Antenna Diversity Scheme for Broadcasting System Signal Detection

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Abstract. In order to improve robustness of bootstrap signal, this paper studies on multi-antenna transmit and receive diversity. This paper proposes bootstrap symbol detection scheme using multi-antenna technique for ATSC 3.0 system to improve detection performance. Multi-antenna technique has diversity scheme for obtaining SNR gain and multiplexing scheme for improving data rate. This paper treats transmit and receive diversity scheme for detecting bootstrap symbol by space time block code(STBC) and maximum ratio combining(MRC). The simulation results show that the performance of the proposed scheme is improved when the first bootstrap symbol at a symbol error rate of 0.01 obtains a signal to noise ratio(SNR) gain of 4dB compared to 1 by 1 single-input single-output(SISO).

1. Introduction

Advanced television system committee(ATSC) is standardization group for digital television in USA. Recently, ATSC developed standard called ATSC 3.0 and this standard has been adopted at Korea in 2016. This standard constitutes the normative specification for the initial entry point of a physical layer waveform [1][2]. The A/321 standard was established in March 2016 and the standard for bootstrap symbols was published in this document.

In this standard, bootstrap uses several fixed configuration (e.g., sampling rate, signal bandwidth, subcarrier space, time domain structure). The bootstrap is also located in front of the physical layer frame and transmits a total of four symbols in the ATSC 3.0 specification. Bootstrap symbol is generated by multiplying Zadoff-Chu sequence and pseudo-noise sequence in the frequency domain. In time domain, each symbol except the first symbol has a cyclic shifted structure and represents symbol information according to the degree of cyclic shift relative to adjacent symbols [3].

This paper deals with antenna diversity technique, which is used in communication systems, to improve robustness of bootstrap symbols. The spatial diversity scheme can be classified into a transmit and receive diversity scheme. In this paper, a space-time block code(STBC) of Alamouti is used as a transmit diversity and a maximum ratio combining(MRC) is used as a receive diversity. STBC is a technique to encode transmission signals using multiple transmit antennas and maximizes diversity gain by using orthogonality [4]. Similar to STBC, MRC is a technique to maximize diversity gain using multiple receive antenna.

2. System model

2.1. Structure of bootstrap signals
In frequency domain, bootstrap symbols is generated by multiplying Zadoff-Chu(ZC) sequence and pseudo-noise(PN) sequence. The ZC sequence is as follows:

\[
z_q(k) &= e^{-j\frac{q(k+1)}{N_{zc}}}, \quad k = 0, 1, 2, \cdots, N_{zc} - 1,
\]

where \(k\) is subcarrier number, \(q\) is the root of the ZC sequence which means the major version of the broadcasting signal and \(N_{zc} = 1499\) is the number that results in a channel bandwidth 4.5MHz with a subcarrier spacing of \(f_s = 3kHz\) except DC component. For ATSC 3.0, root of ZC sequence is 137 which means that major version is 0.

PN sequence is generated by linear feedback shift register(LFSR) with length \(l = 16\). PN sequence generator polynomial is given by \(p(x) = x^{16} + x^{15} + x^{14} + x + 1\). Initial state of PN sequence generator, called seed, indicates the minor version. The sequence generated by multiplying ZC sequence and PN sequence forms a symmetry around the DC component. Each symbol has a total of 2048 subcarriers, but uses only 1498 subcarriers excluding the DC component. The formula of the generated sequence is as follows:

\[
s_n(k) = \begin{cases} 
    z_q(k + 749)c(749(n+1) + k), & -749 \le k < 0 \\
    z_q(k + 749)c(749(n+1) - k), & 1 \le k < 749 \\
    0, & \text{otherwise}
\end{cases},
\]

where \(z_q\), \(c\) denote ZC and PN sequence respectively, and \(s_n(k)\) denotes the \(k\)-th sequence in the \(n\)-th symbol.

\(s_n(k)\) is transformed into a time domain signal with 2048 sampling length, and the cyclic shift of the signal is performed. Cyclic shift has relative, absolute cyclic shift. The cyclic shift is represented by the cyclic shift value of the current symbol relative to the previous symbol and the absolute cyclic shift is expressed as the sum of the previous symbol and the current symbol. When the cyclic shifted symbol is \(A_n(l)\), \(n\) and \(l\) mean symbol and sample number, respectively. Finally, the bootstrap symbol consists of a combination of three areas: A, B and C in the time domain. The first bootstrap symbol is generated with the structure shown in ‘figure 1’. The remaining bootstrap symbols are generated into the structure shown in ‘figure 2’.

2.2. Proposed spatial diversity scheme for bootstrap

First, the block shape of the transmission signal of the $2 \times 2$ STBC, which is a transmit diversity technique, is as follows:
\[ S = \begin{bmatrix} s_0 & s_1 \\ -s_1^* & s_0^* \end{bmatrix}, \]

where each row represents a time slot and each column represents a transmit antenna. Assuming a quasi-static channel between transmission time slots, the STBC receive signal is as follows:

\[ Y_s = \begin{bmatrix} y_{n,1} \\ y_{n,2} \\ y_{n,1}^* \\ y_{n,2}^* \end{bmatrix} = \begin{bmatrix} h_{1,1} s_0 + h_{1,2} s_1 \\ h_{2,1} s_0 + h_{2,2} s_1 \\ -h_{1,1} s_1^* + h_{1,2} s_0^* \\ -h_{2,1} s_1^* + h_{2,2} s_0^* \end{bmatrix} + \begin{bmatrix} w_{s,1} \\ w_{s,2} \\ w_{s,1}^* \\ w_{s,2}^* \end{bmatrix}, \]

where \( y_{n,j} \) \((n=1,2)\) is received symbol in the \( n \) th timeslot, \( y_{n,j} \) is the received signal at the \( j \) th receiver in the \( n \) th time slot, \( h_{i,j} \) \((i=1,2, j=1,2)\) is the channel coefficient between the \( j \) th receiver and the \( i \) th transmitter and \( w_{s,j} \) is additive white Gaussian noise(AWGN) in the \( n \) th timeslot at the \( j \) th receiver. In addition, the STBC receiver can detect the transmitted signal in a simple linear combination due to the orthogonality [5]. The detection equation is as follows:

\[ \hat{S} = \begin{bmatrix} s_0 \\ s_1 \end{bmatrix} = \begin{bmatrix} \sum_{j=1}^{N_r} |h_{j,1}|^2 y_{n,j} + h_{j,2}^* y_{n,2,j} \\ \sum_{j=1}^{N_r} |h_{j,2}|^2 \end{bmatrix} \begin{bmatrix} \sum_{j=1}^{N_r} h_{j,1} y_{n,j} - h_{j,2} y_{n,2,j} \\ - \sum_{j=1}^{N_r} h_{j,2} y_{n,2,j} \end{bmatrix}. \]

Similar to STBC, receive diversity is a technique that maximizes diversity gain using multiple receive antennas. In the \( N_t \times N_r \) system, the equation representing the MRC received signal is as follows:

\[ Y_M = \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{1,1} \\ h_{2,1} \end{bmatrix} \begin{bmatrix} s \\ w_1 \end{bmatrix} + \begin{bmatrix} w_2 \end{bmatrix}, \]

where \( y_i \) is the receive signal at the \( i \) th receiver, \( s \) is transmit signal and \( w_i \) is the \( i \) th AWGN at receiver. The MRC scheme achieves diversity gain by performing a linear combination operation. The transmit signal detection equation of the MRC scheme is as follow:

\[ \hat{S} = \frac{\left( h_{1,1} + h_{2,1} + h_{1,2} + h_{2,2} \right)}{\left| h_{1,1} + h_{2,1} + h_{1,2} + h_{2,2} \right|^2} y_i. \]

In this paper, STBC and MRC are used to improve detection performance. Bootstrap symbol structure for using STBC is shown ‘figure 3’.
In addition, in order to make the STBC structure, the cyclic shift effect from the structure of the bootstrap signal generator should be processed in the frequency domain unlike the conventional one.

\[ IFFT\{x((k-M) \mod 2048)\} = X(k)e^{\frac{2\pi i k M}{2048}} \]  

(8)

The modified bootstrap structure consists of four kinds of orthogonal frequency division multiplexing (OFDM) symbols in the bootstrap frame and \( M_n \) \((n=0,1,2,3)\) is absolute cyclic shift value applied OFDM symbol. In this symbol, each column is timeslot and \( m = 0 \). STBC structure is only applied in timeslot 3 and 4, since symbol 0 uses the CAB structure and the remaining symbols use the BCA structure in ‘figure 1’ and ‘figure 2’. In the \( 2 \times 2 \) system, received signal is as follows: 

\[
Y_s = \begin{bmatrix} y_0 \\ y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} y_{0}^0 & y_{0}^2 \\ y_{1}^0 & y_{1}^2 \\ y_{2}^0 & y_{2}^2 \\ y_{3}^0 & y_{3}^2 \end{bmatrix} = \begin{bmatrix} (h_{1,1} + h_{2,1} )s_0 & (h_{2,1} + h_{2,2} )s_0 \\ (h_{1,1} + h_{2,1} )s_1 & (h_{2,2} + h_{2,2} )s_1 \\ (h_{1,1} + h_{1,2} )s_2 & (h_{2,1} + h_{1,2} )s_2 \\ -(h_{1,1} + h_{1,2} )s_3 & (h_{2,1} + h_{1,2} )s_3 \end{bmatrix} + \begin{bmatrix} w_0^0 & w_0^2 \\ w_1^0 & w_1^2 \\ w_2^0 & w_2^2 \\ w_3^0 & w_3^2 \end{bmatrix},
\]

(9)

where \( y_k^0 \) is received signal at the \( k \)-th receiver in the \( n \)-th timeslot, \( h_{j,i}^n \) is the channel coefficient between the \( j \)-th receiver and the \( i \)-th transmitter in the \( n \)-th timeslot, \( s_m \) is bootstrap symbol and \( w_k^0 \) is AWGN. Also, assuming a quasi-static channel environment during two time slots, timeslot 1 has the same channel coefficients as 2, and timeslot 3 has the same channel coefficients as 4. To obtain cyclic shift \( \tilde{M}_1 \), the received signal combining channel coefficient \( (h_{1,1} + h_{1,2}) \) is used.

\[
\tilde{s}_1 = \frac{(h_{1,1} + h_{2,1} + h_{1,2} + h_{2,2})}{|h_{1,1} + h_{2,1} + h_{1,2} + h_{2,2}|} y_1. 
\]

(10)

Also, STBC demodulation is performed by \( y_2 \) and \( y_3 \) to obtain \( \tilde{M}_2 \) and \( \tilde{M}_3 \) as follows:

\[
\begin{bmatrix} \tilde{s}_2 \\ \tilde{s}_3 \end{bmatrix} = \begin{bmatrix} \frac{(h_{1,1})^* y_1^2 + h_{2,1}^* (y_1^2)^* + (h_{1,2})^* y_2^2 + h_{2,2}^* (y_2^2)^*}{|h_{1,1}|^2 + |h_{2,1}|^2 + |h_{1,2}|^2 + |h_{2,2}|^2} \\ \frac{(h_{1,2})^* y_1^2 - h_{1,1}^* (y_1^2)^* + (h_{2,1})^* y_2^2 + h_{2,2}^* (y_2^2)^*}{|h_{1,1}|^2 + |h_{2,1}|^2 + |h_{1,2}|^2 + |h_{2,2}|^2} \end{bmatrix}. 
\]

(11)

Since the receiver knows the value of the bootstrap symbol that is not cyclic shifted, the value of absolute cyclic shifted \( \tilde{M}_n \) is known by multiplying the detected symbol by the conjugate of the symbol that has not cyclically shifted.
3. Simulation results

‘Figure 4’ shows the SER performance of the bootstrap transmission frame of the proposed scheme and the conventional scheme in the 7-tap multi-path Rayleigh fading environment. When multiple transmit antennas are used, the transmit power is normalized for comparison under the same conditions as the 1x1 fading channel environment. Symbol 1 obtains a SNR gain of about 4dB in 2×2 system when the SER is $10^{-3}$ compared to symbol 1 in SISO system.

‘Figure 5’ shows the SER performance results of proposed scheme according to the number of receiving antennas in the 7-tap multi-path Rayleigh fading environment. In the 2×1 system, the receive diversity gain is not obtained and the performance is worse than 2×2. In addition, the 2×3 system has better diversity gain than 2×2 and improved performance.

![Figure 4](image1.png)  
**Figure 4** The SER performance of the bootstrap transmission frame of the proposed scheme and the conventional scheme

![Figure 5](image2.png)  
**Figure 5** SER performance results of proposed scheme according to the number of receiving antennas

4. Conclusion

This paper shows the structure and generation process of the bootstrap symbol of the ATSC 3.0 standard, and then proposes a technique for obtaining diversity gain using STBC and MRC, which are transmit and receive diversity techniques. The proposed scheme improves detection performance by using multiple antennas to obtain diversity gain. The simulation results show that 2×2 multi antenna diversity scheme can improve SER performance compared to the 1×1 system under the Rayleigh fading environments. The increase in the number of transmit and receive antennas shows a performance improvement in the proposed scheme.

5. Reference

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