Cell Segmentation-based Wireless Channel Modeling for 4G Base Station Self Optimal TM Selection

I. Kolani and N. Mastorakis

***Abstract*—**In this paper, we investigate MIMO wireless propagation characteristic by proposing a time-evolving MIMO spatial channel which performs instantaneously and optimally the selection of the appropriate Transmission Mode at the eNode B. The proposed spatial channel model is elaborated assuming a multi-sector cell scattering environments where each sector consists of multiple scattering rings with different beamwidth seen at the eNode B (or base station).Therefore, with a the motion of the User Equipment (UE) within multiple sectors, the channel may experience many realizations known at the eNode B which is then capable to adapt dynamically and select the optimal TM.

***Keywords*—**MIMO Spatial Correlations, LTE/LTE-A Transmission Mode, Cell Sector, Time-Evolving Channel

I. Introduction

LONG Term Evolution (LTE) network downlink transmission system differently from others wireless network, is mandated to operate in multiple transmission modes related to MIMO systems[1].Each transmission mode may consist of transmitting one or two independent data streams (code words) assisted respectively by precoding matrix (phase matrix indicator), transmit diversity and by a cyclic delay prefix. In LTE, the transmission system can be grouped into transmission modes(TM) 1,2,3,4,5,6,7 and 8.However it should be noted the transmission modes are extended to TM9 and TM10 specifying multiple layers transmission up to 8 layers in LTE-Advanced Release 10[2].

Differentiation is required among transmit diversity, spatial multiplexing and beamforming –based TMs .So the capability of the eNB to dynamically and optimally select the MIMO TM that matches the channel conditions, is a key focus of LTE/ LTE-Ad systems. However, until the release 9, it has been observed [3] that the 3GPP is silent about on whether switching scheme can be performed. With the advent of the release 10, the TM9 can be seen as the opened–discussion since this transmission mode should support the spatial multiplexing and beamforming SU-MIMO/MU-MIMO switching on the rank 1 basis. And since the mobile, within the cell coverage region, is subject to mobility over multiple and different scattering environments, the transmitter need to select instantaneously the appropriate TM depending on the channel behaving [3][4][5].This suggests the implementation of a MIMO channel model that evolves with time or the motion of the UE. However the 3GPP LTE channel derived from an Extended Spatial Channel Model (SCME), suffers from this lack and is only specified for fixed typical cell environments [6].

In this paper, we propose a practical time-evolving MIMO channel model for a LTE/LTE-A downlink TM adaption. The model is formulated upon a multi-sector scattering cell environment criterion. Within a cell, the mobile is assumed moving over sectors where each sector consists of multiple *n* one-ring [7] scattering environments with different beamwidth seen at the base station. Therefore in this model, the spatial characteristic of the cell channel is varying accordingly to each sector and is known at the base which then is capable to dynamically and optimally adapt the transmission mode following the motion of the mobile.

II. Problematic of LTE/LTE-A Downlink TM Switching

In LTE /LTE -advanced standards, the physical layer is mapped into multiple transmission modes(TM) and each TM should be dynamically selected depending on the time-varying MIMO channel. Besides the single antenna SISO transmission (TM1), multielement antenna (MIMO) technology such as Open Loop Spatial Multiplexing (OLSM) and Close Loop Spatial Multiplexing (CLSM) transmissions are also specified in release 9 by the 3GPP standard for LTE downlink transmission which supports TM1 to TM8 (fig.1). TM1 indicates the single antenna port transmission SISO(Single Input Single Output); TM2 and TM6 denote respectively transmit diversity known also as open loop spatial multiplexing (OLSM) and the close loop spatial multiplexing(CLSM) where in both case one data stream is transmitted (Rank 1); TM3 and TM4 are respectively OLSM and CLSM, both consisting in transmitting two (rank2) data streams.TM7, TM8 implement beamforming respectively with one layer transmission and with dual layer transmission. In practice, most of mobile communications deal with multi users sharing the same resources. Hence, a high diversity gain

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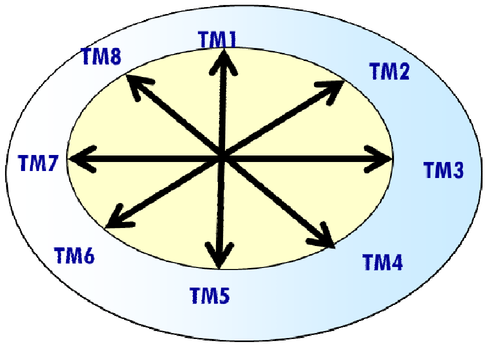

Fig.1 LTE/LTE-A Transmission Modes in release 8

can be achieved by transmitting to users with high channel quality conditions .This technic is commonly known as multi-user diversity. In LTE/LTE-Advanced, Multi User MIMO technique (MU-MIMO) is enabled and performed by the transmission mode TM5 while the remaining TMs have SU-MIMO features.

Hence, the above description, the eNode B (enhanced Node) or the base should be mounted at least by height antennas. It can be also observed that the entire TM can be grouped in five groups of transmission mode:-SISO, CLSM, OLSM, MU-MIMO groups.

III. Time Evolving Channel Concept

Although the concept of time evolving channel is closely related to the concept of time varying channel, a differentiation can be made between them at certain level. The second one describes the behavior of wireless channel that changes instantaneously .It often referred to as the channel impulse response and implies directly the temporal channel evolution according to certain Doppler characteristics [8]. The time evolving concept, beyond can be applied to the channel statistics in order to characterize the temporal evolution of the channel stationary [8].

Let's now consider a MIMO channel H with n_t transmit and n_r receive antenna. The time-frequency selective channel H (*t*, *f*) properties can be drawn from the double-directional theory [10].The rapidity of the time variation of the channel can be estimated from the computation of the mean Doppler shift or the Doppler spread. However in all scenario of practical relevance, dealing directly with the channel impulse response is almost infeasible. It is rather reasonable to adopt stochastic approaches to study the channel through its correlations which in contrast have large scale stationary properties.

Consider two arbitraries multipath sub-channels $h_{kl}(t,f)$ and $h_{qs}(t,f)$ defined by antennas *k, q* at the receiver side array and antennas *l, s* at the transmitter array. Their correlation $r_{kl,qs}$ is written:

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

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

Under the assumption of Wide Sense Stationary Uncorrelated Scattering (WSSUS) criterion, we may write:

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

F denoting a specific function which depends on the geometry 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 between sub-channels.

It should be noted that (2) stipulates that channel statistics are time and frequency-independent. However in practice, due to the motion of the transceiver which leads to non-stationary channel, WSSUS assumption is never fulfilled completely [10]. Alternatively, the interest is pointed on quasi- stationarity models [11] involving that the channel statistics remain constant during a given stationarity time T_s. The fact that the channel correlation $r_{kl,qs}$ changes during each T_s, evokes a time-evolving system.

IV. System Model

In this section, we develop our proposed time- evolving channel for wireless communications network as well as LTE transmission system using MIMO based multi transmission modes. Since MIMO channel variation is inherently related to scattering environments, our methodology herein is in:

- First, split the cell environment governed by the eNode B into multiple(see fig.2) sectors S1, S2….S*m*. Each sector S*m* environment is characterized by a spatial correlation $r^{m}_{kl,qs}$.
- Secondly, adopt the Multi Ring Scattering Channel Model [7] as the cell channel. Hence, in this configuration ,each sector S*m* spatial characteristic is given as:

$$r^{m}_{kl,qs} = \frac{1}{N}\sum_{n=1}^{N} d_n(\alpha_n).r_{kl,qs}(\Delta t, \Delta f, \alpha_n)$$

Where $r_{kl,qs}(\Delta t, \Delta f, \alpha_n)$ stands for an arbitrary one ring scattering *n* MIMO channel correlation; d_n denotes the distribution of scattering rings following the beamwidth α_n seen at the base station.

Assuming a Gaussian distribution of d_n [7] within each sector S*m*:

$$d_n = \frac{2.c}{\sqrt{\pi}} e^{-c^2(\alpha_n - \alpha_0^m)^2}$$

the spatial correlation is computed :

$$r^{m}_{kl,qs} = e^{j2\pi(s-l)}.J_0\left(2\pi\left(\frac{D(q-k)}{\lambda} \pm f_d \Delta t\right)\right).\frac{1}{\sqrt{\pi}} J_0\left(\frac{2\pi}{\lambda} d(s-l)\alpha_0^m\right)$$

$$\mathbf{X}\sum_{p=0}^{\infty} \frac{(-1)^p}{(2.c)^{2p}} \frac{\Gamma(p+1/2)}{(p!)^2}$$

With

$$k,q \in [1,n_t] \qquad s,l \in [1,n_r]$$

$$k-q \geq 0 \qquad s-l \geq 0$$

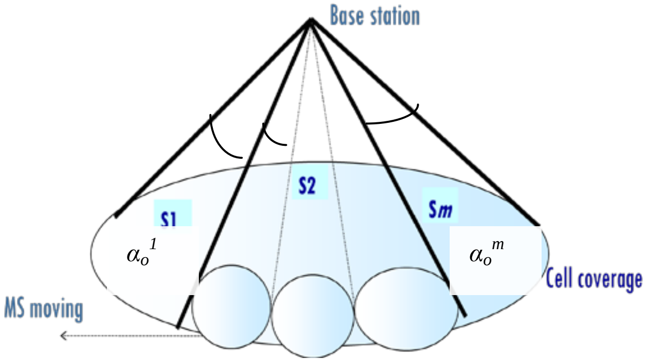

Fig.2: Channel Model (sectored-cell based wireless channel modeling)

where α_0^m is the beamwidth representing the location of the peak of d_n in a given sector Sm of the cell. Note that c can be chosen in order to ensure that d_n decreases rapidly beyond the interval of α_n € [0^o 15^o]. 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. In equation $r^m{}_{kl,qs} = F\left(\Delta t, \alpha_0^m\right)$ is function of variable Δt and α_0^m, describes a time and space selectivity channel and then is suitable to depict the behavior of narrowband time evolving channel.

- Finally , the proposed time evolving channel can be written as follows:

$$\frac{\partial r^m{}_{kl,qs}}{\partial t} = r^m{}_{kl,qs}\left(T_s, \alpha_o^m(t)\right) \quad \text{with}$$
$$\alpha_o(t) = [\alpha_o^1, \alpha_o^2, \alpha_o^3 \ldots\ldots \alpha_o^m]$$

During the motion of the mobile station over multiple sectors within the cell, the channel $r^m{}_{kl,qs}$ is evolving following the beamwidth α_o seen in each sector at the base station. Consequently each sector is then indexed by the corresponding beamwidth.

V. MIMO TM Adapting Mechanism

MIMO signal processing in general involves three technics known as transmit diversity, spatial multiplexing and beamforming. However beamforming can be seen as a special case of spatial multiplexing since both signal processing require the knowledge of the channel state information(CSI) while transmit diversity blindly can be used for data transmission. In addition, the instantaneous choice of the signal processing is inherently related to MIMO spatial correlation. High correlated channels are less diversity channels, therefore transmit diversity and beamforming are suitable for data transmission. In contrast, spatial multiplexing is strengthened from low to moderate correlated channels which are high diversity channels.

Therefore in LTE/LTE-adv transmission system, transmit diversity and beamforming based TMs should be used in highly correlated channel environments or sectors. The switching mechanism should be also capable to dynamically select spatial multiplexing based TMs when the mobile station moves toward low correlation environments.

VI. Correlation Measure

A significant drawback remains the huge size of the full correlation matrix R and its high number of elements to be estimated. Indeed for a MIMO system with n_t transmit antenna and n_r receive antenna, $n_t n_r (n_r n_t - 1)$ correlation parameters $r^m{}_{kl,qs}$ should be taken into account in a given sector Sm. 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, $k \neq q$;

$$R = \begin{pmatrix} 1 & r_{11,21} & r_{11,12} & r_{11,qs} & \cdots & r_{11,n_t n_r} \\ r_{11,21}^* & 1 & r_{21,12} & r_{21,qs} & \cdots & r_{21,n_t n_r} \\ r_{11,12}^* & r_{12,21} & 1 & r_{12,qs} & \cdots & r_{12,n_t n_r} \\ r_{11,qs}^* & r_{kl,21} & r_{kl,12} & 1 & \cdots & r_{kl,n_t n_r} \\ \vdots & \ddots & \ddots & \ddots & \ddots & \vdots \\ r_{11,n_t n_r}^* & r_{21,n_t n_r} & r_{12,n_t n_r}^* & r_{kl,n_t n_r}^* & \cdots & 1 \end{pmatrix}$$

Indeed for a MIMO system with n_t transmit antenna and n_r receive antenna, $n_t n_r (n_r n_t - 1)$ correlation parameters $r^m{}_{kl,qs}$ should be taken into account in a given sector Sm. 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, $k \neq q$; Hence, to dispense with the study of the effect of each element, we adopt the correlation measure metric of the amount correlation $\psi_{n_t n_r}$ [12][13].

$$\psi^m{}_{n_t n_r} = \sqrt{\frac{1}{n_t n_r (n_t n_r - 1)} \left(\sum_{\substack{k,q=1 \\ k \neq q}}^{n_t} r^m{}_{kl,ql} \cdot r^{m*}{}_{kl,ql} + \sum_{\substack{l,s=1 \\ l \neq s}}^{n_r} r^m{}_{kl,ks} \cdot r^{m*}{}_{kl,ks} + \sum_{\substack{k,q=1 \\ k \neq q}}^{n_t} \sum_{\substack{l,s=1 \\ l \neq s}}^{n_r} r^m{}_{kl,qs} \cdot r^{m*}{}_{kl,qs} \right)}$$

This metric can be seen as the average on the overall element $r^m{}_{kl,qs}$. It measures the state correlation in MIMO channel. High (resp.low) amount of correlation implies high (resp. low) correlated channel .

Taking a working frequency of 2GHz, the antenna spacing used is that specified by LTE standard i.e. d=4λ at the eNode B and D=0.2 λ at the UE when considering the 3-sector cell configuration in Urban macro propagation environment. The corresponding amount of correlation (figure 3) of 2X2 MIMO and 4X2 MIMO configuration channel is plotted following the beamwidth α_0 of the cell sectors. From this result a set of correlation are drawn.

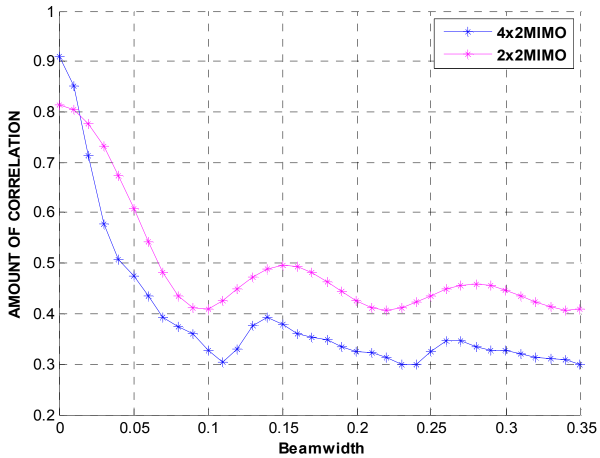

Fig.3: Amount of correlation versus sector beamwidth α_0

Table1. Correlation levels in different sectors of the same cell.

	Sector 1	Sector 2	Sector 3
α_0	0.025	0.1	0.15
2x2 MIMO	Ψ=0.64: high correlation level	Ψ=0.3283: moderate correlation level	Ψ=0.3782:moderate correlation level
4x2 MIMO	Ψ=0.7558:high correlation level	Ψ=0.4094: moderate correlation level	Ψ=0.4963:moderate Correlation level

VII. Transmission Switching scheme Analysis

In this section the error rate and capacity performances for MIMO TM are analyzed in different sectors (table 1) of the cell. Following those performance levels, the switching scheme at the base should decides for the optimal TM to be selected for data transmission when the mobile station within the cell moves from one sector to another. We adopt the 10MHz bandwidth as specified by the 3GPP LTE standard. We also assume that the eNode B requests a 4 CQI_ index. From figures 4, 5 it can be noted that in sector 1, while achieving its highest capacity in acceptable SNR range, TM3 remains reasonably performing in terms of BLER. In contrast, within the same sector TM2 being an error-rate motivation based design, naturally achieves a lowest error rate while not being able to offer a high capacity. In this case of moderate From figures 4, 5 it can be noted that in sector 1, while achieving its highest capacity in acceptable SNR range, TM3 remains reasonably performing in terms of BLER. In contrast,

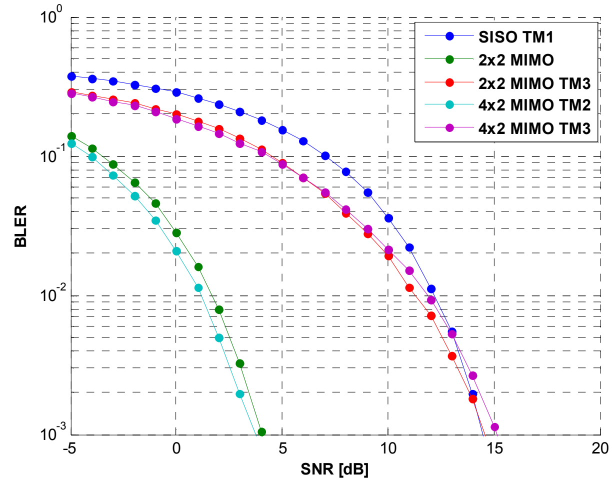

Figure.4 Block error rate performance in the sector 2 region α_0 =0.1(moderate correlation level environment)

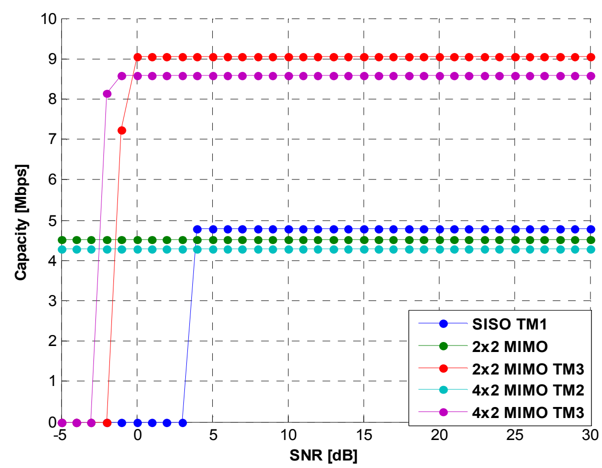

Fig.5 Capacity performance in the sector 2 region, α_0 =0.1(moderate correlation level environment).

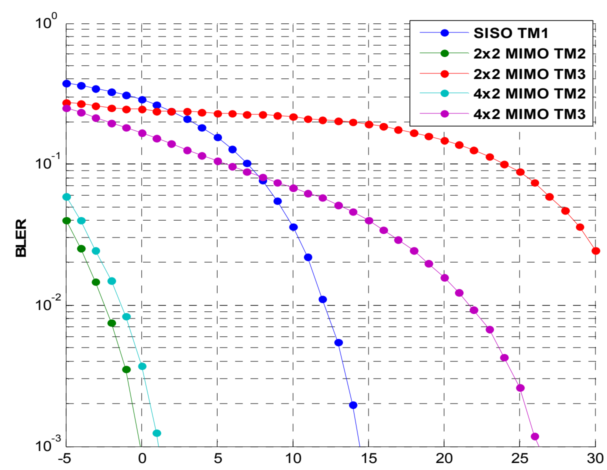

Figure .6 Capacity performance in the sector 1, α_0 =0.025(high correlation level).

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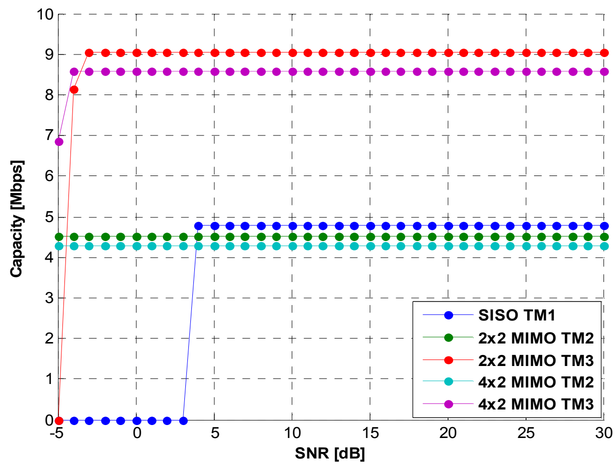

Fig.7 Capacity performance in the sector 1, α_0 =0.025(high correlation level).

within the same sector TM2 being an error-rate motivation based design, naturally achieves a lowest error rate while not being able to offer a high capacity. In this case of moderate correlation level, the eNode B can only choose to optimize the capacity and thus enable TM3.

Similar analysis for the BLER and capacity performances can be done in sector 2. As depicted in fig.6 and fig.7, it can be seen that the error–rate for TM3 becomes catastrophic while its capacity also may take slightly an increase. In this case, the eNode B can optimally choose to maximize the spatial diversity by enabling TM2 mode which remains more robust and performing. Therefore, we can conclude that when the mobile station moves from sector 1 to sector 2, the base station can adapt the transmission mode from TM2 to TM1.

VIII. CONCLUSION

A time-evolving MIMO channel model is formulated for wireless communications as well as for LTE/ LTE-A MIMO transmission mode adaption. The proposed spatial channel model is elaborated assuming a multi-sector cell scattering environments where each sector consists of multiple scattering rings with different beamwidth seen at the eNode B (or base station).Therefore, with a the motion of the User Equipment (UE) within multiple sectors, the channel may experience many realizations known at the eNode B which is then capable to adapt dynamically and select the optimal TM. We also provide simulation results corroborating our study.

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