Source: **Nortel Networks**

Title: **SCM Model Correlations**

Document for: **Discussion**

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1. Introduction

The SCM Text v1.9 [1] presents frameworks for both system and link level channel models. Central to both these models are the correlations that result between the multiple elements of either the Node B or UE ends of the link. These correlations are determined by the angular spread of the sub-rays of each tap. All the taps in the system level channel model and the majority of taps in the link level channel model proposed by the SCM group in [1] assume that the sub-ray powers are Laplacian distributed in angle (with a specified σ) and a mean AoA.

The SCM Text achieves a Laplacian distribution of power in angle by the combination of setting all of the sub-ray powers to be equal and their angles about the mean AoA to be those defined in Table 4 of [1], which have been determined a-priori to provide a Laplacian PAS with a certain σ.

When implementing the SCM sub-ray modelling approach provided in [1] it was observed that the correlations between the fading waveforms obtained from the time evolution of the sub-ray phases were not converging to the expected correlations defined in Table 2.8 of [1].

This SCM contribution considers four methods of deriving the correlation between elements when assuming a mean AoA, a Laplacian with a specific σ and a certain element spacing. The results of this analysis show that the approach proposed in [1] for modelling the AoA and powers of the sub-rays does not provide waveforms with the required correlations as presented in Table 2.8 of [1]. An alternative method of modelling the sub-ray powers and angles is provided and is shown to provide convergence to the correlations of Table 2.8 of [1].

2. Methods of Deriving Correlation

The four methods used to derive correlations are explained below:

Method 1. Correlations derived via Continuous Integral

The integral given in Equation 2-1 and Equation 2-2 can be used to determine the correlation between the elements of a ULA for any given ray AoA, when the standard deviation of the Laplacian distribution and the element spacing is defined.

Equation 2-1
$$\rho = \int_0^{2\pi} \exp\left[j \frac{2\pi r}{\lambda} \sin(\theta) \right] L(\theta)\ d\theta$$

Equation 2-2 $$L(\theta)=\frac{1}{\sigma_s\sqrt{2}}\ \exp\left[\frac{-\sqrt{2}\left|\theta-\bar{\theta}\right|}{\sigma_s}\right]$$

where

ρ is the correlation between two elements which are a distance 'r' separated when assuming a Laplacian PAS with a standard deviation of σ_s

θ is the sub-ray AoA(as seen at the array) with respect to the centre of the Laplacian distribution

σ_s is the sigma of the Laplacian distribution (this is the same as the rms value)

$L(\theta)$ is the Laplacian distribution which represents the power distribution with angle of the scatterers, as given in Equation 2-2*.*

r is the element separation distance in meters

The correlations[1] obtained from this integral are the same as those presented in Table 2.8 of [1] and are given in the column entitled 'Corr SCM Text (1)' in Table 2-1.

Method 2. Correlations derived via the sampled Laplacian Approach

The sampled Laplacian approach models the sub-rays by specifying asymmetric angles about the mean AoA (within an angular range over which the powers are significant) and then evaluating what the powers of a Laplacian distribution are for a given σ at the angles specified. The 200 sub-rays ensure the Laplacian is well sampled and the asymmetry ensures that no non-physical periodic constructive and destructive phase summations are introduced. An example of the powers and angles attributed to the sub-rays for a mean AoA of 20° and a Laplacian with σ=5° is given in Figure 2-1. For the 5° Laplacian angles in Figure 2-1 the significant powered components are considered to lie between ±15° about the mean AoA.

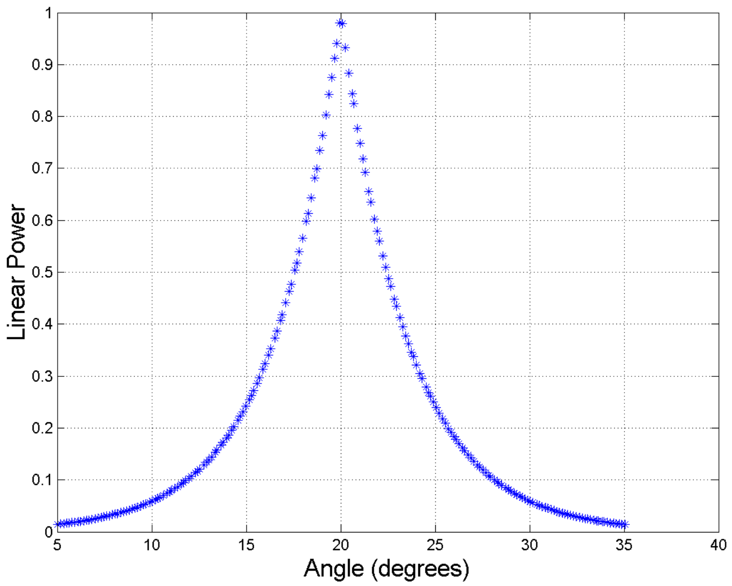

Figure 2-1 Sub-ray powers and angles used in the sampled Laplacian Approach

1 all instances of the term 'correlation' within this document refer to the magnitude of the complex correlation

The sub-rays are attributed angles which are uniformly distributed between ±15° about the mean AoA and then randomly perturbed within ±0.5*sample spacing, i.e. ± 0.5*(Angular range/number of rays) which for the case shown in Figure 2-1 is ±0.5*(30/200) = ± 0.075°. The powers for each sub-ray are then derived directly from the Laplacian function with the specified σ.

The sub-rays are then attributed random starting phases as proposed in the SCM Text [1] which can then be time evolved with respect to their AoA and distance travelled. This provides a fading waveform as seen between a Tx and Rx element. To determine the fading as seen at a spatially offset Rx element each sub-ray has a phase offset applied which represents the phase offset due to the spatial separation of the elements and the sub-rays AoA. Given these two fading waveforms, a correlation can now be derived. Correlations obtained using this approach are presented in the column entitled 'Corr Sampled Laplacian method (2)' in Table 2-1.

It should be noted whilst 200 sub-rays were used to ensure convergence for the purposes of this document, it is believed that good convergence can be achieved with a considerably smaller number of sub-rays, although currently this optimisation is an area for further work.

Method 3. Correlations derived via the SCM Model

The SCM Text [1] proposes that there are 20 sub-rays, all of which are given an equal power, i.e. (1/20) = 0.05 if assuming unity power total. The angles attributed to the sub-rays are defined in Table 4 of [1] for a Laplacian of σ =2°, 5° and 35°. These angles are defined a priori and have been derived to provide the required Laplacian PAS σ when assuming equal amplitude sub-rays. An example of the powers and angles attributed for a mean AoA of 20° and a Laplacian with σ = 5° is given in Figure 2-2.

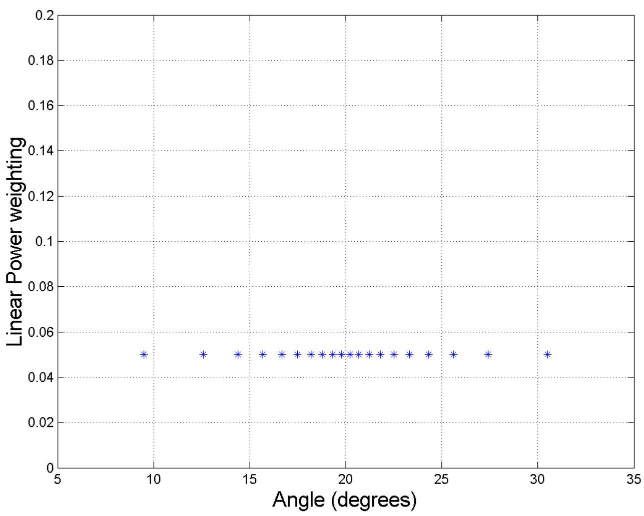

Figure 2-2 Sub-ray powers and angles used in the SCM channel model [1]

As in method 2, the sub-rays are attributed random starting phases which are time evolved with respect to distance moved and the sub-ray AoA to provide a fading trace. The fading is then determined at a spatially offset element by applying a phase shift to all sub-rays which is dependent upon both their AoA at the array and the element separation. The correlation between the two fading waveforms can now be calculated. Correlations obtained using this approach are presented in the column entitled 'Corr SCM Model (3)' in Table 2-1.

Method 4. Correlations derived via numerical Integration of discrete components

To understand what the correlations obtained via Method 3 (i.e. the SCM Text method) should be converging to, it is possible to evaluate a discrete form of Equation 2-1 and Equation 2-2 where the angles and powers of the 20 sub-rays provide the discrete component information to determine a correlation. The correlations obtained from this numerical integration of discrete components, using SCM defined angles and powers, is presented in the column entitled 'Corr Integral (4)' in Table 2-1.

Configuration	Element Spacing	Laplacian sigma	AoA	Corr SCM Text (1)	Corr Sampled Laplacian method (2)	Corr SCM Model (3)	Corr Integral (4)
1	4	5	20	0.3224	0.3222	0.2039	0.2036
2	0.5	35	20	0.4399	0.437	0.3507	0.3527
3	10	2	50	0.5018	0.5009	0.4032	0.4029
4	0.5	35	67.5	0.7744	0.7746	0.7433	0.743
5	4	2	50	0.8624	0.8636	0.8582	0.8598
6	0.5	5	50	0.9688	0.9686	0.9692	0.9692
7	0.5	2	50	0.9975	0.9976	0.9976	0.9976

Table 2-1 Correlations obtained using different methods and configurations

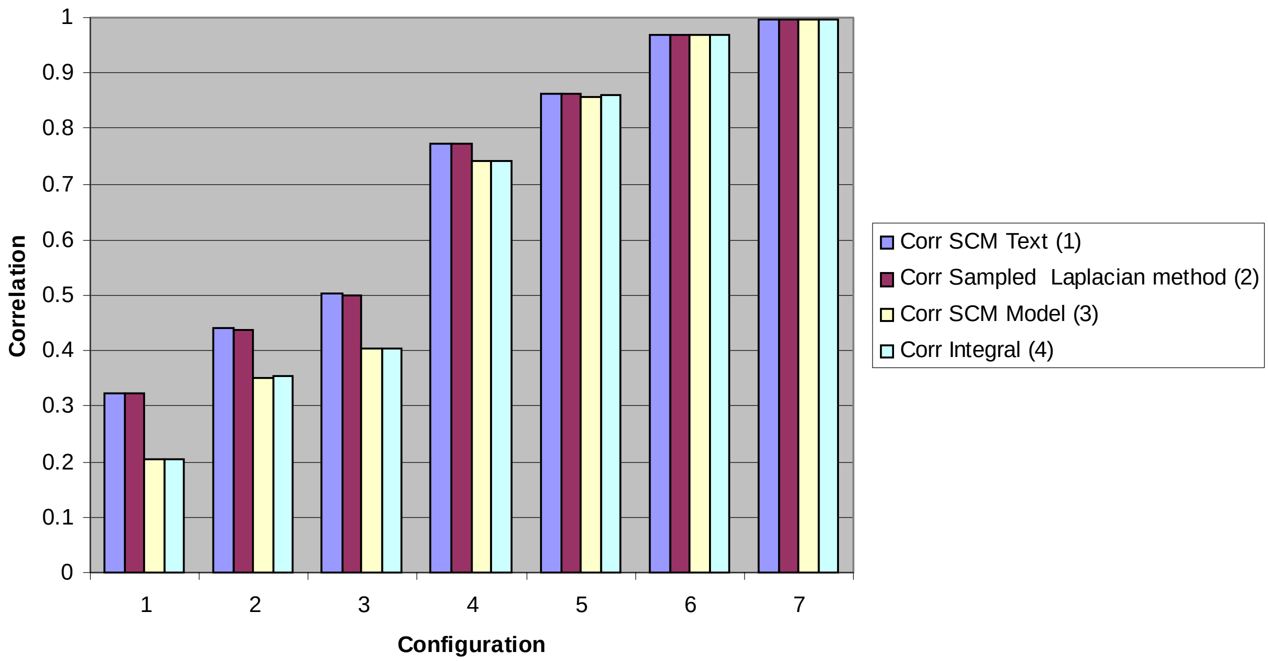

Figure 2-3 Comparison of Correlations obtained via specific methods and configurations

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(1) The correlations given in Table 2.8 of the SCM Text v1.9 (SCM-062)

(2) The correlations obtained when assuming 200 sub-rays, each of which has a power and angle from a Laplacian Distribution with a specified sigma (the angles are asymmetric about the mean)

(3) The correlations obtained when using the 20 equal powered sub-rays with angles defined in the SCM system level model in the SCM Text v1.9 (SCM-062) for each Laplacian sigma case considered.

(4) The correlations obtained when using a discrete integral method with the sub-ray angles as defined in the SCM Text v1.9 (SCM-062)

3. Comparison of Sub-ray modelling methods

The four methods of determining correlation described in section 2 were used for 7 different combinations of array element separation, mean AoA and Laplacian σ, and the resulting correlations tabulated. The values used for the configuration parameters and the associated correlations obtained from each of the four correlation derivation techniques are presented in tabular form in Table 2-1 and graphically in Figure 2-3.

The results presented in Figure 2-3 show clearly that the correlations obtained when using the SCM method (method 3 in section 2) of attributing powers and angles to the sub-rays is not providing convergence to the required correlations as presented in Table 2.8 of the SCM Text v1.9 [1] which can be derived using the continuous integral method (method 1 in section 2). Indeed numerical evaluation of a discrete form of the continuous integral used in method 1 of section 2 (i.e. method 4 in section 2) were the powers and angles as proposed by the SCM method are used as the discrete components can be seen to yield the same correlations as those obtained via the SCM spatial approach (method 3 in section 2). This shows that when the SCM proposed angles and powers for the sub-rays are used, it is not possible to converge to the required correlation values, they converge to the values calculated from the discrete numerical integral method, i.e. method 4 of section 2).

The alternate sampled Laplacian method proposed by Nortel (method 2 in section 2) which uses asymmetric angles at which to sample a Laplacian of a specified σ to determine sub-ray powers, can be seen in all cases to provide good convergence to the expected correlations as derived via method 1 of section 2 (i.e. the correlation values provided in Table 2.8 of the SCM Text v1.9 [1].

4. Possible causes of non-convergence of correlation in the SCM model

At present the cause of the non-convergence observed when using the SCM approach of equal powered, defined angles for the sub-rays is not known. Possible sources of non-convergence include:

- Symmetric sub-ray angles introduce a periodicity in the constructive and destructive phase combinations of the sub-rays which may introduce a phase shift between the waveforms as seen at two spatially separated elements and hence change the correlation observed between them.
- The symmetry of the 20 sub-ray angles mean that there are only 10 effective sources, i.e. frequency components which contribute to the fading. Also when considering the vector summation of these in the Argand plane, since they are all equal amplitude, the end components have a disproportionately large effect on the resultant and hence the ability for convergence to be achieved.

5. Summary

This contribution has shown that method of modelling the angles and powers of the sub-rays proposed in the SCM Text v1.9 [1] does not provide the correlations, as specified in Table 2.8 of [1], between waveforms as observed between spatially offset elements. An alternative approach (method 2 of section 2) has been presented and has been shown to provide convergence to the required correlations and hence is proposed as a replacement for the current method described in the SCM Text.

6. References

[1] 'Spatial Channel Model Text Description v1.9', Spatial Channel Model AHG (combined ad-hoc from 3GPP & 3GPP2), SCM-057, 9th October 2002.