory from the Tx to the Rx, the signal experiences bounces at several objects know as scatters. This propagation effect is known as multipath as many paths are formed by the propagation scenario. All these reflected and/or diffracted signals arrive together to the Rx and produce amplitude changes (fade out) to the received signal.

Fig. 2. The multipath propagation phenomena.

If the propagation conditions would not change, the CIR would not either; but real channels due change in time: cars and people are moving, the leaves moves due the wind, etc. This provides variability of the CIR with the time, hence providing dependence on the \( t \) and \( \tau \) domains. It should be mentioned here that on contrary to the SIR at (2), all phenomenon involved at the channel have a random nature, so the CIR must be studied in the same sense.

Fig. 3. The MIMO channel structure.

In a MIMO channel (see Fig. 3) it is established a channel between each Tx to Rx antenna pairs. Every connection has its own multipath conditions and its time variability. The scatters provide time delay and space dispersion and the
time dispersion is due to the changes in the scenario.

It is should be clear that paths that arrive to a pair of neighbor antennas at the Rx, will experience almost the same channel impairments, so the spatial correlation given by the antennas should be properly printed to the channel realizations.

At the time delay domain, the problem consists on giving a particular power to the signals as they arrive to the Rx. Figure 4 shows a CIR realization of the scenario depicted at Fig. 2. It can be noticed there that the trajectories are few and distinguishable. When we have such kind of scenarios, it is needed only to characterize the weights associated to each delay, but this is not the one usually presented in nature.

For such scenarios as the one shown at Fig. 5, the CIR function has a continuous form, and the previous simulation procedure is no longer valid as the paths are many and undistinguishable. In these scenarios it is useful to consider the orthogonalization principle [4], which decomposes the continuous multipath profile into a discrete one, but in this case the multipath scenario is no longer associated to the real propagation scenario, this is why they are called artificial trajectories.

There are many way in which the artificial trajectories can be built but the best one is by means of the Karhunen–Loeve Equation (KLE). This method provides the minimum number of these trajectories for a predefined error, but is highly dependent to the channel propagation conditions.

Instead of using the KLE set, we proposed a universal set called the Prolate Spheroidal Wave (PSW) functions which are invariant to the channel and are easy to build. The PSW set is used at the orthogonalization process both for the time delay and space domains [4–5] but it can be used also at the time domain as well [6]. At the spatial domain the PSW are called propagation beams.

III. PROJECT STATUS

The whole framework has been finished: The use of geometrical models allows us to obtain the channel statistics both at the spatial and time delay domain. The PSW set is used into the orthogonalization process in order to minimize the required set of functions with a predefined error and at the same time, making the MIMO channel representation invariant to itself.

The answer to the PhD project is the MIMO channel model known as the Generalized Kronecker wideband Channel Model (GKCM) [5] which can be used to any antenna array topology and any propagation conditions as it was already validated [7]. The complexity in terms of adds and multiplications is reduced compared to others in the literature [8–9].

IV. MAIN RESULTS

The structure of the simulator is shown at Fig. 6. There it is shown that the spatial structure is provided by the PSW basis in the spatial domain. This will print the spatial correlation to the signals at the Rx. Each established connection is done by a wideband channel weighted by the power of the connection (the appropriate coupling matrix element). It should be mentioned that the orthogonalization process provides a reduction in the number of virtual channels needed but all required channels are constructed, just in an intelligent way.

Figure 6. The GKCM structure.
It will be shown two examples in which it is assumed that the Tx has 7 antennas and the Rx has 5 elements. Both examples assume that the angle distribution at the Tx is uniform, but the first one assumes that the angle distribution at the Rx is uniform and the second assumes a Laplacian one.

The link connection between Tx–Rx antenna pairs is done by means of a coupling matrix, which determines the average power in which the propagation beams are connected. As it can be seen from Fig 7 and 8, we have got a dramatic reduction, compared to the direct method (pure Kronecker) in about 60% and 55% respectively. This makes the MIMO channel proposal, the GKCM,

- Has the ability to work with any arbitrary topology of planar antenna arrays both at the Tx and Rx.
- Contains as the most used MIMO channel models in literature: the Sayeed model [8], the Weichselberger model [9] and the Kronecker model [9–10].

The papers generated by this project are [1, 4, 10–18].

Figure 9 shows a wideband MIMO channel realization. There it can be seen the two domains dependency as in the SIR at (2). In it there has been considered a maximum time delay of 10 μs and a time duration of 1.7 ms.

V. CONCLUSIONS

The GKCM has the following advantages:
- Provides MIMO channel realizations with predefined error and space and time delay propagation statistics.
- Has a low complexity and use a reduced dimensionality easy–to–build set of functions to work with.
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