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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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# Open Issues on Channel Modeling

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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 mandate, when the simulation is to be performed via two independent stage as 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 decoding method 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 $\sigma^2$. Since no fading is assumed in an AWGN channel $s^2(t) = 1$ holds during the simulation. As the result of such a simulation, the PER is then plotted as a function of $1/\sigma^2$. AWGN channel, however, is the best-case channel model, and, as such, does not suffice to charaterize the 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 a different $h(t)$ as their channel realization. The effect of a non-trivial $h(t)$ is the short term variation and correlation of the received signal. As a result, $[s(t) * h(t)]^2$ is no longer a constant over time. This poses a difficulty in relating the instantaneous received signal power to the observed packet error, because the mobile channel is no longer stationary; the best assumption can be made about the mobile channel is the wide-sense stationarity. Therefore, strictly speaking, the process is not ergodic,i.e.

$$\bar{r}^2(t) = [\frac{1}{T}\sum_{\tau=-T/2}^{T/2} r(t+\tau)]^2 = [\int h(t')\frac{1}{T}\sum_{\tau=-T/2}^{T/2} s(t+\tau-t')dt']^2 \leq ||h(\cdot)||_2^2 \cdot ||\frac{1}{T}\sum_{\tau=-T/2}^{T/2} s(t+\cdot)||_2^2 \to 0 \tag{3}$$

does not converge to the expected value at time $t$ for $T \to \infty$, where $|| \cdot ||_2$ refers to $L_2$ norm. In reality, $T$ is limited by the finite packet size. Consequently, the instantaneous power $\bar{r}^2(t)$ is time depedent and the outcome of the reception does not depend on SNR alone, unless the dependency of $PE(SNR, h)$ on $h(t)$ is already captured by the link-level simulation.

## 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, i.e. the link curve generated for the given channel environment. As the link-curve is evaluated before any system level simulation can start, each system level simulation utilizes the given link-curve by tossing a fair coin for the measured SNR to decide whether the outcome is decoded or not decoded, i.e. the decision is made in the following fashion

$$\begin{aligned} p < PER(SNR) &\Rightarrow \ error \\ p \geq PER(SNR) &\Rightarrow \ decoded \ \ correctly \end{aligned}$$

where $p \in (0, 1]$ is the random number generated at the a 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 produced that corresponds to the dynamics of the channel and traffic ? The key to a solution of this problem is the link-system interface.

## 4 Link-System Interface

While the SNR is computed in the link simulation and system level simulation independently, at a given time instance the mobile measures an SNR and look at a corresponding link curve for the $PER(SNR)$ value and tosses a dice to make decision. As different channel condition have different stochastic process to characterize, there have to be a family of link curves for different channels and different packet size. Let the packet size be fixed, so that the link-curve depends only on the SNR value. Different ways of determining the statistics of $PER(SNR)$ may capture different nature of the statistics, and caution is required to choose the correct statistics. Depending on the way the statistics is evaluated, the same SNR may result in different PER. The rational for this is that the SNR measured over a given time interval depends on instantaneous pattern of the in this time interval. Roughly speaking, there is two different categories of link-curve: the short term and the long term. The long term link curve is the numerical estimation of the probability distribution

$$Pr(PER|SNR = \frac{E\{\bar{r}^2(t)\}}{E\{n^2(t)\}} \tag{4}$$

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

$$Pr(PER|SNR - \Delta < \frac{\bar{r}^2(t)}{E\{n^2(t)\}} \leq SNR + \Delta) \tag{5}$$

where $2\Delta$ corresponds to the packet size. The short-term link-curve has obviously the advantage of universal applicability; one needs to generate it for each given channel type, i.e. given $h(t)$. As long as we compute the SNR in the system level simulation and the link-level simulation the same way, the consistency is maintained by the short-term link-curve.

When $T$ is so short that the channel variation can be neglected, the $PER(SNR)$ becomes independent of the short term variation within the packet duration. The decoder, then, is not affected by the channel variation within the packe duration, rather by its amplitude. In case $E\{s^2(t)\} = 1$ and $E\{n^2(t)\} = \sigma^2$, this is equivalent to an AWGN link-curve with a scaling of the ordinate that amounts to

$$F(t) = \frac{\bar{r}^2(t)}{s^2(t)} \tag{6}$$

The so-called quasi-static method makes the assumption that $F(t)$ is independent of $t$ and thus can be determined by empirical experiments. Thus, using the quasi-static method, one needs to use a set of predetermined fudge factors together with an AWGN link-curve. The assumption that $F(t)$ is independent on $t$ is, however, only valid under very limited conditions. The applicability of such method, as mentioned earlier, depends on whether the variation within a packet duration can be neglected or not. The latter depends on the channel condition as well as the packet size.

## 5 Limitation of the Spatial Channel Model

The spatial channel model is an attempt to capture the complex channel impact on non-trivial antenna structure. It is based on the physical background of those impact and make use of many available empirical results. Despite its complexity in implementation, it does provide sufficient information to allow for a good evaluation of the antenna performance under the given channel condition. However, the SNR computation within the frame work of spatial channel model turns out to be a challenge for a simulator architecture that is based on independent link-level simulation and system-level simulations. That is because the SNR in spatial channel model depends on many more parameters that just time, location and channel type. While in ITU model, the link curve is a function of SNR, channel type and packet size, in SCM the link-curve depends in addition on the incident angle and transmit angle. The arrival and departure angle take continuous values. Therefore, it is not possible to reduce the link-curve to a family, or multiple families, of functions of a single variable, not to mention its implication to the required simulation efforts. As a results, the SCM can only be deployed consistently using the quasi-static method. Whether reliable fudge factors can be found and to which extent they apply is another issue.

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 approximation called GTD(geometrical technique of diffraction). GTD assumes the high frequency approximation and depends on the shape and the electrical size of the obstacle. Therefore, a successful deployment of ray tracing depends on the appropriate application of GTD to the diffraction surface, wedge, corner and edges. Therefore, no ray tracing tool can deliver reasonable results without careful design and application of GTD 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 each channel type and 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 means, e.g. the classification of ITU models. The only thing that is missing in the ITU model 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 integrated 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

$$\mathbf{r} = \mathbf{C} \cdot \mathbf{s}_{in} + \mathbf{n} \tag{7}$$

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

$$\mathbf{C} = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} \\ c_{21} & c_{22} & c_{23} & c_{24} \\ c_{31} & c_{32} & c_{33} & c_{34} \\ c_{41} & c_{42} & c_{43} & c_{44} \end{bmatrix} \tag{8}$$

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

$$\sum_i c_{i,j} = \sum_j c_{i,j} = 1 \tag{9}$$

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, i.e.

both component simulators have the same way of computing SNR and the same way of interpreting the packet error probability. At the stage of defining the evaluation criteria, the packet size is unknown, hence the impact of the short term variation of the channel on the link-curve. 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