위성/지상 통합 이동통신시스템을 위한 인터리빙 SM-MIMO 기법

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An Interleaved SM-MIMO Scheme for Integrated Mobile Satellite Systems

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요 약

본 논문에서는 위성/지상 통합 시스템에서 효율적으로 동작할 수 있는 공간 다중화 다중 안테나 방식을 위한 효율적인 인터리빙 기법을 제안한다. 제안된 인터리빙 방식에서는 위성 경로로 전송되는 비트들에 대하여 효과적으로 인터리빙을 적용함으로써, 수신 부호어에서 이웃하는 매 비트마다 서로 다른 채널 이득을 가질 수 있도록 한다. 이와 같은 인터리빙 방식을 적용하면 위성 경로에서의 긴 상관시간으로 인한 성능 저하를 효과적으로 보상할 수 있다. 또한, 제안된 인터리빙 방식은 하드웨어 복잡도 측면에서 효율적으로 구현이 가능하며, 시간 지연도 최소화 할 수 있다.

Key Words : satellite system, MIMO, interleaver, mobile satellite services, SM-MIMO.

ABSTRACT

In this paper, a new interleaving method for spatially-multiplexed multi-input-multi-output (SM-MIMO) scheme in an integrated mobile satellite and terrestrial system is proposed. In the proposed scheme, the transmitted bits for satellite path are interleaved in an innovative way to make sure that bits multiplied with different channel gains will be located alternatively in one received codeword after demapping, in order to compensate the performance degradation due to high-correlation of the satellite path. In addition, the interleaver can be implemented in a computationally efficient way and with the minimum time delay.

I. Introduction

Multimedia broadcast and multicast services (MBMS) will play important roles in future mobile systems, and an integrated satellite and terrestrial system providing mobile satellite service (MSS) can be a very efficient means to provide high-quality MBMS by seamlessly mixing the most powerful aspects of each technology. The satellite can provide the best and most comprehensive coverage for low-density populations, while the terrestrial network or the ground component can provide the highest bandwidth and lowest cost coverage for high-density populations in urban areas [1].

Multi-input and multi-output (MIMO) is the technology which can enhance the communication system capacity and spectrum efficiency without increasing additional bandwidth, and it can be an effective means for a satellite system. However, it may be not always applicable to satellite systems because the channel conditions from satellite to the user terminal are quite different from those of the terrestrial systems.

This paper presents SM-MIMO application for

※ 이 논문은 미래창조과학부가 지원한 2013년 정보통신·방송(ICT) 연구개발사업의 연구결과로 수행되었음
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integrated MSS systems. SM-MIMO is an effective technique to achieve high spectral efficiency without any increase in bandwidth by transmitting multiple date streams via independent paths in parallel. It can be used for an integrated MSS system, where data streams are transmitted from satellite and terrestrial component independently. In addition, the user terminal with multi-path signals from the satellite and terrestrial components can achieve spatial and time diversity gains [2].

However, in practice, both the time and space diversity gains will be reduced due to the highly correlated satellite paths. As channels are not memoryless, errors always occur in bursts rather than independently, in the sense that there can be a local concentration of many errors, too many for error correction schemes to handle. In order to counteract the effect of burst errors, an interleaver can be employed to improve the performance of an MIMO system by efficiently de-correlating the channel gains across the codewords.

In [3], we presented a bit-interleaver (BI), symbol-interleaver (SI), and the interleaving method combining them together for an integrated MSS system. However, by utilizing a SI, we may have an improper channel factor location problem at the receiver. In this paper, we present the improved interleaving method and several other kinds of interleaving schemes, such as a coordinate interleaver (CI) and bit-wise interleaver. In addition, we propose an efficient interleaving scheme with a simple implementation structure, by combining advantages of the introduced interleaving schemes. It can be expected that the BER performance can be improved by combining multiple interleavers together, and taking advantages of these interleavers.

The remainder of this paper is ordered as follows. Section 2 introduces the configuration of the integrated satellite and terrestrial system with SM-MIMO technique. Section 3 presents several interleaving schemes in details, including their advantages and disadvantages. The proposed interleaving scheme is presented in Section 4. Section 5 demonstrates the bit error rate (BER) performance simulation results. Finally, conclusions are drawn in Section 6.

Ⅱ. System model

In this paper, we consider an integrated MSS system which is defined as a system employing MSS and a ground component (GC) where the GC is complementary to and operates as a part of the MSS system and, together with the satellite component, provides an integrated service offering [1]. Fig. 1 shows the system model for an integrated MSS system in which a satellite is in the geostationary orbit (GEO) and an ensemble of GCs are deployed. The main purpose of GC in the integrated system is to relay the satellite signal to the users who are not in a prevailed LOS condition, including urban areas.

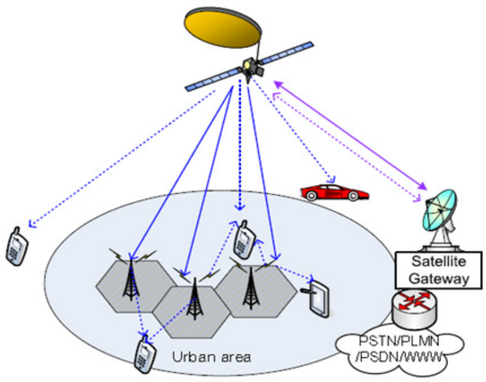

Fig. 1. System model for an integrated MSS system providing MBMS [1]

By considering an integrated MSS system in which satellite and GC transmit different information through different antennas, we can simply model it as a 2□2 SM-MIMO scheme, where the first transmit antenna is considered as the satellite and the second transmit antenna is considered as the GC. We assume a frequency non-selective Rayleigh fading channel for the GC to user terminal path, so every transmitted symbol is assumed to be experienced by independent channel gain. On the other hand, we assume a high correlated Rician fading channel coefficient for the satellite to user terminal path, and the correlation length is assumed to be as long as the codeword length.

Since the high correlation problem in the satellite paths will seriously degrade the performance of the system, we need an efficient technique to alleviate this problem. This can be done by employing an interleaver, such as a SI or BI which was presented in [3]. More efficient interleaving schemes will be introduced in the next section.

Ⅲ. Interleaving schemes for SM-MIMO

In order to counteract the effect of bursty errors, interleaving is utilized to disperse error bursts by shuffling source information across several codewords. In [3], we presented the SI which allows every m ($m = \log_2 M$) input bits treated as one M-ary constellation symbol and get interleaved across the data streams. This SI is an effective scheme to decorrelate a long fading, as the effect of interleaving gradually increased by increasing interleaving depth (ID).

However, by utilizing a SI, we may have a problem to extract accurate soft decision detection (SDD) information at the receiver. In order to extract SDD bit information either by using maximum likehood (ML) or minimum mean squared error (MMSE) algorithm. channel gain values play an important role. For soft ML algorithm, de-interleaving process should be done before soft demapping because we mapped symbols before interleaving process. However, with this way, symbols in a MIMO frame will be separated out, and thus we cannot perform the detection.

The situation does not become much better when soft MMSE algorithm in [4] is utilized, even the soft bit detection is performed in two steps. We firstly do the symbol-level MMSE detection, then extract the soft bit information from each detected symbol by multiplying the distance between the detected symbol and hard decision threshold for the bit with a weighting factor. The weighting factor is a function of channel matrix for a MIMO frame, but after deinterleaving symbols in a MIMO frame will be separated out. This results in estimating inaccurate gain values. Consequently, inaccurate SDD value will affect the BER performance of the system.

In order to solve this problem, we need an interleaving scheme so as MIMO detection process to be performed before the de-interleaving process. Therefore, a block-wise interleaver is presented in this paper as a technique which can not only solve the improper channel factor location problem, but also take advantages of BI and SI. The interleaving effect is the same with the one utilized BI and SI separately in [3]. In the improved method, the interleaver considers a block of the transmitted bits as a symbol and performs the symbol interleaving process on them. After interleaving, effect of BI and SI can be performed on the transmitted bits contained in blocks. Therefore this method can be referred as block-wise interelaving.

In this paper, we present another interleaving scheme which can be applied to MIMO systems by utilizing the potential diversity of real and image parts of coordinates, This is a technique called coordinate interleaving (CI) which was first proposed for single stream communication systems [5][6], and has been applied to MIMO systems [7][8].

If we assume modulated symbols are $S_k, (k=1,...,p)$, after CI, the transmitted signals are $X_k, (k=1,...,p)$, X_k can be presented as:

$$X_k = R_e\{S_a\} + jI_m\{S_b\}, \quad a \neq b \text{ and } a,b \in \{1,...,p\}, \tag{1}$$

where p is the number of modulated symbols. $X_k$contains information of two different symbols will be experienced the same channel condition. As the real part and the imaginary part of a symbol are in different transmitted signals, it can be said that one symbol experience two different channel conditions. Hence, CI can provide additional spatial diversity gain.

In order to take advantages of BI and CI, they can be combined together working cooperatively. Bit interleaving process should be performed first, and after mapping a set of bit-interleaved bits into symbols, imaginary parts of two different symbols which supposed to be experienced different channel factors are exchanged.

Nevertheless, CI is also an interleaving technique which is performed on symbols, the system will suffer from the same improper channel factor location problem as the system employed a SI.

In order to counteract this problem, and also take advantages of BI and CI, an improved interleaver called bit-wise interleaver is presented. By utilizing a bit-wise interleaver, the CI process is performed before mapper on bit-wise instead of symbol-wise. And this is also the reason why this method is referred as a bit-wise interleaving scheme. The interleaving effects are the same whether the CI process is performed before or after mapper.

An example of bit-wise interleaver is shown in Fig. 2, where the ID and symbol length are all 4. The Arabic number $1 \leq i \leq 4$, stands for a bit comes from codeword Ci. Different colors in the figure indicate different channel gains. Bits are assumed to be mapped into the imaginary part of a symbol are exchanged between different bit-interleaved sequences. At the receiver, every received codeword contains four different channel gains, same as the example utilized BI and SI together showed in [3], except Fig. 2 has shorter correlation length of the channel gains in the de-initerleaved codeword at the receiver. Thus, we may expect more BER performance improvement. The simulation results will be presented in section 5.

However, Fig. 2 shows a simple example with the symbol length of 4. If we increase the modulation order, it will become very difficult to select which bits should be exchanged. The hardware implementation will be extraordinarily complex.

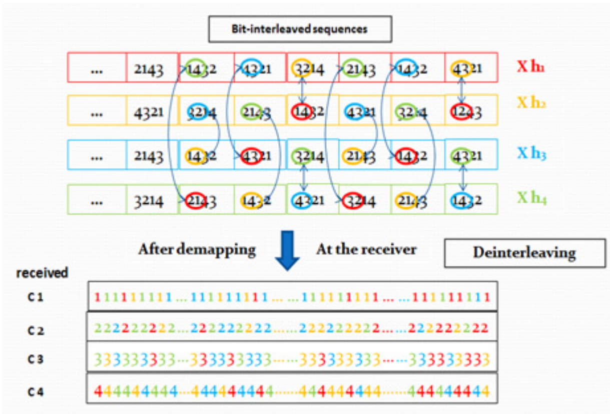

Fig. 2. Example of utilizing bit-wise interleaver with *ID*=4

Ⅳ. The proposed interleaving scheme

Several improved interleaving schemes have been introduced in this paper, mainly to improve the BER performance and also to solve soft MIMO detection problem mentioned in the previous section. However, we did not pay much attention on time delay problem or a complex structure to make it impractical for the hardware. Therefore, more efficient interleaving method with less complexity is needed. This section proposes an efficient interleaving scheme by considering not only the performance enhancement problem but also hardware implementation issues.

The proposed interleaver attempts to integrate diverse interleavers to achieve the maximum diversity gain, but with minimum complexity. An example of the proposed interleaving scheme is shown in Fig. 3, where the *ID* and symbol length are all 4. As the arrows show in the figure, the interleaving is performed in a diagonal way, so that every transmitted symbol consists of coded bits from different codewords with different columns. If we assume that there are *ID* codewords are stacked in a block memory before and after interleaving, A_r and A_c are row and column addresses of the codeword block before interleaving, $1 \le A_r \le n$,and $1 \le A_c \le ID$, n is the length of the codeword, the row and column addresses of the interleaved bits, $A_r^{'}$ and $A_c^{'}$, respectively, can be presented as follows:

$$A_r^{'} = (A_r + A_c)\% ID, \quad (2)$$

$$A_c^{'} = A. \quad (3)$$

Considering the satellite path is highly correlated, if we assume the correlation length is same as the codeword length, channel coefficient is considered to be consistent for the codeword length. By using the proposed method, as bits in one symbol are experienced the same channel coefficient, bits from different codewords with diagonal positions can be experienced the same channel coefficient for a codeword length. Therefore, in every de-interleaved received codeword different channel gains are distributed alternatively. It may help the system to achieve the maximum performance improvement. Simulation results with different *ID* will be demonstrated in the next section.

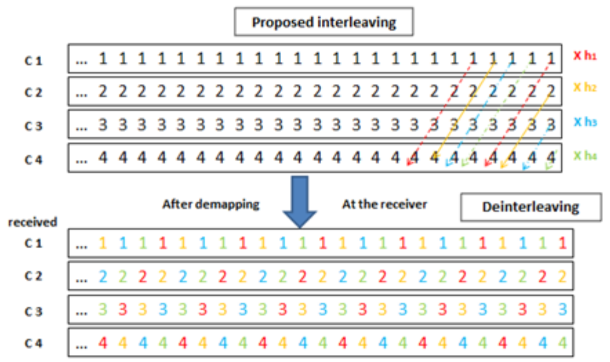

Fig. 3. Example of of utilizing the proposed interleaver with *ID*=4

Ⅴ. Simulation results

This section demonstrates the simulation results of the interleaved SM-MIMO satellite system with different interleaving schemes along with different *ID*. The performance of the interleaving techniques can be varied relying on different channel conditions and *ID*.

In the simulation results in this paper, it is assumed that the high correlated satellite path is a Rician channel with Rician factor of 10 dB, and the terrestrial path is a frequency non-selective Rayleigh channel with all independent channel gain for each transmitted symbol. It is also assumed that the signal is modulated by using 16-QAM and detected by using a soft MMSE MIMO detector. A binary turbo code with information length of 378 bits and code rate of 1/3 is utilized. In addition, the maximum iteration number of MAP iterative decoding algorithm is limited to 8.

In order to counteract the improper channel factor location problem in a MIMO system where a SI or CI is employed and take advantages of diverse interleavers, block-wise interleaver and bit-wise interleaver was presented. They perform the SI or CI process on bit-lever before mapping process instead of symbol-level. At the same time, instead of using two interleavers separately, the structure of the system is simplified.

Table 1. Simulation parameters for Fig. 4.

Modes	*ID*		Interleaver
BL1	4		Block-wise
BL2	8		
BS1 [3]	4 (BI)	4 (SI)	BI and SI [3]
BS2 [3]	8 (BI)	8 (SI)	

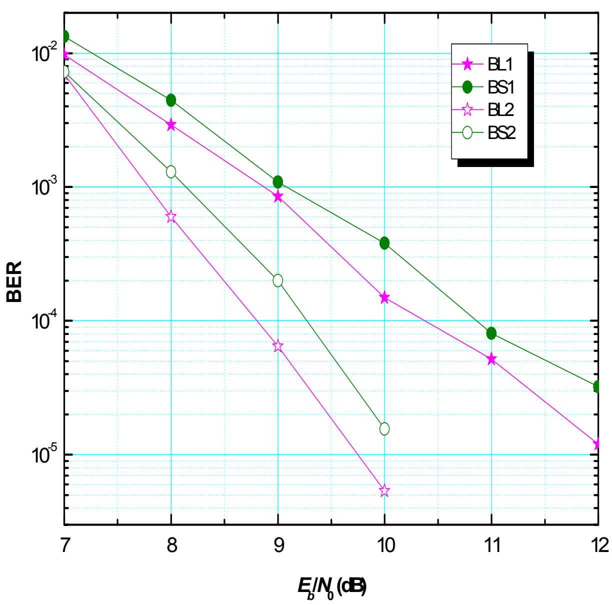

Fig. 4. BER performance of SM-MIMO satellite system using block-wise interleaver

Fig. 4 shows the simulation results of a SM-MIMO satellite system by utilizing a block-wise interleaver, and the situation where a BI and SI are employed separately in [3] is shown as a comparison, Table 1 summarizes the simulation conditions. BL1 and BL2 stand for the system which employs the block-wise interleaver with different *ID*. BS1 and BS2 are the ones employ BI and SI together with different *ID*, but *ID* of BI and SI are the same. It can be noted that with the same *ID*, BER performance is improved by utilizing block-wise interleaver as we expected, comparing to bit and symbol interleaving in [3]. For example, when *ID* is 4, BL1 achieved 0.6 dB gain at BER of around 10^{-5} comparing with BS1. In addition, the performance gets better by increasing *ID*. Comparing with BL1 with *ID* of 4, BL2 with *ID* of 8 produces about 2.3 dB performance gain at BER of around 10^{-5}.

Table 2. Simulation parameters for Fig. 5.

Modes	*ID*	Interleaver
C	4	Bit-wise
BL	4	Block-wise
N	0	No

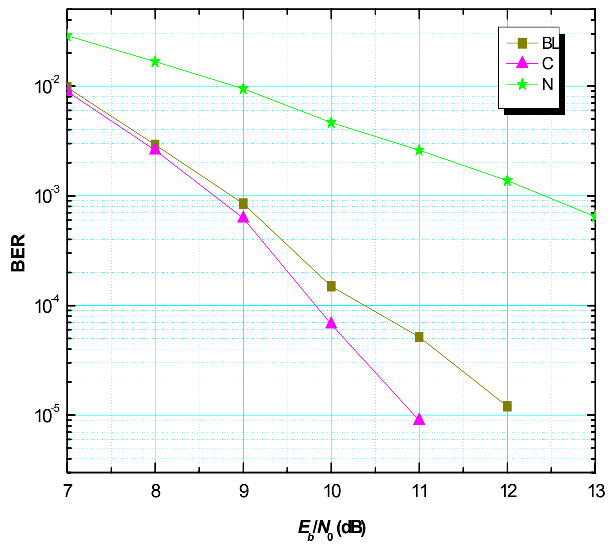

Fig. 5. BER performance of SM-MIMO satellite system using bit-wise interleaver

The simulation results of utilizing a bit-wise interleaver is presented in Fig. 5 which illustrates the BER performance comparison between utilizing a block-wise interleaver and a bit-wise interleaver in an integrated SM-MIMO system. Table 2 summarizes the simulation conditions. With the same *ID* of 4, performance of utilizing a bit-wise interleaver which is denoted as C in Fig. 5 can achieve 1 dB gain at BER of around 10^{-5} comparing with BL. For comparison purpose we also present the performance of non-interleaved one with the situation when a Rician channel factor is consistent for one codeword, which is shown as N. Comparing with N, the performance of C improves significantly. As *ID* is increased, the BER performance of the system by utilizing a block-wise interleaver increases. Similarly, the performance of bit-wise interleaver with higher *ID* may also provide performance improvement.

Fig. 4 and Fig. 5 showed that the performance can be improved by modifying the BI, SI and CI schemes. Block-wise and bit-wise interleavers are introduced mainly for solving the improper channel factor location problem in a MIMO system. Considering a interleaver can not only provide performance improvement, but also can be implemented with a simple hardware structure, the most efficient interleaver was proposed. Fig. 6 presents the simulation results of the proposed interleaving scheme, comparing with the block-wise and bit-wise interleavers in an integrated SM-MIMO system. Table 3 summarizes the simulation conditions. For comparison purpose we also present the performance of non-interleaved one, N.

Table 3. Simulation parameters for Fig. 6.

Modes	*ID*	Interleaver	Channel condition
P1	4	Proposed	Satellite paths: One codeword length of Rician fading GC paths: Per symbol independent Rayleigh fading
P2	8		
BL1	4	Block-wise (Fig. 4)	
BL2	8		
C	4	Bit-wise (Fig. 5)	
N	0	No	
I	0	No	all independent fading

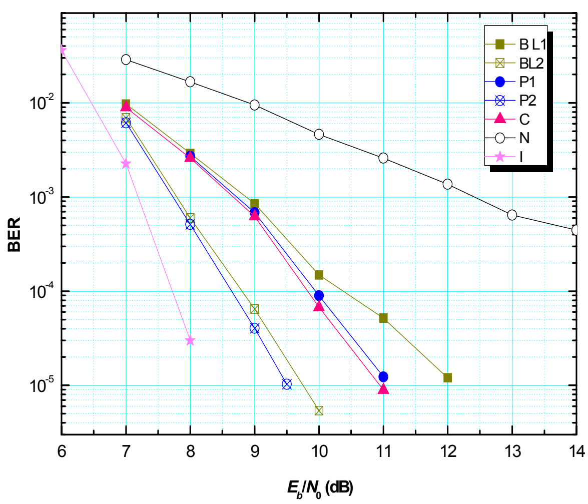

Fig. 6. BER performance comparison of the proposed and other interleaving schemes for SM-MIMO satellite system

As shown in Fig. 6, performance of the proposed interleaving scheme outperforms the block-wise interleaver. For example, P1 (*ID* = 4) achieves 1 dB gain at BER around 10^{-5} comparing with BL1 (*ID* = 4), and P2 (*ID* = 8) achieves 0.2 dB gain at BER around 10^{-5} comparing with BL2 (*ID* = 8).

However, with *ID* of 4, performance of the proposed interleaving scheme is slightly worse than that of the bit-wise interleaving scheme. Nevertheless, the implementation complexity of the proposed scheme is much lower than the bit-wise interleaving scheme. The bit-wise interleaver has to exchange specific bits between two different codewords, which depends on modulation order and *ID*. By increasing the modulation order and *ID*, this exchange process becomes more difficult.

On the contrary, the proposed interleaving scheme can alleviate these problems. It is easy to be extended to any modulation order and *ID*. In addition, if *ID* is greater than the modulation order, CI may not able to achieve more performance improvement than the proposed scheme can.

In this example, in order to get the maximum diversity we need *ID* of 1134, resulting in all independent channel gains bit by bit across the received codeword, shown as "I" in Fig. 6. If we compare the performance of P2 and I, we may conclude that only with *ID* of 8, which is about 1/142 of the maximum required *ID* of 1134, the performance is degraded about 1 dB, compared to the maximum achievable performance. It indicates that the proposed method is efficient to alleviate the high correlation problem in satellite system with less complexity.

Ⅵ. Conclusion

In order to compensate the performance degradation due to high-correlation of the satellite path for an integrated MSS system, we tried to combine diverse interleavers as proposed in [3]. However, the system is subjected to the improper channel factor location problem if a SI or CI is employed. At the same time, separate interleavers in the same system may cause serious time delay problem, Therefore, block-wise and bit-wise interleavers were introduced to solve these problems and take advantages of diverse interleavers, except that they are still difficult to be implemented and extended.

By considering all these problems, we proposed an efficient interleaving scheme which could achieve almost the maximum diversity gain among the interelaving schemes investigated in this paper, while allowing low implementation complexity. The simulation results demonstrated that the proposed scheme produced better performance than the other conventional schemes.

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