Project	**IEEE 802.20 Working Group on Mobile Broadband Wireless Access** **<http://grouper.ieee.org/groups/802/20/>**
Title	**Open Issues on Channel Modeling**
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Re:	Evaluation criteria.
Abstract	This document eludes the critical issues in channel modeling that has not been addressed so far..
Purpose	Discuss and adopt.
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1 Introduction

Any simulation effort in the mobile communications requires a consistent application of the given channel model. The consistency is not an option, rather a requirement, when the simulation is to be performed via two independent stages, i.e. link-level simulation and system-level simulation, as is the case for the evaluation of MBWA. A common assumption made so far, without any discussion, is that the spatial channel model is going to be used. It should be pointed out that

- the spatial channel model does not necessarily provide the consistency required by the link-system interface and it assumes a certain link level simulation methodology that is yet never scrutinized with respect to its applicability.
- there exists alternative channel model that is consistent in terms of the link-system interface and can also capture the spatial diversity as experienced by non-trivial antenna systems.

This contribution will discuss these two aspects

2 Link Level Simulation

The goal of the link-level simulation is to compute the PER of a given packet as a function of the measured SNR, the so-called link curve. The shape of the link curve depends not only on the details of the receiver such as modulation, channel coder, interleaver and packet size, but also on the channel model assumed. The most straightforward link curve is the so-called AWGN curve, which assumes the received signal

$$r(t) = s(t) + n(t) \tag{1}$$

where $s(t)$ is the transmitted signal, $r(t)$ the received signal and $n(t)$ the AWGN with a given variance σ^2. Since no fading is assumed in an AWGN channel $s^2(t)$ is constant during a packet duration. Thus, the packet error rate for an AWGN channel can be plotted as a function of $s^2(t)/\sigma^2$. AWGN channel, however, is a rather simpler channel model and does not suffice to charaterize the typical mobile communication channels. The mobile channels are fading channels,

$$r(t) = s(t) * h(t) + n(t) \tag{2}$$

where $h(t)$ is the fading channel response and $*$ indicates the convolution of two functions. The function $h(t)$ is in fact a stochastic process and is generated according to the given distribution in the simulation. Different channel models have different functions $h(t)$ as their channel realization. The effect of a non-trivial $h(t)$ is the variation of the received signal even when the transmitted signal does not vary. As a result, $[s(t) * h(t)]^2$ is no longer a constant over any given time period. This poses a difficulty in relating the instantaneous received signal to the observed packet error event to be simulated, because the mobile channel is a stochastic process and is typically non-stationary.

Let the packet to be observed stretch over a time interval $[t, t+T)$ and the signal-to-noise ratio be measured as

$$SNR_{[t,t+T)} = \frac{\int_t^{t+T} |r(t)|^2 dt}{\int_t^{t+T} |n(t)|^2 dt} \tag{3}$$

where $r^2(t)$ and $n^2(t)$ are the received signal power and noise power at time t, respectively. Since $n(t)$ is white, it is independent of time instance t. This allows us to repalce the denominator by the power spectrum density (both have unit of energy)

$$N_0 = E\{\int_t^{t+T} |n(t)|^2 dt\} \tag{4}$$

for a non-trivial T. That is

$$SNR_{[t,t+T)} = \frac{1}{N_0} \int_t^{t+T} |r(t)|^2 dt \tag{5}$$

This is a mapping of

$$L_2([0,T)) \mapsto [0,\infty) \tag{6}$$

i.e. a functional. Although, for simplicity, the received signal $r(t)$ is noted as a function of single variable, it depends on many other paramters. In particular, it depends on the channel via $r(t) = s(t) * h(t)$. The task of a link-level simulation is to determine $PER(SNR)$ for the use by the system-level simulation, where SNR is independent of t.

3 System Level Simulation

The goal of system level simulation is to capture the macroscopic effect of the mobile communications environment, such as mobile location, speed, traffic, antenna configuration etc. It can only be performed when the corresponding link curve is given; the link-curve is evaluated before any system level simulation can start and the results are stored as look-up tables. The system level simulation utilizes the given link-curves by tossing a fair coin for the measured SNR to decide whether the outcome is decoded or not decoded, i.e.

$$\begin{aligned} p < PER(SNR_{[t,t+T)}) &\Rightarrow \quad \text{error (i.e. bad packet)} \\ p \geq PER(SNRSNR_{[t,t+T)}) &\Rightarrow \quad \text{decoded correctly (i.e. good packet)} \end{aligned}$$

where $p \in (0,1]$ is the random number generated via a coin tossing at the given time instance. At any given time instance, each mobile has a definitive location, a channel condition and a fixed size of packet. Therefore, the correct behavior can be simulated only when the mobile (or the base station in case of uplink), having measured its SNR for the given location, given channel condition and given packet at the given time, to read the corresponding link-curve to determine the success or failure of the reception. Now that the link level simulation and the system level simulations are performed independently, how can the results be combined to produce a sequential random events that corresponds to the "coherent" dynamics of the mobile channel ? The key to a solution of this problem is a statistical consistent interface between the system-level simulation the link-level simulation.

4 Link-System Interface

As different channel conditions require different stochastic processes to characterize, we need a family of link curves for different channels and different packet sizes, in order to perform the system level simulation. A link-curve, being a function of a single variable, ought to be generated by computer experiments with the packet size, channel model,...etc. fixed. Since SNR measured over a given time interval is not sufficient to characterize the channel $h(t)$, different approaches to evalute $PER(SNR)$ result in different results with different meanings. A link-system interface is a rule that specify how the link-level and the system-level simulators shall generate and interpret the same $PER(SNR)$: They shall do so in a consistent way based on the underlying statistic model. Statistically, there is the notion, for instance, of "short term" and "long term". The long term link curve is the numerical estimation of the probability distribution

$$Pr(\frac{\text{no. of good packets}}{\text{no. of total packets}} < PER|SNR = \frac{E\{\bar{r}^2(t)\}}{E\{n^2(t)\}}) := PER(SNR,T) \tag{7}$$

where T is used to emphasize the dependence on the time duration, because of the average

$$\bar{r}(t) = \frac{1}{T}\int_{t-T/2}^{t+T/2} r(t)dt, \tag{8}$$

while the short term link curve is the numerical estimation of the probability distribution

$$Pr(\frac{\text{no. of good packets}}{\text{no. of total packets}} < PER|SNR - \Delta/2 < \frac{\bar{r}^2(t)}{E\{n^2(t)\}} \leq SNR + \Delta/2) := PER(SNR,T) \tag{9}$$

where Δ corresponds to the granularity of SNR. When the channel is constant over the packet duration, the long term link-curve is identical to AWGN link-curve. But if the channel is non-trivial, the long-term link-curve fails to characterize the channel in its microscopic nature within a given time interval $[t, t+T)$, as it loses the characteristic of the temporary varaion of the channel in short time period. On the other hand, the short-term link-curve is capable of capturing the impact of the channel variation within $[t, t+T)$ on the receiver outcome. Now that the system-level simulation computes the SNR packet-wise, using the short term link-curve, the system level simulator and the link level simulator are refering to the same statistic, as long as the parameters, which include e.g. $h(t)$, used in both simlators coincide. That is to say that the consistency is maintained by using the short-term link-curve.

When T is so short that the channel variation can be neglected, the $PER(SNR, T)$ becomes independent of the short term variation within the packet duration. The error events within a packet is not much affected by the channel variation within the packet duration, as long as its amplitude is accurately measured by the system-level simulation. This is equivalent to an AWGN link-curve with a scaling of the ordinate by

$$F(t) = \frac{\bar{r}^2(t)}{s^2(t)} \tag{10}$$

The so-called quasi-static method makes the assumption that $F(t)$ is independent of t and the constant is called fudge factor. Under this assumption a fudge factor can be determined by empirical experiments for different channel conditions. Using the quasi-static method, one needs to use a set of predetermined fudge factors together with an AWGN link-curve, i.e. the channel characterisitc should be captured by the fudge factor. The applicability of the assumption that $F(t)$ is independent of t depends, as mentioned earlier, on whether the variation within the packet duration can be neglected or not with regard to its impact on the decoding and demodulation. The latter depends on the channel condition as well as the packet size. This is typical for all link-system interface that is based on scaling SNR.

5 Limitation of the Spatial Channel Model

The spatial channel model is an attempt to capture the complex channel impacts on non-trivial antenna structures. The model is based on the statistical parameterization of empirical results gained from the field. To reproduce the complex nature of wave propagation and diffraction, the model deploys numerous statistic models in paralell as well as in serial. Using this model to generate link-cuver, the number of deterministic parameters needed to generate link-curve becomes infinite.

Even under the condition that the number of the deterministic parameters is limited to a finite set, the size of the set is still huge in order to take the advatage of the available sptial information in the SCM. Therefore, the only practical approach is to use a link-system interface based on SNR scaling, so that only AWGN link-curve is needed plus a set of fudge factors. As mentioned above, such an approach is only reasonable when the packet size is small relative to the coherence time of the channel. As result, the SCM can only be deployed consistently using the quasi-static method within the architecture of 2 stage simulation. Whether reliable fudge factors can be found and to which extent they apply is another issue. The issue we have here is the following:

Standard scientific approach to solve a problem consists of three steps:

- Identifiy and charcterize the problem,
- Find and formulate the solution,
- Evaluate the solution under the given condition (or assumption), and apply approximation whenever necessary and appropriate.

The procedure may be iterative, but it always starts with a quantitative description of the problem. Voilation of this principle leads to wrong, or misinterpretation of the, results. One example is the ray-tracing technique, a method to compute the spatial power distribution of a given channel based on a numerical approximations, typically the GTD(geometrical technique of diffraction). GTD assumes the existence of rays at diffraction location, which are determined by canonical geometry by high frequency approximation and, as such, depends on the shape, material and size of the canonical geometry. Therefore, a successful deployment of ray tracing depends on the appropriate application of GTD (or PO, GO) to the appropriate diffraction surface, wedge, corner and edges. Therefore, no ray tracing tool can deliver reasonable results without careful design and application of the canonical results to the specifics of the application environment.

Back to the spatial channel model, the dilema we are facing now is that we don't know yet what kind of sizes each technical proposal will use. Without knowing the packet size, or the ratio of the packet size versus the coherent time, it is not possible to determine whether the quasi-static method applies, or to which extent it applies when it applies. Without knowing whether quasi-static method applies to link-system interface, we cannot judge the applicability of the spatial channel model to the simulation evaluation task we set for us.

6 Alternative Channel Model

As shown above, the short-term link curve always provides the consistency required by the link-system interface. One needs only to generate a family of link- curves for given paramters, say each channel type, packet size. For the same channel type and the packet size, the system level simulation can compute SNR for each packet and read the corresponding link-curve to determine the reception error or success. By channel type we mean, e.g. the classification of ITU models. The only thing that is missing in the ITU models is the spatial relation between channels arriving/departing from different antenna elements of a non-trivial antenna system. How can the spatial variation of the channel be incorporated into the ITU model ? The answer to this question is the correlation matrix.

Assume a transmit antenna system of N elements and a receive antenna of M elements. For a given ITU channel model, an independent instance of channel realization can be generated for each transmit antenna element, resulting in N independent channel instances. When these N channels arrive at the receiver, they hit all M receiver antennae. The received signal by the M receive antenna elements can be related to the signal carried by the N independent channels quantitatively via a correlation matrix

$$\mathbf{r} = \mathbf{C} \cdot \mathbf{s}_{in} + \mathbf{n} \tag{11}$$

where the correlation matrix has the defined as, e.g. by $N \times M = 4 \times 4$,

$$\mathbf{C} = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} \\ c_{21} & c_{22} & c_{23} & c_{24} \\ c_{31} & c_{32} & c_{33} & c_{34} \\ c_{41} & c_{42} & c_{43} & c_{44} \end{bmatrix} \tag{12}$$

and $\mathbf{r} = [r_1(t), r_2(t), r_3(t), r_4(t)]^T$, $\mathbf{s}_{in} = [(h_1 * s)(t), (h_2 * s)(t), (h_3 * s)(t), (h_4 * s)(t)]^T$ and $\mathbf{n} = [n_1(t), n)_2(t), n_3(t), n_4(t)]^T$. Physically, $c_{i,j}$ captures the fraction of transmitted signal by antenna j that is received by the receive antenna i. Needless to say

$$\sum_i c_{i,j} = \sum_j c_{i,j} = 1 \tag{13}$$

must hold. A correlation coefficient has two physical backgrounds: channel correlation due to correlated scatterers and antenna correlation due coupling of the antenna elements. An estimation of the values of $c_{i,j}$ should be based on a summation of the contributions comming from these two sources.

Unlike the SCM, a correlation coefficient does not tell us how and where this value is physically generated, and, as such, it is not explicitly dependent of the physical parameters that may have possibly produced this specific correlation value. Both the SCM and the correlated ITU model have pros and cons. It appears to be a rather religious debate as to whether it is better to characterize the spatial diversity by means of physical modeling or by a measureable quantity. Fact is that the approach of correlation matrix is completely based on the ITU model and is capable of capturing the spatial diversity. As such, this method is consistent in terms of link-system interface, since it allows for the usage of the short-term link curve in the system level simulation.

7 Conclusion

For a simulator with an architecture of independent link-level component and system-level component, it is important that the interface between these two component simulators is consistent in terms of the statistic method used, i.e. both component simulators have the same way of computing SNR and the same way of interpreting the $PER(SNR)$. At the stage of defining the evaluation criteria, the packet size, hence the impact of the short term variation of the channel on the link-curve, is unknown. By this circumstance, the spatial channel model posses certain difficulty to provide a consistent link-system interface for the simulation.

On the other hand, ITU models can be augemented by the correlation matrix to capture the spatial relation between transmit and receive signals. As this method is based on short-term link curve, it is consistent in terms of link-system interface. We recommend the group to reconsider the channel model issue and adopt the proposed method.

References

[1] IEEE802.20 "Evaluation Criteria Document"

[2] IEEE802.20 "Spatial Channel Model Document"

[3] ITU Channel Model