Baseband Wireless Channel Emulator

Background and Simulation Task

# Wireless Channel and its baseband model

The wireless channel is the component between transmitter antenna(s) and receiver antenna(s) in mobile telecommunication systems. There are three types model in mobile radio propagation: Large Scale Path Loss, and Shading Losing, and Fading with Multipath (Referring *Wireless Communications: Principles and Practice*, T. S. Rappaport).

Generally, only Fading and Multipath will be considered in the baseband channel model. And the other two will be ignored and analyzed in load balance, and networks planning, and system level simulations.

## Structure for Baseband Wireless Channel

Technically, Maxwell's equations can describe the electromagnetic field perfectly. But they are hard to be applied in the engineering scenarios for various environments. The same problem stands there to analyze the channels in the fields. Although there are many theories on the channels, the measurement and statistical methods are more important in engineering.

There are some different structures for baseband wireless channel emulator/simulator products in current market. The tapping model is the most common one which will be introduced in the following. While, the replay model is applied with huge memory to record the channel data and they will be replayed when the channel is requested to be generated. Last but not least the angle spreading models are presented with MIMO technology applying more and more in the systems as LTE and LTE-A.

## Tapping Models

The assumption for tapping model is that there are independent fading taps with different delays and powers in the channel, as

 (1)

Where N is the number of taps; hi is the fading coefficient for the tap i, which following the Rayleigh or Ricean fading distribution with weights for power assignment; ti is the delays of the tap i; n is the noise.

Without loss of generality, the average channel factor will be assumed as 0 dB. In the other words, there will be no power losing with the signal passed the 'baseband wireless channel', and

 (2)

Where E{ } is the average operation for the possibility variables.

And the same time, there interference by the other transmitters should be considered in the environment. The effect will be looked as Additive White Gaussian Noise (AWGN) by Central Limit Theorem.

All in all, the tapping model for SISO systems will be presented as Figure 1-1. The structure for SISO systems is the simplest one, but the simulator for MIMO can be created with and coherent matrix inserted base on it.



Figure 1-1. Structure of Tapping Model for SISO Systems

## Taps Component

Although the mathematic model is descripted as function (1) for the taps component, some transformations should be taken for the implement.

Introducing s(t) as the transmitter output signal, the signal without noise v will be

 (3)

Where pi is the constant power weights on power assignment; fi is the independent fading coefficients following the Rayleigh or Ricean fading distribution with average of 1. For each tap in the model, the structure will be designed as Figure 1-2. In which, the signal will be in the complex number format except the power weight pi.



Figure 1-2. One Tap Path

And the whole Taps Component will be presented in Figure 1-3.



Figure 1-3. Structure for Taps Component

# Rayleigh Distribution and Coefficient Generation

The Rayleigh distribution has a probability density function as

 (3)

The f coefficients can be generated by general random number method. But there is an engineering way to create them more easily together with the Doppler spreading, which called Jakes Model.

In his book ( *Microwave Mobile Communication*, W. C. Jakes), Jakes popularised a model for Rayleigh fading based on summing [sinusoids](https://en.wikipedia.org/wiki/Sine_wave). Let the scatterers be uniformly distributed around a circle at angles \alpha_n with k rays emerging from each scatterer. The Doppler shift on ray n is

\,\!f_n = f_d\cos{\alpha_n} (4)

and, with M such scatterers, the Rayleigh fading of the k^{th} waveform over time t can be modelled as:

R(t,k) = 2\sqrt{2}\left[\sum_{n=1}^{M}\left(\cos{\beta_n} + j\sin{\beta_n}\right)\cos{\left(2 \pi f_n t + \theta_{n,k}\right)} + \frac{1}{\sqrt{2}}\left(\cos{\alpha} + j\sin{\alpha}\right)\cos{2 \pi f_d t}\right].(5)

Here, \,\!\alpha and the \,\!\beta_n and \,\!\theta_{n,k} are model parameters with \,\!\alpha usually set to zero, \,\!\beta_n chosen so that there is no cross-correlation between the real and imaginary parts of R(t):

\,\!\beta_n = \frac{\pi n}{M+1} (6)

and \,\!\theta_{n,k} used to generate multiple waveforms. If a single-path channel is being modelled, so that there is only one waveform then \,\!\theta_{n} can be zero. If a multipath, frequency-selective channel is being modelled so that multiple waveforms are needed, Jakes suggests that uncorrelated waveforms are given by:

\theta_{n,k} = \beta_n + \frac{2\pi(k-1)}{M+1}. (7)

In fact, it has been shown that the waveforms are correlated among themselves — they have non-zero cross-correlation — except in special circumstances.[[7]](https://en.wikipedia.org/wiki/Rayleigh_fading#cite_note-7) The model is also deterministic (it has no random element to it once the parameters are chosen). A modified Jakes' model chooses slightly different spacings for the scatterers and scales their waveforms using Walsh–Hadamard sequences to ensure zero cross-correlation. Setting

\alpha_n = \frac{\pi(n-0.5)}{2M} and \beta_n = \frac{\pi n}{M}, (8)

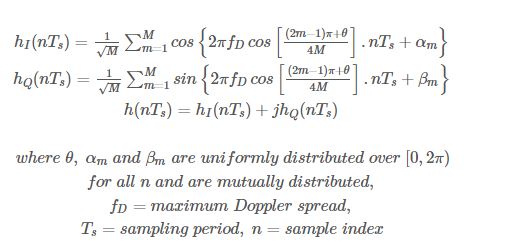
results in the following model, usually termed the Dent model or the modified Jakes model:

R(t,k) = \sqrt{\frac{2}{M}} \sum_{n=1}^{M} A_k(n)\left( \cos{\beta_n} + j\sin{\beta_n} \right)\cos{\left(2\pi f_d t \cos{\alpha_n} + \theta_{n}\right)}.(9)

The weighting functions A_k(n) are the kth Walsh–Hadamard sequence in n. Since these have zero cross-correlation by design, this model results in uncorrelated waveforms. The phases \,\!\theta_{n} can be initialized randomly and have no effect on the correlation properties. The fast Walsh transform can be used to efficiently generate samples using this model.

The Jakes' model also popularized the Doppler spectrum associated with Rayleigh fading, and, as a result, this Doppler spectrum is often termed Jakes' spectrum.

In one word, the Rayleigh fading can be implemented as

 (10)

(Referring <http://www.gaussianwaves.com/2011/05/simulation-of-rayleigh-fading-clarkes-model-sum-of-sinusoids-method-2/> and <http://library.utem.edu.my/index2.php?option=com_docman&task=doc_view&gid=5459&Itemid=342> )

# AWGN Generation

The generation of uniform random numbers was introduced in my book, *Diving into IP Core*, as

 (11)

Where，u is random numbers; n is a primer in format of 2k + 1; g is the minimum Primitive root modulo n; the initial value of u(0) and n should be relatively prime. For example, n = 216 +1 = 65537, g = 75 and u(0) = 4.

AWGN signal can be generated from the uniform ones.

The Box–Muller transform, by George Edward Pelham Box and Mervin Edgar Muller 1958, is a pseudo-random number sampling method for generating pairs of independent, standard, normally distributed (zero expectation, unit variance) random numbers, given a source of uniformly distributed random numbers.

To generate the AWGN, the [Box–Muller method](https://en.wikipedia.org/wiki/Box%E2%80%93Muller_transform) uses two independent random numbers U and V distributed [uniformly](https://en.wikipedia.org/wiki/Uniform_distribution_(continuous)) on (0, 1). As


    X = \sqrt{- 2 \ln U} \, \cos(2 \pi V) , \qquad
    Y = \sqrt{- 2 \ln U} \, \sin(2 \pi V) .
   (12)

X and Y will both have the standard normal distribution, and will be [independent](https://en.wikipedia.org/wiki/Independence_(probability_theory)). This formulation arises because for a [bivariate normal](https://en.wikipedia.org/wiki/Bivariate_normal) random vector (X, Y) the squared norm X2 + Y2 will have the [chi-squared distribution](https://en.wikipedia.org/wiki/Chi-squared_distribution) with two degrees of freedom.

Task 1

Write the structure description and design documents for Wireless Channel Emulator in Taps Model. And write the code in MATLAB formation with the Matlab form with matrix, vector, and functions.