確率的時空間チャネルモデルと用いた時空間ダイバーシチ方式の特性シミュレーション

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あらまし　本稿では、送信機、チャネルおよび受信機からなる移動体通信システムのシミュレーションを行う。遅延スプレッドが移動機の移動に伴ってランダムに変化するような都市エリアに、時空間動的チャネルモデルを適用して検討を行った。２つの異なる方式を用いた受信機の、受信ダイバーシティの効果についてシミュレーションを行った。一つは MLSE 受信機で、もう一方は時空間受信機であり、これは１対の branch metric combining scheme を用いた constrained アレイプロセッサ、および最終段に MLSE 用いた構成である。また、アレイアンテナの形式がシステムに及ぼす影響を検討するために、リニアアレイアンテナおよび円形アレイアンテナの２つのアレイアンテナを用いた。さらにそれぞれのアレイアンテナに対して、エレメント間隔が及ぼす影響を考慮するため、異なるエレメント間隔を用いて検討を行った。

キーワード　ダイバーシチ, 時空間チャネルモデル, 時空間レシーバ

Performance Simulation of Spatio-Temporal Diversity Schemes Using Stochastic Spatio-Temporal Channel Models

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Abstract　A mobile communication system composed of transmitter, channel and receiver is simulated. A spatio-temporal dynamic channel model is implemented for a metropolitan area where the delay spread changes randomly during the movement of the mobile station. Two different receivers have been simulated to analyze the effects of receive diversity on their performance separately. One is a maximum-likelihood-sequence-estimator (MLSE) receiver The other one is a space-time receiver comprising a pair of constrained array processors with a branch metric combining scheme and MLSE at the final stage. Two array configurations, a linear array antenna and a circular array, are used to analyze the impact of configurations of array antenna on the system. Also for each of the configurations of arrays different element separations were assumed to add the antenna separation effects to the analysis.

Key words　Diversity, Spatio-temporal channel model, Space-time receiver

1. Introduction

Diversity is a powerful communication receiver technique that provides wireless link improvement at relatively low cost. There is a wide range of diversity implementations, many of which are very practical and provide significant link improvement with little cost. Diversity exploits the random nature of radio propagation and is best performed when there are independent or at least highly uncorrelated signal paths of communication.

In fact, the earliest attempts to find a description and evaluation of signal reception using multi element antennas goes back to more than 30 years ago. Since then, studying performance of the diversity antenna has been continuously a research subject for the people of the field. However, the realistic analysis of this widely used technology is still an open problem. This is due to the nature of a wireless channel which comprises of a random statistical structure resulting in an unpredictable receiving behavior. It is this random attribute of the wireless channel that actually makes diversity an advantageous technique. On the other hand this unpredictability has the disadvantage of making every kind of exact analysis of diversity behavior difficult.

The "diversity gain" that is the amount of improvement in the system performance as a result of applying diversity is very much dependent on some characteristics of the system. Specifically, the diversity gain depends on:

- The configuration of antenna elements. This includes the distance between elements and the position of elements relative to each other.
- The nature of the communication channel. Especially, the time dispersion, fading and correlation of the received waves and the nominal direction and the dispersion of received paths compare to each other and to the array have significant effects here.
- The architecture of transmitter-receiver system in use.

A valuable amount of research has been done on evaluating each of these factors affecting the performance of the diversity system. Nevertheless more effort seems to be essential in this area. This is due to two factors. First, as previously mentioned the diversity performance is affected by receiving-transmitting techniques, where by introducing new techniques, the diversity has to be investigated again. Second, with introducing advanced channel models, which can simulate the real mobile wireless channel more significantly and with a better precision, new chances to obtain more precise evaluation of the diversity effect has appeared.

In this article we describe the structure and approach of the research we are currently carrying out about evaluating the diversity performance of mobile communication systems.

2. System Model

To evaluate the performance of a diversity system and inspect its effects on the performance of the mobile communication system through simulation, the first step is to obtain an overall model. The simulation then can be implemented based on this model. Obviously the precision of the model and the degree of its agreement to reality is a crucial issue affecting the validity of the results. To model a mobile communication system the most important and subtle part is the channel. Even though a big amount of effort has been done to obtain an acceptable channel model, uncertainties about mobile channel models accracy remains. In addition, implementation of more precise models usually brings about absurdly complicated simulations.

On the other hand, modelling rceiver and transmitter are not as hard as channel modelling, although it is a minutely exact job. Finding the optimum configuration for transcievers in context of divesity efficiency, which is subject of current research, can be a complicated task. In the remaining of this paper we first will explain the models of our choice for the mobile channel and receiver system, then will show our approach to the simulation of the system.

3. Channel Model

General structure chosen for wireless channel model is based on a tapped-delay line model. This structure consists of a number of cascaded taps where each one indicates a received signal path. The tapped-delay line model is characterized by the number of taps and tap parameters which are the time delay relative to the first arrival path, the average power relative to the strongest path and the direction-of-arrival (DOA) of the path. In a tapped-delay line model, channel impulse response can be expressed with superposition of a number of weighted impulses each one representing one tap:

$$h_c\,(t,\tau,\mathbf{\Omega})\;=\;\sum_i A_i(t)\;h(\tau_i,\Omega_i) \tag{1}$$

Where $h_c(t)$ is the channel impulse response and A_i is the amplitude of the tap. τ_i and Ω_i which can be a function of time in general case, represent the path delay relative to the first arrival path and the DOA of the path respectively. These parameters will be explained in following subsections.

3.1 Dynamic Tap Sets

In a mobile communication scenario the mobile station (MS) is in motion and as a consequence channel characteristics are changing all the time. This means that the received paths can not be steady and are changing too. In fact new paths are being created and some other paths are being vanished continously. The life time for each path is different and depends on the movement of the mobile and the condition of the environment.

In addition, within the life time of a path, its parameters are also a subject of variation. As a consequence, one set of tap weights with fixed parameters can not be a good approximation for the mobile channel. Instead, if we employ several sets of tap weights with different parameters, it can be a better approximation for the mobile channel.

Our channel model is composed of three tap weight sets according to ITU recommendation [7]. Each of the sets comprises 6 taps, with various delays, amplitudes and direction of arrivals. To best fit a real channel behavior, the tap weights in one of the sets are designed with relatively small delay spread, where another set is produced with relatively large delay spread. The third set is “worst case” tap weight set which is designed with even larger delay spread to indicate

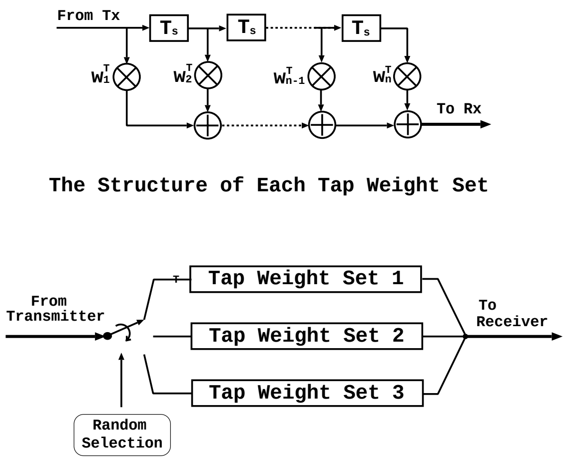

Figure 1 Dynamic Tapped-delay Line

the channel behavior in the most dispersive instances.

One of the tap sets is chosen randomly for each consecutive time interval equal to the "shadow fading decorrelation lenght" which we will disuss it later. The recommended probabilities of tap weight set occurrence are equal to 0.40, 0.55, and 0.05 respectively. Figure 1 illustrates the strucrue of the dynamic tap set channel model. In the following subsections we will explain about tap model parameters.

3.2 Direction of Arrival

Measurments imply that the DOA of received paths for a mobile communication system in an urban area can vary much from one scenario to another and have usaully a cluster format [17] [4].

As no description is presented in [7] with respect to angular characteristics, in our tapped-delay line channel model. DOA of each path is also chosen randomly within the estimated angular spread of each tap weight set. The angular spread of each tap set is chosen in accordance to the simulated environment taking into account the street orientations due to the direction of incident wave, length of the street where the mobile is moving, and the distance between base and mobile stations. In addition, tap sets with larger delays are considered more probable to have larger delay spread.

3.3 Path Amplitude

Three different phenomena are considered to estimate path's amplitude value A_i. These are path loss, shadow fading and fast fading. We can therefore show the contribution of these three phenomenon as:

$$A_i(t) = a_i^t \, a^p \, a^s \, a_i^f(t) \qquad (2)$$

Where a_i^t is an envelope delay profile whose value is equal to 1.0 for the strongest path and less than 1.0 for other paths. a^p stands for path loss factor and a^s indicates shadow fading effects. For the two latter factors we did not use the subscript i because they are common within tap weight set. Finally $a_i^f(t)$ is fast fading coefficient. This factor has been expressed as a function of time because fast fading causes very fast variations in amplitude and phase of the path within its life time.

3.3.1 Path Loss

Path loss (a^p) is the propagation wave attenuation in passing from transmitter toward the receiver which affects the average of the signal. Path loss models for urban areas often comprise two components that correspond to dominant mechanisms of propagation: **a**. an expression relevant for the propagation in the vertical plane (over roof tops). **b**. an expression relevant for the propagation in the horizontal plane (along street canyons). Total path loss is described by three terms:

(1) The free space loss L_o.

(2) Additional multiple screen diffraction loss L_{ms}.

(3) The roof top to street loss L_{rts}.

Important parameters for the path loss values are [4] : **a**. distance d between the base station (BS) and MS, **b**. the base-station height h_b paticularly when the BS is located above the roof-tops, **c**. The orientation of the street (where the mobile is located) with respect to the direct radio path between the BS and MS, **d**. In some models the average distance between buildings b also has an important role.

The model of our choice for path loss is "COST231-Walfish-Ikegami" model (accepted by ITU-R and inculded into Report 567-4) [5]. This is a combination of Walfisch [18] and Ikegami [6] models. This model allows improved path loss estimation by consideration of more data to describe the character of urban environment, namely:

- heights of the buildings h_{Roof},
- widths of roads w,
- builings separation b,
- road orientaion with rspect to the direct radio path ϕ.

The model distinguishes between line-of-sight (LOS) and non-line-of-sight (NLOS). For the current work we are only interested in NLOS case. In the NLOS case the basic transmission loss is comprised of the three aforementioned terms free space loss L_o, multiple screen diffraction loss L_{ms} and roof-top to street diffraction and scatterer loss L_{rts}:

$$L_b = \begin{cases} L_o + L_{rts} + L_{ms} & for \;\; L_{rts} + L_{ms} > 0 \\ L_o & for \;\; L_{rts} + L_{ms} \leqq 0 \end{cases} \qquad (3)$$

The free space loss is given by:

$$L_o(dB) = 32.4 + 20\log(d/Km) + 20\log(f/MHz) \qquad (4)$$

The term L_{rts} describes the coupling of the wave propagating along the multiple screen path into the street where the mobile station is located. The determination of L_{rts} is mainly based on Ikegami model. It takes into account the width of the street and its orientation. However the orientation factor that applied here is different from Ikegami's model:

$$\begin{aligned} L_{rts} &= -16.9 - 10\log(w/m) + 10\log(f/MHz) \\ &\quad +20\log(\triangle h_{Mobile}/m) + L_{ori} \end{aligned} \tag{5}$$

and:

$$\triangle h_{Mobile} = h_{Roof} - h_{Mobile} \tag{6}$$

L_{ori} is the factor representing street orientation expressed with:

$$L_{ori} = \begin{cases} -10 + 0.354(\phi/deg) & 0^\circ \leqq \phi \leqq 35^\circ \\ 2.5 + 0.075(\phi/deg - 35) & 35^\circ \leqq \phi \leqq 55^\circ \\ 4.0 - 0.114(\phi/deg - 55) & 55^\circ \leqq \phi \leqq 90^\circ \end{cases} \tag{7}$$

ϕ is the angle between incident wave and the direction of movement.

In the formula for the third term of NLOS pass loss, multi-screen-diffraction, the heights of buildings and their spatial separations along the direct radio path are modelled by absorbing screens for the determination of L_{ms}:

$$\begin{aligned} L_{ms} &= L_{bsh} + k_a + k_d \log(d/Km) + 10\log(f/MHz) \\ &\quad +K_f \log(f/MHz) - 9\log(b/m) \end{aligned} \tag{8}$$

We refrain to bring the lengthy explanations about each factor, but clarify each one in brief:

- L_{bsh} is an adjusting factor which distinguishes between roof top base antenna and other kinds of base antennas,
- k_a represents the increase of the path loss for the base station below the roof tops of the adjacent buildings,
- k_d controls the dependence of multi-screen diffraction loss versus distance,
- k_f is the term to control the frequency dependency which distinguishes between metropolitan centers and other kind of urban areas.

Some default values for the parameters used in this model are supplied for the cases which data on structure of buildings and roads are unknown. The estimation of path loss by this model agrees rather well with measurements for base station antenna heights above roof-top level.

3.3.2 Shadow Fading

The path loss model does not consider the fact that the sorrounding environmental clutter may be vastly different at two different locations having the same transmitter-receiver separation. This leads to measured signals which are vastly different than the average value depicted by path loss formulas. This phenomenon is called shadow fading. The major mechanism causing shadow fading is "changing visibility" or obstruction of multipath components when MS is moving through a certain scenario. Expeiments show that measured signal levels at a specific transmitter- receiver separation have a gaussian (normal) distribution about the distance dependent mean depicted by path loss formulas, where the measured signal levels have values in dB units. This leads to a log-normal empirical model. In this model, the mean amplitude "a^s" is log-normally distributed over time or space:

$$f(a^s) = \frac{1}{\sqrt{2\pi}\sigma_s a^s} \exp\left(-\frac{\ln a^s - \mu}{2\sigma_s}\right) \qquad , a^s > 0 \tag{9}$$

That means power or path loss values in dB appears to be normally distributed. The mean value μ is determined from the path loss model.

An accepted empirical bound up to which the mean amplitude remains constant has been set up to "movement over a few tens of wavelength" [13]. This length is called "shadow fading decorrelation length".

3.3.3 Fast Fading

Fast fading is rapid amplitude variations of a signal received via a time or space-variant multipath channel. These rapid variations can occur for movements even in order of a wavelength and are caused by constructive or destructive superposition of received paths that reveal different phase evolution over time or space.

For large movements fast fading is superimposed on the shadow fading. Precise studies on fast fading shows that fading profiles are different. It is well known that for line-of-sight (LOS) scenaios fast fading exhibits very different behavior compare to NLOS cases. We are here interested only in NLOS scenarios and will not discuss about LOS fast fadings models.

The most common model for a NLOS fast fading is the assumption of a Rayleigh fading amplitude [11]. Accordingly the distribution of instantaneous amplitude of the received signal can be expressed as:

$$f(a_i^f) = \frac{a_i^f}{\sigma_f^2} \exp\left(-\frac{{a_i^f}^2}{2\sigma_f^2}\right) \qquad , a_f \geqq 0 \tag{10}$$

This formula actually shows the amplitude distribution of the sum of a large number of uncorrelated rotating vectors, each with equal amplitude and uniformly distributed phase. This interpretation motivated W. Jakes to design his famous fading generator [10]. Later it was uncovered that waveforms produced by Jakes model are uncorrelated only under certain conditions. To create multiple uncorrelated fadings, modifications on original Jakes model is necessary. Modified Jakes model is a method to create uncorrelated fadings using orthogonal transforms [12].

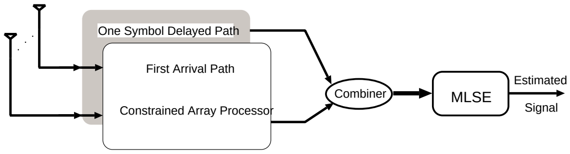

Figure 2 The Receiver Architecture

4. Receiver

To exploit the diversity of the received signals, the branches of received signals are combined in the receiver. One of the most prevalent space diversity techniques is maximum-ratio-combining (MRC) [2]. In an MRC receiver branches of the signal received by diversity system are cophased, weighted according to their signal-to-noise-ratio (SNR) and superimposed. MRC is an efficient technique for gaussian channels. However in channels with interferences, optimum-combiners (OC) [1], [19] are preferable. When the dominant interference is intersymbol interference, to compensate the sparsity of the channel, equalization is the technique of choice [14]. Maximum-likelihood-sequence-estimation (MLSE) using viterbi algorithm [8], [16] is an effective technique to equalize ISI. MLSE equalizer also provide the diversity effect.

Our choise for the receiver system is a space time processor composed of two constrained array processors following by an MLSE [9]. Figure 2 shows the receiver's architecture. The received signals by the array antenna are fed to two array processors. One of the array processors is constrained to maximize signal-to-interference-plus-noise (SINR) while the the desired signal is considered to be the first arrival path. The second array processor is constrained in the same way, but here the desired signal is 1-symbol-delayed path.

4.1 Array Processing

Figure 3 illustrates the array processor architecture. The signal vector $\mathbf{x}(t)$ indicates the received signal by the array elements. We define vector $\mathbf{y}$ as:

$$\mathbf{y}(k) \;=\; [\,\mathbf{x}^T(k)\,,\,-s(k)\,,\,-s(k-1)\,]^T \tag{11}$$

The criterion for the array processing is:

$$\min_{\mathbf{w}}\ \mathbf{w}^H\,\mathbf{R_{yy}}\mathbf{w} \qquad \textit{sobject to} \qquad \mathbf{c}^T\,\mathbf{w} \;=\; f \tag{12}$$

Where f is the desired response usually set to 1. $s(k)$ indicates the training symbols in the training period, and candidate symbols for the MLSE algorithm during the direct mode. Vector $\mathbf{w}$ is the vector of array processor coefficients:

$$\mathbf{w} \;=\; [\,\mathbf{w}_a^T\;,\;\mathbf{g}^T\,]^T \tag{13}$$

$\mathbf{w}_a$ is the array coefficient vector and $\mathbf{g}$ is the vector of replica generator coefficients. $\mathbf{c}$ is the constraint vector defined as:

$$\mathbf{c} \;=\; [\,\mathbf{h}^T\;,\;0\;,\;0\,]^T \tag{14}$$

While $\mathbf{h}$ is the estimated channel impulse response vector.

The solution to the minimization problem using the method of sample matrix inverion (SMI) [3] is:

$$\mathbf{w} \;=\; \mathbf{R_{yy}}^{-1}\,\mathbf{c}^*\,[\,\mathbf{c}^T\,\mathbf{R_{yy}}^{-1}\,\mathbf{c}^*\,]^{-1}\,f \tag{15}$$

After processing the received signals and acquiring the outputs of each array processor, they are supplied to a branch metric combiner to extract the most suitable form of data for MLSE.

4.2 Branch Metric Combining

In the branch metric combiner, the outputs of the array processors are combined and supplied to the MLSE. The coefficient for combining is inversely relative to the error between array combined output and the replica for each array processor. The combined metric is:

$$CM \;=\; q_0\,|e_0(k)|^2 \;+\; q_1\,|e_1(k)|^2 \tag{16}$$

Where $e_i(k)$ is the error between the array output signal and its replica for each array processor neglecting the subscript which indicates one of the array processors:

$$e_i(k) \;=\; \mathbf{w}_i^T\,\mathbf{y}(k) \tag{17}$$

We define here the quality estimate factor q as:

$$q_i \;=\; \frac{\mathbf{h}_i^H\,\mathbf{h}_i}{\frac{1}{N}\sum_k\;|e_i(k)|^2} \tag{18}$$

In this equation N is the error power averaging length.

Branch combining has the effect of reducing the contribution of the branch metric from the path diversity branch which contains excess ISI, to the sequence estimation. This results in mitigating the bit-error-rate (BER) degradation which is caused by the residual excess ISI.

Calculating the combined metric (CM), it is supplied to the MLSE algorithm to estimate the transmitted data sequence.

5. Simulation

To evaluate the performance of a diversity antenna system, and inspect its effects on the performance of the communication system, we have been developing a simulator of the

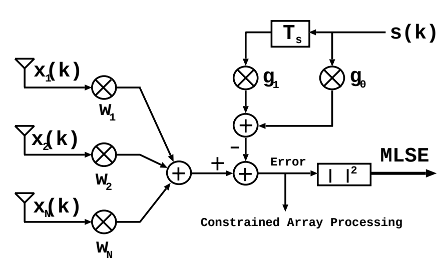

Figure 3 Array Processor

system from transmitter to the receiver. The simulation parameters are chosen in accordance to the experiments of [9] performed in a dense metropolitan area in central Tokyo near the Kanda station.

The over the roof-top micro-cell base station antenna was used on the top of a tall (70 m) building, some 600 meters apart from the mobile. The mobile station moved with an average speed of 20 km/h in a street canyon where the average height of surrounding buildings is around 30 m.

QPSK modulation with a transmission rate of 4.096 Mbps has been chosen for the transmitter where the carrier frequency is assumed 3.35 GHz. Each frame contains 512 bits (256 symbols) including 40 training bits used in the training mode. An oversampling rate of 16 and a pulse shaping with the help of two root-roll-off filters are applied.

The simulation algorithm is illustrated in Figure 4. In the transmitter block, the input stream symbols, data or training, are modulated in a QPSK scheme. The data is then oversampled with an oversampling rate of 16 sample per bit and then the transmitter pulse shaping is applied through a root-roll-off filter. The output stream is supplied to the channel.

In the channel, path loss and shadow fading factors are calculated and shadow fading decorrelation length is estiamated. For the current scenario considering the carrier frequency and the speed of the MS, shadow fading decorrelation length is usually around 5 m in distance or equally 4000 frame time. This amount is supplied to the tap set random selector and DOA generator where their values are refreshed for every shadow fading decorrelation length. Fast fading is calculated for each tap using a modified Jakes fading generator and then gaussian noise is added.

At the receiver each element of the array receives the transmitted bit stream with a different delay, fade and noise corresponding to the array element separation and their alignments. The received streams are processed in array processor after passing through receiver's pulse shaping filter. The output of array processors are obtained by SMI algorithm and then combined in the branch metric combiner which was discussed previously. The 4-state MLSE then estimates the the transmitted stream and finally the bit error calculations are performed.

To simulate the statistical nature of the channel, Monte Carlo simulation technique is employed repeat the algorithm, sending hundreds of thousands of frames to obtain an acceptable estimate of the system BER. To bring it to this end, Monte Carlo technique is applied not only to the transmission but also apllied to the propagation as described in section 3.

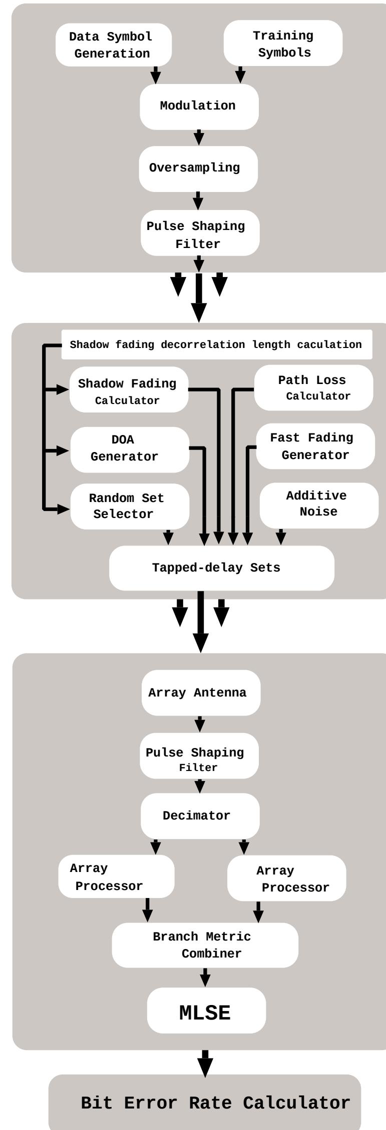

Figure 4 The Simulator Architecture

6. Conclusion

In this paper we made a review of our current research about effects of diversity technique on the performance of a communication system through simulation. Details of the channel model and receiver architectures used in the system were explained. The implementation and improvement of this simulator is still ongoing.

Completing the data obtained from the simulation and its analysis are our future work. We are interested specially in clustering channel model to be simulated in future. For the receiver part we would like to try other options specially turbo equalizers, to evaluate the effect of diversity technique on their performance.

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