Gaussian Distributed Scattering Rings-based MIMO Channel Modeling for Wireless Communication

Illa Kolani and Bertrand Moubagou

Abstract— This paper presents a MIMO channel performing the prediction of wireless channel behaviour particularly in fast fading scenario. The proposed spatial channel model is elaborated assuming a scattering environment system consisting of multiple contiguous one-ring scattering with different beamwidth seen at the enodeB (base station).Since an arbitrary one ring scattering channel (Reference Model) in this model stands for channel realization, therefore the motion of the User Equipment (UE) over multiple scattering rings will induce the channel to experience many realizations. Following a given Probability Density Function (PDF) of beamwidth, an estimation of the behaviour of the channel can be available at the enodeB by averaging upon the overall channel realizations. AS application of the proposed model, we provide a performance analysis of LTE downlink performing and suggesting the optimal and suitable choice of the transmission mode in real MIMO channel spatial correlations environments.

Keywords— Beamwidth, Channel realization, Gaussian PDF, MIMO, One Ring scattering, Scattering Channel.

I. Introduction

Modeling MIMO time-variant channels as real world of wave propagation environments dictates becomes crucial in wireless communication where an accurate knowledge about the channel state information is expected to be available for the transceivers. However instead of having unreliable and inefficiency instantaneous channel state information (CSI) particularly in fast fading where feedback mechanisms often generate a delay in receiving information and thus the loss[1]in throughput, a partial information can be obtained by means of the channel covariance or correlation[1][2].In general correlations characteristics can be obtained either by field measurements or geometrical stochastic channel modeling .Mainly, because of their relative simplicity ,accuracy and suitability in any propagation environment, geometrical based MIMO channel modeling have been used for wireless performance analysis. For instance, standard MIMO channels as 3GPP Spatial Channel Model (SCM) and WINNER Models [3] and non-standard channels [4] are driven from this framework. The main lack and limitation of geometrical based models resides in the fact they are most suitable to describe the channel in stationary manner and then usually fails to describe fast fading scenario. For instance, the LTE channel model specified by the 3GPP is an Extended (ESCM) version of the SCM amputated of the time evolution features or the concept of 'drops'[5][6] . Consequently, the channel is specified and limited for well-known and fixed propagation environments A, B, C, and D [6] with fixed well-known parameters such AOA, AOD and velocity for the mobile. However realistic scenario may suggest dealing with the motion of the mobile implying rapid evolutions of those parameters in fast fading scenario.

In this paper, the concept of 'drops' is used to formulate the proposed dynamic scattering MIMO channel. Following the motion of the mobile within a given scattering environment system S_N. Since the cell coverage area system S_N is assumed consisting of multiple stacked and contiguous one-ring scattering environments with different beamwidth seen at the base, each drop is referred to as an arbitrary one-ring scattering environment channel correlation. Therefore, following a given Probability Density Function (PDF) of beamwidth, the estimation of the channel is formulated by averaging upon the overall channel realizations.

The organization of the paper is as follows: Section II sets up the system model preliminaries, section III presents the model in detail and compares its correlation properties with existing reference model. Section IV analyses the diversity and capacity performances of LTE transmission modes through the channel model and in Section V we summarize the study.

II. System Model Preliminaries

Let us consider a MIMO channel H with n_t transmit and n_r receive antenna. At instant t an arbitrary correlation $r_{kl,qs}$ between two arbitraries multipath channels $h_{kl}(t,f)$ and $h_{qs}(t+\Delta t, f+\Delta f)$ is written:

$$r_{kl,qs} = h_{kl}(t,f).h^{*}_{qs}(t+\Delta t, f+\Delta f) \quad (1)$$

$$k,q \in [1,n_t] \text{ And } ,l \in [1,n_t]$$

Assuming a transceiver within a scattering subsystem n, we

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may write $r_{kl,qs} = F(\Delta t, \Delta f)$ under the assumption of Wide Sense Stationary Uncorrelated Scattering (WSSUS) process, and F denoting a specific function which depends on the geometry (sub-system) formed by scatterers around the transceiver and the resulting distribution of Angle of Arrival (AOA) and Angle of Departure (AOD). Δt and Δf respectively stand for time and frequency lags within an arbitrary subsystem. Since $r_{kl,qs}$ is geometrical-based scattering model, without lose any generality, let's introduce a parameter α of the geometry. We may rewrite:

$$r_{kl,qs} = F(\Delta t, \Delta f, \alpha) \tag{2}$$

It should be noted that (2) describes a stationary state and then is only suitable to illustrate correlation for fixed transceiver (or relative fixed scattering environments).

Let's now consider a dynamic scattering environment system S_N wherein a transceiver is assumed moving through N contiguous and stacked subsystems of scatterers. In this scenario, taking into account the mobile velocity v within a given subsystem n, the corresponding channel correlation can be written:

$$r^n{}_{kl,qs} = F(\Delta t_n, \Delta f_n, \alpha_n, v_n) \tag{3}$$

Following the motion of the mobile, the correlation $r^n{}_{kl,qs}$ may be born and died during the beginning and the end of each drop, evoking the concept of birth and dearth described in [5]. Therefore, $r_{kl,qs}$ may experience many intractable realizations. As consequence of contribution by N scattering subsystem, (2) can be extended as follows:

$$\overline{r_{kl,qs}} = \frac{1}{N}\sum_{n=1}^{N} nF(\Delta t_n, \Delta f_n, \alpha_n, v_n) \tag{4}$$

Where $\overline{r_{kl,qs}}$ denotes the average correlation upon the overall channel realization $r_{kl,qs}$.

III. Gaussian Distributed Scattering Rings

A. One Ring Scattering model

Thanks to its accordance with experimental result, the one ring scattering model is considered suitable to simulate narrow band communication systems as well as communication system using MIMO- OFDM scheme. In this model, it is assumed that a fixed mobile station is surrounded a ring of scatterers while the base station is elevated and not obstructed (Fig.1). Considering a parallel Uniform Linear Array (ULA) antenna between the transmitter and the receiver, employing a uniform Probability Density Function (PDF) of Angle of Arrival (AOA) and following the method of computation used in [7][3], the correlation function $r_{kl,qs}$ in an arbitrary one ring scattering with a given radius r is as:

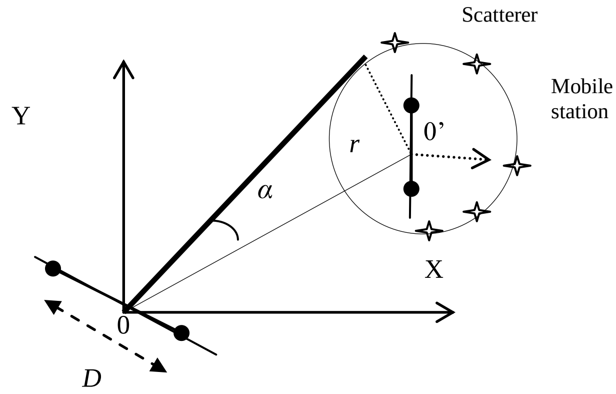

Figure 1: One-Ring Scattering Environment

:

$$r_{kl,qs}(\Delta t, \alpha, f_d) = \exp j2\pi(s-l)\frac{d}{\lambda} J_0\left(2\pi\left(\begin{array}{l}\frac{D}{\lambda}(q-k)+\\ \frac{d}{\lambda}\alpha(s-l)+f_d\Delta t\end{array}\right)\right) \tag{5}$$

$$k,q \in [1,n_t] \quad s,l \in [1,n_r]$$
$$k-q \geq 0 \quad s-l \geq 0$$

Where D, d and λ denote respectively the antenna spacing at the base station, at the mobile station and the wavelength. $f_d = v/c$ is the maximum Doppler spectrum . α denotes the beamwidth seen at the base station and is related to the geometry (ring) formed by scatterers . Δt standing for the time lag between MIMO sub channels $h_{kl}(t,f)$ and $h_{qs}(t+\Delta t, f+\Delta f)$, correspond to the symbol period Ts

B. Proposed Dynamic Scattering Channel Model

In practice, it is obvious that the mobility of the user equipment results in the *dynamicity* of scatterers around the mobile.

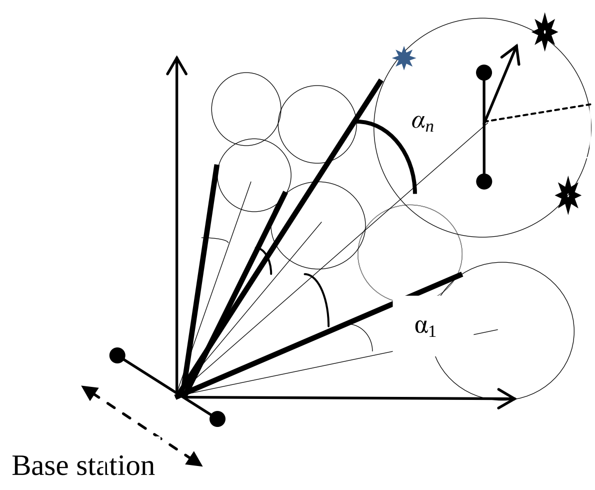

Figure .2 Scattering rings

Therefore, the above one ring scattering channel model valuable only for fixed mobile station become obsolete. In this section, we will focus on the dynamic (mobility of the mobile station) aspect of the mobile taking into account dynamic scattering aspect. To elaborate our model, we consider the following evidences:

1. Considering a constant velocity *v*, therefore for an arbitrary scattering ring *n* wherein the correlation behavior is given by $r_{kl,qs}(Ts,\alpha_n,v/c)$ in equation 5, can be seen as a stationary state regarding the beamwidth α_n.

2. Assuming that the cell coverage area S_N is consisted of continuous multiple one ring scattering environments (see figure 2), therefore each arbitrary one ring scattering *n* with the correlation $r_{kl,qs}(Ts,\alpha_n,v/c)$ depicts a channel realization.

Indeed, from (5), α depends on the distance between the base mobile and the radius of the scattering ring, both parameters are subject of variation following the motion of the mobile. Hence, the system S_N channel will experience the distribution $r_{kl,qs}(Ts,\alpha_n,f_d)$ with $\alpha_n=[\alpha_1,\alpha_2,\alpha_3,....\alpha_N]$.

The expectation $\overline{r_{kl,qs}}$ of $r_{kl,qs}(\Delta t,\alpha_n,f_d)$ can be written following (4) as:

$$\overline{r_{kl,qs}}=\frac{1}{N}\sum_{n=1}^{N}n.r_{kl,qs}(\Delta t,\alpha_n,f_d) \qquad (6)$$

3. From (6), n/N can be interpreted as the probability p_n of the of the correlation matrix channel $r_{kl,qs}(\Delta t,\alpha_n,f_d)$ to be occurred.

4. According to the experiments result leaded at different locations and frequencies in [7], the beamwidth α_n seen at the base in an arbitrary one scattering ring scenario is generally small, most often than 15^o, and some case, very small, less than 5^o. Hence, within the coverage zone of a cell (macrocell or microcell), the range of the values that can be taken by the beamwidth is α_n **=** **[**tang (0^o) tang (15^o)].

5. For *N* large the central limit theorem allows to approximate (7) can be approximated by the integral form:

$$\overline{r_{kl,qs}}=\int p_n.r_{kl,qs}(\alpha_n)\,d\alpha_n \qquad (7)$$

6. Since the proposed dynamic scattering channel implies the knowledge of the distribution p_n, we will adopt Gaussian distribution because its accuracy and suitability in many systems dealing with infinite numbers. We may write:

$$p_n=\frac{2.c}{\sqrt{\pi}}e^{-c^2(\alpha_n-\alpha_0)^2} \qquad (8)$$

where α_0 represents the location of the peak of p_n .Note that *c* can be chosen in order to ensure that p_n decreases rapidly beyond the interval of α_n.

From (5), and (7), (8) the correlation is given as:

$$\overline{r_{kl,qs}}=\frac{1}{\sqrt{\pi}}.e^{j2\pi(s-l)d/\lambda}.J_0\left(2\pi\left(\frac{D(q-k)}{\lambda}+f_d\Delta t\right)\right)\mathbf{X}$$
$$J_0\left(\frac{2\pi}{\lambda}d(s-l)\alpha_0\right)\mathbf{X}\sum_{m=0}^{\infty}\frac{(-1)^m}{(2.c)^{2m}}\frac{\Gamma(m+1/2)}{(m!)^2} \qquad (9)$$

where Γ (x) denotes the gamma function.

It should be noted that in downlink the transmit, receive and cross-correlations can be derived from by setting up respectively $l \neq s$, $k=q$; $l=s$, $k\neq q$ and $l \neq s$, $k\neq q$;

C. *Kronecker's Model* validity

Kronecker's model representation of MIMO channel is often considered in correlation based and analytical based MIMO channel modeling because of the simplicity that this assumption offers in analysis of correlation parameters. However a rapprochement can be done with geometrical based MIMO channel modeling with the requirement [8]:

$$\overline{r_{kl,qs}}=\overline{r_{kl,ks}}.\overline{r_{kl,ql}} \qquad (10)$$

Let's investigate the validity of this assumption in this model.

- Considering a quasi-static case or slow fading channel, approximating $f_d\Delta t\approx 0$, it can be shown that the relationship (10) is respected fulfilling the Kronecker's assumption.
- Let's assume also the beamwidth α_0 large, it is clearly seen the close form of Kronecker's model is respected; however, this is utopic due to the fact that α_0 is specified not exceeding 15^o.
- Antennas largely spaced induce a Kronecker's representation of MIMO channel.

D. *MIMO Channel Correlation Properties*

A significant drawback remains the huge size of the full correlation matrix R and its high number of elements to be estimated in (2). Indeed, in order to analyze the correlation proprieties of a MIMO system with n_t transmit antenna and n_r receive antenna, strictly $n_t n_r(n_r n_t-1)$ parameters should be taken into account. Hence, to dispense with the study of each element of the matrix R, we adopt the correlation measure metric of the amount correlation $\psi_{n_t n_r}$ [9].

Since in LTE systems 2x2MIMO and 4x2 MIMO antenna configurations can be used, their channels correlation proprieties are simulated in a dynamic scattering environment

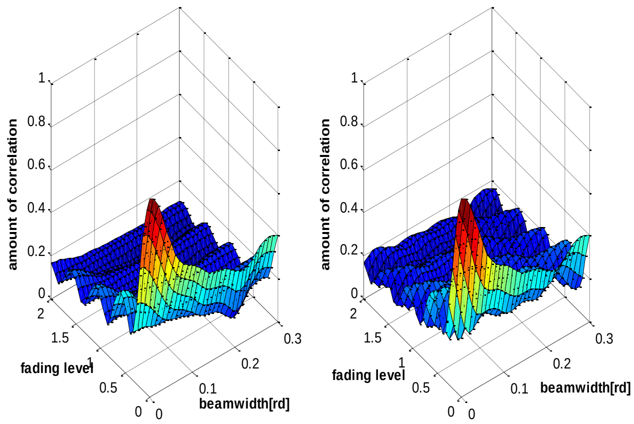

Figure.3: 4x2 MIMO correlation properties, (a) in the proposed model, (b) in One ring scattering model

system in comparison with their proprieties in the one-ring scattering channel (reference channel model) and following the parameters of the beamwidth $\alpha = \alpha_0$. The parameter *c* of the Gaussian PDF is chosen as 200 to ensure the rapid decreasing of the function beyond α_n = **[**tang (0^o) tang (15^o)]. The antenna spacing are *D* =2 λ at the enodeB and *d*= 0.2 λ at the mobile where λ= 1/2GHz denotes the wavelength (working Frequency) as specified in LTE transmission system.

In can be observed that correlations in different scattering (fig.3) channel scenario decrease with the increase of the beamwidth and the fading level while some similarities can be depicted. Indeed, the amount of correlation function of channels in the proposed model behaves approximately as a translation (by a given factor) of the amount of correlation function in the reference model at fading level $f_d T_s \le 1$ (quasi slow fading).In this case the reference model can be used for wireless performance prediction.

However with a fast fading level $f_d T_s > 1$ scenario in which case the mobile is assumed moving too rapidly, from the simulation result, differentiation is required between the two models and the proposed model can be used for wireless MIMO system performance prediction.

IV. Application to LTE Downlink PERFORMANCE ANALYSIS

The transmission error rate and the data rate are analyzed through the proposed channel. The channel is assumed slow fading i.e. $f_d \Delta t \approx 0.2$. The antenna spacing are *D* =2 λ at the enodeB and *d*= 0.2 λ at the mobile where λ= 1/2GHz denotes the wavelength (working frequency) as specified in LTE transmission system. The bandwidth use is 1.4MHz. We chose α_0 equal α_{max} = tang (15^o) and *c* =200.

We assume that the UE requests the Channel Quality Indicator (CQI) index 7 for both Close Loop Spatial Multiplexing (CLSM)-based LTE transmission mode and Open Loop Spatial Multiplexing (OLSM)-based LTE

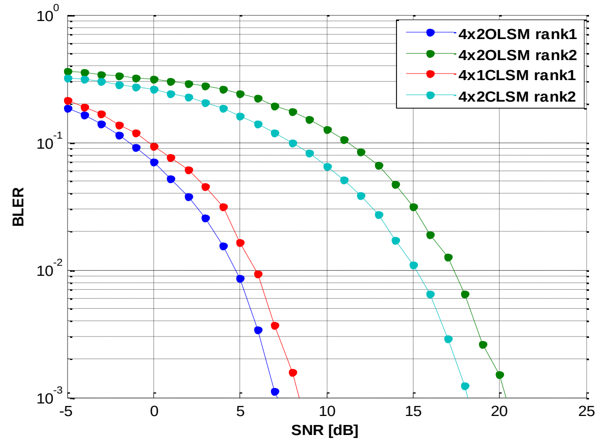

Figure 4: Block Error Rate of 4x2 MIMO transmission modes (BLER)

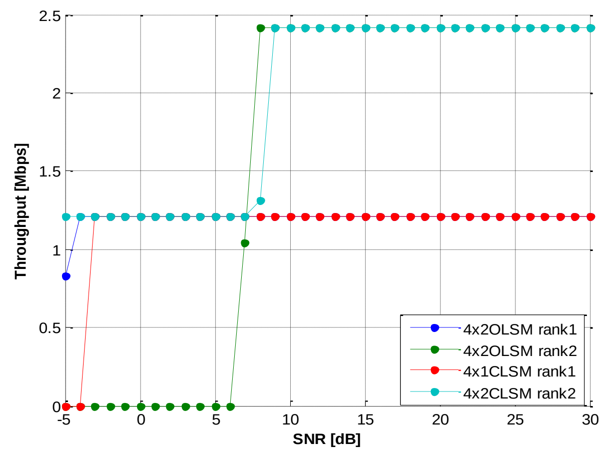

Figure 5: Throughput of 4x2 MIMO transmission modes

transmission mode(TM). Figure 4, 5 depict their performances associated with different number of antenna.

We note that for OLSM rank1 as well as for CLSM, rank1 transmission modes remain robust in terms of BLER (fig.4) while being able to offer their maximum throughput (fig.5) in reasonable Signal to Noise Ratio (SNR). However, although rank2 transmission modes may offer high throughputs in relative high SNR, their link performances may be seen as catastrophic. In this case the enodeB can chose optimally rank1 TMs for data transmission for both 2x2 MIMO and 4x2 MIMO configurations.

Those performances analysis results can be explained by considering the channels highly correlated since rank 2 TM_s as MIMO capacity -target design, perform well in relative low to moderate correlations environment while rank1 TM_s as MIMO diversity-based design, remain performing in highly correlated channels.

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V. Conclusion

The proposed MIMO channel model can be used suitably for wireless MIMO communication systems, to evaluate the state of channels correlations. It is also shown that the one ring scattering model (reference model) is the approximate form of proposed model in low fading scenario $f_d T_s \leq 1$. However in fast fading level $f_d T_s > 1$, in which case the mobile is assumed moving too rapidly, differentiation is required between the two models and the proposed model is suitable to be used for wireless MIMO system performance prediction.

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