SUMMARY In this paper, an imaging components transmission scheme for the improvement of multipath delay resolution in a Fractional Sampling (FS) OFDM receiver is proposed. FS has been proposed as a diversity scheme and achieves path diversity by enlarging the bandwidth of the baseband filters in order to transmit the imaging components of the desired signal. However, FS is not able to achieve diversity with very short delay multipaths because of its low multipath delay resolution. Wider bandwidth of the transmission signal is required to improve the resolution of the delay. On the other hand, cognitive radio is an emerging technology to utilize frequency spectrum flexibly through dynamic spectrum access (DSA). To resolve the small delay multipaths and to use the spectrum flexibly with DSA, this paper investigates the FS path diversity with the imaging components on the separated frequency channel. The correlation between the 2 FS branches is analyzed theoretically on the 2 path channel under the conditions of sampling interval, delay spread, and frequency separation. Numerical results through computer simulation show that the proposed scheme improves the multipath resolution and the bit error rate (BER) performance under the existence of small delay multipaths.

key words: OFDM, fractional sampling, imaging component, multipath, resolution, DSA

1. Introduction

Frequency spectrum is getting scarce since more numbers of wireless systems have been launched in order to realize ubiquitous network society. Since the demands for these wireless systems are increasing, it is expected that radio channels will be crowded and the throughput performance of these systems will be deteriorated. A cognitive radio is a technology that enables flexible usage of frequency spectrum and improves the capacity of a system. One type of the cognitive radio technologies is dynamic spectrum access (DSA). DSA utilizes frequency spectrum which is not in use by the systems primarily assigned to the bands [1], [2]. There are a lot of literatures regarding the cognition of radio frequency environments and the cognitive radio systems that employ unused spectrum [3], [4].

DSA is mainly used for peer-to-peer indoor communications [5]. Recent investigations have demonstrated that indoor multipath channels are assumed to have short delay spread [6]. This leads to less frequency diversity gain over a single channel. Thus, the terminals have to exploit the other types of diversity schemes in order to improve the quality of the communication links.

One of the typical diversity techniques is antenna diversity. Multiple antenna elements must be spatially separated to reduce the correlation among the received signals [7]. However, it is difficult for small terminals to implement multiple antenna elements. For a reliable communication without increasing an antenna element at a receiver side, delay diversity has been investigated for OFDM systems [8], [9]. In the delay diversity, additional transmit antennas send the signals that are cyclically shifted from the original signal in the time domain. They create artificial multipath components and frequency diversity is achieved with channel coding. However, it is difficult in some cases to be used in peer-to-peer indoor communications because the size of the terminal may prevent the implementation of multiple transmit antenna elements.

Fractional sampling (FS) has been proposed for OFDM that can achieve path diversity with a single antenna by oversampling the received signal [10]. The FS can resolve the multipaths by sampling the received signal at a rate higher than the Nyquist rate and taking DFTs of the sampled signals in parallel. It is known that the diversity gain with the FS greatly depends on the imaging components of the desired signal over the excess bandwidth of the filter [11], [12]. When the signal is upsampled at the transmitter, the images of the desired signal is generated outside of the main channel. The path diversity with the FS is achieved through these imaging components that pass the enlarged baseband filter and is downconverted and folded to the main channel in the baseband. However, the FS is not able to realize diversity effectively if the delay spread of the multipath is small because of its low multipath delay resolution. The multipath delay resolution of the FS improves with the wider bandwidth of the baseband filter. However, larger bandwidth deteriorates the spectrum efficiency.

In this paper, to achieve higher multipath resolution and to use the spectrum flexibly with DSA, the FS path diversity scheme with the imaging components on the separated channel has been investigated. The correlation between the 2 FS branches is analyzed theoretically on the 2 path channel under the conditions of sampling interval, delay spread, and frequency separation. With the appropriate sampling interval and the channel allocation for the imaging components,
the correlation between the FS branches is reduced even on the small delay spread channel.

This paper is organized as follows. Section 2.2 explains the focus of this paper, the FS path diversity through the proposed scheme, and the correlation between the FS branches. The simulation results are shown in Sect. 3. Finally in Sect. 4, conclusions are presented.

2. Fractional Sampling Scheme

2.1 Problem Statement

The performance improvement through path diversity with signal bandwidth enlargement has been investigated in many literatures in conjunction with the development of RAKE receivers [13]. If the signal bandwidth is \( W \), taps over a delay line with the interval of \( 1/W \) delay can resolve multipath components. The RAKE receiver has been implemented in spectrum systems since a transmit signal is multiplied by a sequence to spread its spectrum [14], [15].

The same idea has been introduced in an OFDM system in [10]. Instead of spreading the spectrum, the imaging components of the desired signal are transmitted with the use of the transmit and receive filters that have wider frequency responses than the desired signal bandwidth. It is the conversion of frequency diversity to path diversity and it achieves almost the same amount of diversity gain. Literatures such as [11], [12] have investigated the relationship between total signal bandwidth and multipath resolution.

FS does not require an additional analog demodulation branch or a larger DFT size. This scheme realizes path diversity only with additional demodulation branches and a faster sampling rate in analog-to-digital converters (ADCs). The conditions of the appropriate sampling points and the effective frequency separation of the imaging components are important to improve the communication quality. In addition, a flexible analog intermediate frequency (IF) filter such as a sampling downconversion filter presented in [16] passes only the desired and image signal components on the IF band.

The condition of the frequency separation of the imaging component that achieves path diversity with an ample amount of multipaths has been investigated in [17]. However, none of previous literatures has been investigated the resolution of the path delay with the imaging component on the separated channel. In addition, path diversity with a limited amount of multipath components has not been investigated for OFDM based DSA systems. Path components with only high correlation may be available for diversity when the delay spread of the path is limited. Thus, this paper presents the analysis on the correlation between the branches for the path delay and the amount of frequency separation of the imaging component in the 2 branch FS receiver.

One thing to remind is that there is a similarity between the cyclic delay diversity (CDD) and the path diversity through FS as the multipath components introduces a diversity gain in the both OFDM systems [18]. These schemes create uncorrelated channel responses over frequency subcarriers in CDD or time domain samples in FS through the superposition of the same signal waveforms with different delays. While the CDD scheme requires multipath components with the delays much larger than the original sampling interval of an OFDM demodulator, the FS scheme focuses on the channel environment when the delay spread is smaller than the sampling interval [19]. This is the reason that the FS system focused in this paper employs the imaging component on the separated channel.

2.2 System Model

The system model assumed in this paper is presented in Fig. 1. Suppose an information symbol on the \( k \)th subcarrier is \( s[k] \) \( (k = 0, ..., N - 1) \), an OFDM symbol is then given as

\[
u[n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} s[k] e^{j2\pi nk/N},\]

where \( n (n = 0, 1, ..., N - 1) \) is the time index. A guard interval (GI) with the length of \( N_{GI} \) is appended before transmission. The length of one OFDM symbol is \( P := N + N_{GI} \). \( u[n] \) is converted from digital to analog and filtered by the baseband filter of the transmitter. As shown in Fig. 2, because the digital-to-analog (D/A) outputs are discrete analog samples, the desired signal and its imaging components are repeated over the frequency band. After filtering, only the desired signal and its specific imaging components are transmitted. This signal is then upconverted and transmitted through a multipath channel with an impulse response \( c(t) \). The received signal is passed through a flexible IF filter to extract the desired signal and the imaging components on the separate channels in order to reject the noise components on the other channels. This kind of flexible IF filter consists of a complex FIR filter [16]. The outputs of the analog filter is
oversampled and digitized on each demodulation branch.

The received signal after downconversion is given as

\[ y(t) = \sum_{n=0}^{P-1} u[n]h(t - nT_s) + v(t) \]  

(2)

where \( h(t) \) is the impulse response of the composite channel and is given by \( h(t) := \rho(t) * c(t) * p(-t) \), \( \rho(t) \) is the impulse response of the filter in the transmitter and the receiver in baseband, \( * \) denotes convolution, and \( v(t) \) is the additive Gaussian noise filtered at the receiver. For the multipath channel, \( h(t) \) can be expressed in a baseband form as

\[ h(t) = \sum_{m=0}^{M-1} \sum_{n=0}^{L-1} \alpha_{p}(t - nTs) \]

(3)

where \( p_{s}(t) := \rho(t) * p(-t) \) is the deterministic correlation of \( p(t) \). It is assumed that the channel has \( L \) path components, \( \alpha_{p} \) is the complex response of the \( i \)-th path that is time-invariant during one OFDM symbol (so-called quasi-static channel model), and \( \tau_{i} \) is the path delay. If \( y(t) \) is oversampled with the interval of \( \tau_{i} \) from every \( T_s \) second, its polyphase components can be expressed as

\[ y_{g}[n] = \sum_{l=0}^{P-1} y_{l}[n]e^{j\frac{2\pi ln}{NG}}, \]  

\[ g = 0, ..., G - 1, \]

(4)

where \( y_{g}[n] \), \( h_{g}[n] \), and \( v_{g}[n] \) are the polynomials of sampled \( y(t) \), \( h(t) \), and \( v(t) \), respectively, and are given as

\[ y_{g}[n] := y(nTs + g\tau_{s}), \]

\[ h_{g}[n] := h(nTs + g\tau_{s}), \]

\[ v_{g}[n] := v(nTs + g\tau_{s}), \]

(5, 6, 7)

where \( g\tau_{s} \) is the sample delay on the \( g \)-th branch, and \( \tau_{s} \) satisfies the condition of \( (G - 1)\tau_{s} < T_s \). These samples are put into \( G \) DFT demodulators in parallel and sampling rate on each branch reduces to \( 1/T_s \). Therefore, the imaging components fold down to the main channel. After removing the GI and taking DFT at each branch, the received symbol is given by

\[ z[k] = H[k]s[k] + w[k] \]  

(8)

where \( z[k] = [z_0[k]...z_{G-1}[k]]^{T} \), \( w[k] = [w_0[k]...w_{G-1}[k]]^{T} \), and \( H[k] = [H_0[k]...H_{G-1}[k]]^{T} \) are \( G \times 1 \) column vectors, each \( g \)-th component representing

\[ [z[k]]_{g} := z_{g}[k] = \sum_{n=N_{G}}^{P-1} y_{g}[n]e^{-j\frac{2\pi kn}{NG}}, \]  

(9)

\[ [w[k]]_{g} := w_{g}[k] = \sum_{n=N_{G}}^{P-1} v_{g}[n]e^{-j\frac{2\pi kn}{NG}}, \]  

(10)

\[ [H[k]]_{g} := H_{g}[k] = \sum_{n=N_{G}}^{P-1} h_{g}[n]e^{-j\frac{2\pi kn}{NG}}, \]

(11)

respectively.

The output of the subcarrier base maximum ratio combining (MRC) among the samples is given as

\[ s[k] = \frac{H^H[k]z[k]}{|H^H[k]H[k]|}, \]

(12)

2.3 Correlation among the FS Branches

2.3.1 Multipath Delay Resolution in FS

The filter bandwidth is required to be enlarged to improve the resolution of the delay in the FS receiver for path diversity as the large bandwidth makes the correlation among the branches lower [13]. From Fig. 3(a), if the transmit and receive filters have the composite frequency response that passes only the desired signal as shown in the left side of the figure, the composite impulse response of the filters, \( p_{s}(t) \), has the zero crossing points only in every \( T_s \) delay. Thus, path diversity is hardly achieved with FS. If the filters
passes the desired signal and its imaging components over \( G \) channels as shown in the left side of Fig. 3(b), the interval between the zero crossing points in the impulse response reduces to \( T_s/G \). Multipath delay resolution improves and path diversity is then realized with the sampling interval of \( T_s/G \). However, the desired signal and its imaging components occupy the large bandwidth. Therefore, it is assumed here that the imaging component of the desired signal is transmitted only on the separated channel as shown in Fig. 3(c). The composite impulse response of the filters depends on the separation between the center frequency of the desired signal and its imaging components, \( F_d \). However, generally speaking, the interval between the zero crossing points of the impulse response is smaller than \( T_s \) and path diversity with FS can be expected. If the number of imaging components can be more than 1 and the zero crossing points within \( T_s \) delay increases proportionally to the number of imaging components. The following section gives the analysis of the correlation between the samples cut into the different FS branches.

2.3.2 Calculation of Correlation among the FS Branches

The correlation between the FS branches depends on the frequency channel response, the path delay profile, and the sampling interval [17]. Suppose that the noise is neglected for simplicity, from the sampling theorem, the sampled signal on the \( g \)-th branch is given as

\[
y_g(t) = \sum_{n=-\infty}^{\infty} \sum_{i=0}^{L-1} \alpha_i x(nT_s + (gT_s - \tau_i)) \cdot \delta(t - (nT_s + (gT_s - \tau_i)))
\]

where \( x(t) \) is the baseband signal that passes through the transmit and receive filters as \( x(t) = \sum_{n=0}^{\infty} u[n] p_{2}(t - nT_s) \), \( \delta \) is the Dirac delta function, \( L \) is the number of multipaths, \( \alpha_i \) and \( \tau_i \) are the gain and the delay time of the \( i \)-th path, and \( y_g[n] = y_g(nT_s) \). Through a Fourier transform, it is then given in the frequency domain as

\[
Y_g(f) = \sum_{q=-\infty}^{\infty} \sum_{i=0}^{L-1} \alpha_i f_i \exp(j2\pi(f + qf_s)(gT_s - \tau_i)) \cdot X(f - qf_s)
\]

where \( f_s = 1/T_s \) is the sampling frequency and \( X(f) = \int_{-\infty}^{\infty} x(t) e^{-j2\pi ft} dt \). If the received signal has been transmitted over two channels, the center channel ( \( q = 0 \) ) and the separated channel ( \( q = Q \) where \( Q = -F_d/20 \) is an integer, i.e. \( X(f) = X(f + Qf_s) \)), the received signal on the \( g \)-th FS branch is derived as

\[
Y_g(f) = \sum_{i=0}^{L-1} \alpha_i f_i \exp(-j2\pi f \tau_i) \left\{ 1 + \exp(-j2\pi Qf_s/G) \exp(-j2\pi Qf_s \tau_i) \right\} X(f) \exp(j2\pi f gT_s).
\]

Equation (15) is the general expression of the frequency spectrum of the sampled signal. In order to calculate the correlation between the branches, the parameters such as the number of multipaths, \( L \), and the number of branches, \( G \), have to be specified. Here, for simplicity of explanation, the following analysis in this section assumes that \( L = 2 \) and \( G = 2 \) with only one imaging component. The received signal on each branch is then given as

\[
Y_0(kf_d) = \sum_{i=0}^{L-1} \alpha_i f_i \exp(-j2\pi(kf_d)\tau_i) \left\{ 1 + \exp(-j2\pi Qf_s \tau_i) \right\} X(kf_d),
\]

(16)

\[
Y_1(kf_d) = \sum_{i=0}^{L-1} \alpha_i f_i \exp(-j2\pi(kf_d)\tau_i) \left\{ 1 + \exp(j2\pi Qf_s \tau_i) \cdot \exp(-j2\pi Qf_s \tau_i) \right\}
\]

\[
\cdot X(kf_d) \exp(j2\pi(kf_d)\tau_i),
\]

(17)

respectively, where \( f_d \) is the frequency separation between the subcarriers and \( \tau \) is the sampling interval between the 0-th and first branches. Suppose that there are only \( L = 2 \) paths and the delay of the first path is \( \tau_0 = 0 \), Eqs. (16) and (17) are expressed as

\[
Y_0(kf_d) = 2\left\{ \alpha_0 + \alpha_1 \left\{ 1 + \exp(-j2\pi Qf_s \tau_1) \right\} / 2 \cdot \exp(-j2\pi(kf_d)\tau_1) \right\} X(kf_d),
\]

(18)

\[
Y_1(kf_d) = 2\left\{ \alpha_0 \left\{ 1 + \exp(j2\pi Qf_s \tau_1) \right\} / 2 \cdot \exp(j2\pi(kf_d)\tau_1) \right\}
\]

\[
+ \alpha_1 \left\{ 1 + \exp(j2\pi Qf_s (\tau_1 - \tau_0)) \right\} / 2 \cdot \exp(j2\pi(kf_d)(\tau_1 - \tau_0)) \right\} X(kf_d).
\]

(19)

If the delay of the second path \( \tau_1 \) equals to the sampling interval \( \tau_s \), Eqs. (18) and (19) turn to

\[
Y_0(kf_d) = \left\{ 2\alpha_0 + \alpha_1 \left\{ 1 + \exp(-j\Phi) \right\} \right\} X(kf_d),
\]

(20)

\[
Y_1(kf_d) = \left\{ \alpha_0 \left\{ 1 + \exp(j\Phi) \right\} \cdot \exp(j2\pi(kf_d)\tau_s) 
\]

\[
+ 2\alpha_1 \right\} X(kf_d),
\]

(21)

where \( \Phi = 2\pi Qf_s \tau_1 \). Therefore, the correlation among the branches depends on the term \( 1 + \exp(-j\Phi) = 1 + \exp(j\Phi) \). This means that the correlation depends on the normalized frequency separation \( Q \) and the delay of the second path \( \tau_1 \) or the sampling interval \( \tau_s \). It is also clear from the equations that normalized frequency separation \( Q \) does not have to be a small integer as \( \exp(-j\Phi) \) is a periodic function in terms of the normalized frequency separation \( Q \). This implies that the imaging component on the separated channel may reduce the correlation between the demodulation branches. The correlation among the branches is shown in Fig. 4.
From Fig. 4, it is found that there are separated channels for the imaging components which realize low correlation between the branches although the delay of the second path is small. It is also clear that if the delay of the second path is small such as 1/8 \( T_s \), the frequency separation of the imaging components should be at least 80 MHz. As the delay of the second path increases, the frequency separation can be smaller for the same amount of the correlation.

### 3. Numerical Results

#### 3.1 Simulation Conditions

Table 1 shows the simulation conditions. Following the IEEE802.11a/g standard, the bandwidth of the desired signal is assumed to be 20 MHz. Information symbols are modulated with QPSK-OFDM. The number of subcarriers \( N \) is 64. As a channel model a 2 path Rayleigh fading model and an exponential delay profile model are assumed. In the 2 path Rayleigh fading model the delay of the second path \( \tau_2 \) is set to \( 1, 2, 3, 4, 5, 6, 7 \) / 8 \( T_s \). In the exponential delay profile model, the delay spread is set to 2 or 18 ns that is equivalent to 0.04 \( T_s \) or 0.36 \( T_s \). The delay spread of 18 ns corresponds to the indoor residential A channel model recommended in IEEE 802.11 [20]. The interval between the multipaths is set to 1/16 \( T_s \). The transmit and receive filters are assumed to have the impulse response with the duration of 8\( T_s \) each. \( E_b/N_0 \) of the desired signal and the imaging components on the separated frequency channel are both set to 20 dB unless it is specified. The frequency separation can be varied as 0–80 MHz. The FS order \( G \) is set to 1, 2, or 4. The sampling interval of the FS \( \tau_s \) is set to \( 1, 2, 3, 4, 5, 6, 7 \) / 8 \( T_s \).

#### 3.2 BER Performance

##### 3.2.1 2 Path Rayleigh Fading Model

The BERs on the 2 path channel (\( L = 2 \)) are presented in this section. It is assumed that the FS order \( G \) is set to 1, 2, or 4 and \( E_b/N_0 \) is 20 dB.

The correlation between the demodulation branches versus the sampling interval \( \tau_s \) for \( G = 2 \) and the frequency separation \( F_d \) with the delay of the second path of \( \tau_2 = 1/8 \ T_s \) is shown in Fig. 5. The corresponding BER performance is shown in Fig. 6. Moreover, the BER versus the frequency separation \( F_d \) is shown in Fig. 7 when the sampling interval and the delay of the second path are set as \( \tau_s = \tau_1 \) that are 1/8 \( T_s \) or 1/4 \( T_s \). It is found from Figs. 5, 6 and 7 that larger \( F_d \) improves the BER with the FS when the sampling interval \( \tau_s \) is 1/8 \( T_s \). This is because the correlation between the branches reduces as the frequency separation increases. On the other hand, even though the imaging components are transmitted, the BER remains the
same for any $F_d$ without the FS. Thus, path diversity works effectively with the FS and the imaging components on the separated channel.

Figure 8 shows the BER versus $E_b/N_0$ for the delay of the second path $\tau_2 = 1/8 T_s$, and the sampling interval of $\tau_s = 1/8 T_s$, for $G = 2$ and $G = 4$. From Fig. 8, it is clear that the BER is lower with the imaging components on the separated channel as $F_d = 80$ MHz. The BER increases as $F_d$ reduces. Therefore, the imaging components on the separated channel make the BER lower since the correlation between the branches decreases even with the small multipath delay such as $1/8 T_s$. This is because the correlation between the branches is small and path diversity is realized. On the other hand, if the FS order increases as $G = 4$, the correlations among the branches increase since only one zero crossing point exists with one imaging component as stated in Sect. 2.3.1. Since the subcarrier based MRC is employed in the proposed system, the correlation among the demodulation branches deteriorates the BER performance as shown in the figure [21].

From Fig. 7, it is observed that the BER with the FS for $F_d = 40$ MHz is lower than the BER for $F_d = 20$ MHz when the sampling interval $\tau_s$ is set to $1/4 T_s$. On the other hand, the BER for $F_d = 80$ MHz does not improve with the FS since the correlation between the branches is high as shown in Fig. 4. Therefore, the proper selection of the frequency separation and the sampling interval is required to realize path diversity in the FS.

The delay of the multipath are fixed in the above results, however, the delays may change on real channels. Figures 9 and 10 show the BERs for various sampling intervals and the path delays with the fixed frequency separation as $F_d = 20$, 40 MHz, respectively. It is assumed that the delay of the second path $\tau_2$ ranges from $1/8$ to $7/8$ $T_s$, the FS order $G$ is set to 2, and $E_b/N_0$ is 20 dB. From these figures, it is clear that the same BER performance appears periodically in terms of the delay of the second path. This is because $\Phi$ in Eqs. (20) and (21) is a periodic function over the delay of the second path. From Fig. 9, it is found that the BER with $\tau_2 = 1/8 T_s$ is larger than that with more delays on the second path since the correlation between the branches is high as shown in Fig. 4. However, for $\tau_s = 1/2 T_s$ in Fig. 10, path diversity with the FS does not work for any amount of the path delay since the correlation between the branches is high as shown in Fig. 4. Therefore, it is clear that some of the sampling intervals should be avoided for the specific amount of the frequency separation because of its high correlation between the branches.

3.2.2 Exponential Profile Model

The BERs on the exponential delay profile channel are presented in this section. The sampling interval $\tau_s$ is $1/8 T_s$, the FS order $G$ is set to 1 or 2, and $E_b/N_0$ is 20 dB.

The BER with the FS versus $E_b/N_0$ on the exponential
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Fig. 9 BER versus delay of the second path $\tau_2$ and sampling interval $\tau_s$ ($F_d = 20$ MHz, FS order $G = 2$, $E_b/N_0 = 20$ dB, 2 path Rayleigh fading model).

Fig. 10 BER versus delay of the second path $\tau_1$ and sampling interval $\tau_s$ ($F_d = 40$ MHz, FS order $G = 2$, $E_b/N_0 = 20$ dB, 2 path Rayleigh fading model).

delay profile model with the delay spread of 2 ns and 18 ns is shown in Fig. 11. The sampling interval $\tau_s$ is $1/8$ $T_s$ and $E_b/N_0$ is 20 dB. It is shown that the imaging components on the separated channel with $F_d = 80$ MHz improve the performance by about 5 dB at the BER of $10^{-4}$ for the delay spread of 2 ns. In the case of the delay spread of 18 ns which is defined in the indoor residential A channel model, the maximum delay of the multipaths reaches $7/4$ $T_s$. However, there are strong multipath signals with smaller delays because of the exponential delay profile. Thus, it is found that the large frequency separation $F_d$, such as 60 and 80 MHz, reduces the BER even though the BER with $F_d = 20$ MHz is better than that with the delay spread of 2 ns.

The BER with the FS versus the delay spread for the sampling interval $\tau_s = 1/8$ $T_s$ is shown in Fig. 12. $E_b/N_0$ is 20 dB and the frequency separation is $F_d = 20, 60$, and 80 MHz. It is also observed that larger frequency separation $F_d$ improves the BER in each delay spread since there are strong multipaths with smaller delays although the delay spread is as large as 100 ns.

If the delay spread is less than $1/8$ $T_s$, the correlation between the branches in the FS increases. On the other hand, if the delay spread increases, some of the multipath components contribute to the reduction of the branch correlation. However, the multipaths with larger delay spread reach the region in which the correlation between the FS branches increases as shown in Figs. 9 and 10. Further increase of the delay spread creates path components whose delays exceed the GI. Thus, the delay spread of $1/8$ $T_s$ shows the best performance.

4. Conclusions

In this paper, the FS path diversity scheme with the imaging components allocated on the separated channel has been
proposed. If the baseband filter has wider bandwidth, the multipath resolution of the FS improves. However, larger bandwidth deteriorates the spectrum efficiency. To achieve higher multipath delay resolution and to use the spectrum flexibly with DSA, the FS with the imaging components on the separated channel has been presented.

The theoretical analysis has been carried out for the system with the 2 demodulation branches on the 2 path channel. It has been confirmed that the correlation between the branches depends on the sampling interval, the frequency separation $F_d$ of the imaging components, and the delay of the multipaths. With larger $F_d$ the FS resolves the multipaths with small delays. It has also been proven that the imaging components on the separated channels may reduce the correlation between the demodulation branches in the FS receiver. Numerical results through computer simulation has shown that the FS with the imaging components on the separated channel with $F_d = 80$ MHz improves the performance by about 5 dB at the BER of $10^{-4}$. It has also been shown that the proper selection of the frequency separation and the sampling interval is required to reduce the correlation between the FS branches.

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References

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