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AN IMPROVED BIT LOADING TECHNIQUE FOR ENHANCED ENERGY EFFICIENCY IN NEXT GENERATION VOICE/VIDEO APPLICATIONS

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Abstract

Multi input multi output (MIMO) and orthogonal frequency division multiplexing (OFDM) are the key techniques for the future wireless communication systems. Previous research in the above areas mainly concentrated on spectral efficiency improvement and very limited work has been done in terms of energy efficient transmission. In addition to spectral efficiency improvement, energy efficiency improvement has become an important research because of the slow progressing nature of the battery technology. Since most of the user equipments (UE) rely on battery, the energy required to transmit the target bits should be minimized to avoid quick battery drain. The frequency selective fading nature of the wireless channel reduces the spectral and energy efficiency of OFDM based systems. Dynamic bit loading (DBL) is one of the suitable solution to improve the spectral and energy efficiency of OFDM system in frequency selective fading environment. Simple dynamic bit loading (SDBL) algorithm is identified to offer better energy efficiency with less system complexity. It is well suited for fixed data rate voice/video applications. When the number of target bits are very much larger than the available subcarriers, the conventional single input single output (SISO)-SDBL scheme offers high bit error rate (BER) and needs large transmit energy. To improve bit error performance we combine space frequency block codes (SFBC) with SDBL, where the adaptations are done in both frequency and spatial domain. To improve the quality of service (QoS) further, optimal transmit antenna selection (OTAS) scheme is also combined with SFBC-SDBL scheme. The simulation results prove that the proposed schemes offer better QoS when compared to the conventional SISO-SDBL scheme.

Keywords: Energy efficiency, OFDM, Optimal transmit antenna selection, Simple dynamic bit loading, Space frequency block codes.

Nomenclatures

B_T	*Target total bits to be transmitted through one OFDM symbol*
$b(m)$	Number of bits on m^{th} subcarrier
b_{max}	Maximum number of bits that can be loaded on a subcarrier
D	SFBC matrix
E_T	*Total energy required to transmit the target bits*
$e(m)$	Energy required for m^{th} subcarrier
$H(m)$	Channel gain on m^{th} subcarrier
L	Total number of subcarriers
N_T	Total number of transmitting antennas
P	Number of groups
S_1,S_2	Selected antenna indices

Abbreviations

CFO	Carrier Frequency Offset
ISI	Inter Symbol Interference
LTE	Long Term Evolution
LTE-A	Long Term Evolution- Advanced
NAS	No Antenna Selection
Wi-MAX	Worldwide Interoperability for Microwave Access

1. Introduction

Broadband data connection through UE is the order of the day. The usage of Personal Computers (PC) for internet access is reducing and the usage of mobile phones for internet access is growing day by day [1]. In countries like China, Korea, United States of America (USA) and Japan 80% of internet access is through mobile phones. 50% of the mobile users use mobile as the primary internet source. High speed media streaming applications like YouTube, Facebook, Google+ attracted huge amount of customers. 65% of time spent on social networks is through mobile phones. 6 billion hours of video are watched through YouTube every month. More than 30% of YouTube's global watch time is through mobile phones. Recent days mobile banking has become very popular. In 2013 globally, 590 million mobile users used their mobile for banking purposes. The number is expected to cross 1 billion during 2017. In 2013, 81 of top 100 financial institutions in USA offered mobile banking services. Skype is very popular for video calls through internet. Around 33 million hours people talking, laughing, joking, singing through Skype in a day. Almost 65% of Skype usage is through mobiles. People also use mobile phones as Wireless Fidelity (Wi-Fi) hot spot. All the above examples and the related statistics clarify the necessity of mobile broadband. The customers are expecting high quality services from mobile operators.

Maintaining acceptable BER or SNR at the receiver is synonymous to QoS at the physical layer level [2]. To achieve the above demands transmission parameters like modulation order and energy are dynamically adopted as per the channel quality. Maintaining within maximum delay and minimum acceptable rate is synonymous to QoS at the higher layer levels. QoS at higher layers are possible by proper channel allocation and scheduling methods. Energy consumption is an important metric for QoS improvement [1]. In this work, QoS improvement by proper energy allocation at physical layer level is considered.

Zero ISI and one tap equalization features attracted the researchers to use OFDM for 4G standards like Wi-MAX, LTE and LTE-A. Usage of OFDM for high quality multimedia services under fading environment is a challenging task. Radio channels are passive circuits where large amount of energy is wasted [3]. Popularity of smart mobiles and its services like video games, video conferencing, High Definition Television (HDTV), web seminars, e-mail and downloading files consumes energy at a higher rate than the normal mobiles.

High performance receivers are expected to offer high spectral efficiency [1]. This increases the system complexity and it also needs costlier components. High performance receivers consume more energy. Increase in multimedia applications increase the signal processing complexity further. Since most of the mobile devices are operating with the battery, high energy consumption will cause the battery to dry soon.

Advanced physical layering techniques like ICI mitigation, DBL,MIMO, dynamic guard interval, blind channel and CFO estimation are required to increase the QoS of OFDM system without increasing the system complexity [2].

The deeply faded subcarriers contribute to more BER, increasing average BER of OFDM symbol beyond the target BER [4]. To maintain the same BER, the deeply faded subcarriers have to be identified and omitted from transmission. This improves BER performance with slight loss in spectral efficiency. This spectral efficiency loss can be compensated by effectively employing DBL.

The frequency selective fading nature of the wireless channel reduces the spectral and energy efficiency of OFDM based systems. DBL is the powerful scheme to improve the spectral and energy efficiency of OFDM system in frequency selective fading environment [5]. To maintain QoS in energy allocation based algorithms, more energy is allocated for poor subcarriers and less energy for good subcarriers. This makes the chances of successful reception high. Thus DBL algorithms improve the QoS. The delay sensitive transmission services like voice and video are usually served with fixed rate. Margin Adaptive (MA) algorithms are better suited for fixed rate applications. These algorithms try to maximize margin or minimize energy required to transmit the target bits with the target of fixed data rate. It can be mathematically represented as [6],

$$\left.\begin{array}{l} \textit{Minimize} \quad E_T = \sum_{m=0}^{L-1} \mathrm{e}(m) \\ \textit{so that} \\ \sum_{m=0}^{L-1} \mathrm{b}(m) = B_T \quad \textit{and} \quad 0 \le b(m) \le b_{\max} \end{array}\right\} \tag{1}$$

where B_T is the target total bits to be transmitted through one OFDM symbol and E_T is the total energy required to transmit the same. b_{max} is the maximum number of bits that can be loaded on a subcarrier. *e(m)* and *b(m)* are respectively the number of bits per subcarrier and energy required to transmit the same. There are many MA algorithms discussed in the literature.

For fast fading conditions, coherence time is small [7] compared to the total delay involved for channel estimation, feedback and DBL algorithm convergence. Since the channel becomes outdated, the parameters adopted based on this will go wrong. This reduces the QoS of the system [4]. To offer superior quality services for long durations an optimal DBL algorithm which takes less iteration for converge is the major requirement [1].

Esfahani and Afrasiabi [6] proved that SDBL algorithm offers better performance than the conventional optimal and sub optimal algorithms like Hughes-Hartogs [8], Fischer and Huber [9] and Chow [10]. SDBL algorithm optimally allocates bits to all subcarriers in iteration whereas the other above mentioned algorithms need more iteration to converge. It is proved that initial bit loading result of SDBL is nearer to Hughes-Hartogs final bit loading result. But Hughes-Hartogs algorithm converges after 200 iterations.

The algorithm works well when the number of subcarriers is sufficient (Case 1) and more (Case 2) when compared to the target bits. An important issue is when the target bits are very large compared with the number of available subcarriers (Case 3); the conventional SISO-SDBL scheme offers high BER. It also consumes more energy to transmit the target bits. In this case, SDBL algorithm forcefully allocates the target bits to limited number of subcarriers irrespective of the channel frequency response. This increases the probability of error. To achieve a certain target BER, it requires more transmit energy. Usually the third case will not converge in an iteration for poor channel conditions. Since overall aim of this work is to reduce the total transmit energy and to improve QoS, an optimum solution is required to efficiently use SDBL for fixed rate applications. A combination of SFBC and antenna selection schemes with SDBL is used to solve the above issue. We modify the algorithm to suit for SFBC based MIMO-OFDM system.

In Multi Carrier Modulation (MCM) scheme such as OFDM, DBL is carried out in frequency dimension. Recent research on DBL in OFDM has proved that the hybrid adaptation based on frequency and space dimension is expected to offer better BER performance than the conventional adaptation which is done only on frequency dimension [5]. MIMO combined with OFDM offers diversity gain which reduces the BER of the system [11]. A suitable diversity scheme coupled with the conventional SDBL algorithm will solve the problems of high BER and large transmit energy.

Receive diversity schemes such as Maximal Ratio Combining (MRC) offers better diversity gain. But limitations to deploy multiple antennas at UE make MRC inefficient. Transmit diversity techniques based on beam forming offers performance similar to MRC. But this scheme requires perfect knowledge about the channel at the transmitter side [5]. Orthogonal Transmit Diversity (OTD) schemes such as Space Time Block Codes (STBC) perform almost similar to transmit diversity based on beam forming [5, 12]. These schemes do not require perfect channel knowledge at the transmitter side. But STBC is more suited for flat fading channels .We prefer SFBC based diversity scheme which is well suited for frequency selective fading channels [13].

To implement SFBC scheme, minimum two transmitting antennas are required. SFBC implemented with more transmitting antennas will increase the diversity gain at the cost of reduced spectral efficiency and increased complexity.

Other limitations like number of Radio Frequency (RF) chains and synchronization make SFBC with more transmitting antennas impractical. Instead of using more transmitting antennas, an alternate approach OTAS scheme is used in this work to improve the BER performance of SFBC scheme [14-16]. This scheme selects two antennas having good channel frequency response out of 4 or 8 transmitting antennas for every coherence period. Bit allocation is done based on the selected antennas. Since the proposed system always use two best transmitting antennas, the energy required to transmit the target bits gets reduced.

The rest of the paper is organised as follows. In Section 2 the proposed system model is briefly explained. Section 3 gives brief description on OTAS. Section 4 provides explanation on the proposed MA-SFBC-SDBL-OTAS algorithm. In Section 5, simulation results are discussed and Section 6 concludes the paper.

2. System Model

The proposed system uses a hybrid configuration of SFBC, OTAS and SDBL. While OTAS provide with better channels, SFBC provide spatial and frequency diversity gain to the system. The SDBL performance is improved dramatically with this hybrid configuration.

The user data in form of bits is modulated by the M-ary Quadrature Amplitude Modulation (M-QAM). The modulated symbols for the I^{th} OFDM symbol of length L can be given as

$$X_I[m] = \left[X_I[0], X_I[1], X_I[2].....X_I[\mathrm{L}-1]\right]^T \tag{2}$$

where $m = 0,1,....,\frac{L}{2}-1$, T represents transpose operation.

These symbols are input to the SFBC block. Here we use SFBC for 2X1 system. In SFBC, Alamouti scheme is implemented over neighbouring subcarriers of the same OFDM symbol. The SFBC coded data is given as [12, 17]

$$D = \begin{bmatrix} X_I[2m] & X_I[2m+1] \\ -X_I[2m+1]^* & X_I[2m]^* \end{bmatrix} = [D_1\ D_2] \tag{3}$$

The symbols coded in the first (D_1) and second (D_2) columns of the matrix D are transmitted through the selected two transmit antennas respectively. It is clear that each modulated symbol is transmitted in two different frequencies and antennas. It adds spatial and frequency diversities to each modulated symbol.

In SFBC-OFDM system, for each subcarrier both antennas sub channel gains are considered. For each received subcarrier at least one antenna's subchannel gain may be good which may lead the system to use higher order modulation for that subcarrier. Same number of bits is allocated for each subcarrier in both the transmitting antennas to reduce the decoding complexity.

The major building blocks of SFBC- SDBL-OTAS scheme is shown in Fig. 1. The channels are estimated at the receiver and the antenna selection is carried out. Based on the selected antennas channel gains, the number of bits that can be loaded on each subcarrier (modulation index, *M*) is identified using SDBL algorithm. The OTAS index and modulation index is fed back to the transmitter using the feedback channel [9]. The input bits are modulated using the received modulation index and the two SFBC modulated OFDM symbols are transmitted through the selected antennas. The SFBC-SDBL scheme which selects 2 out of 4 and 8 transmitting antennas is named as SFBC-SDBL-OTAS (4) and SFBC-SDBL-OTAS (8).

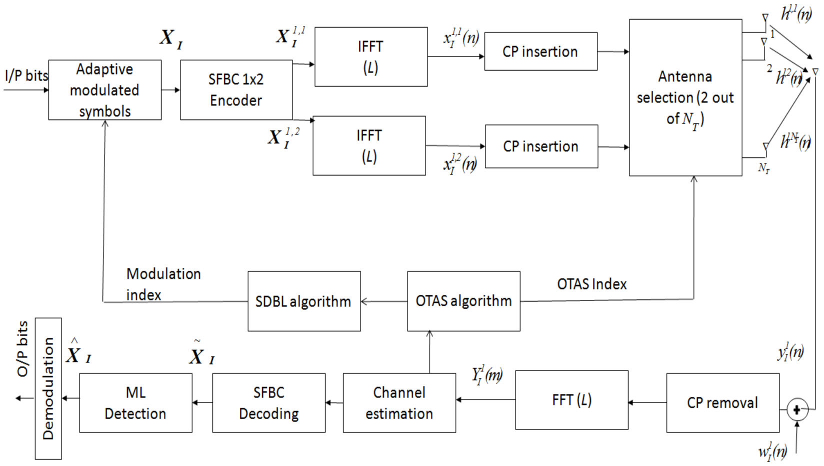

Fig. 1. Block diagram of the proposed MA-SFBC-SDBL-OTAS bit loading scheme.

3. OTAS

When the number of transmitting antennas increases, the complexity also increases along with the diversity gain. The system becomes expensive since each antenna needs separate RF chains [13]. However when MISO system is used in diversity mode, more number of transmitting antennas will reduce the spectral efficiency. SFBC with two transmitting antennas lead to Rate 1 system, where two symbols are transmitted in two subcarriers. Whereas SFBC with three transmitting antennas leads to Rate 0.5 system, where four symbols are transmitted in eight subcarriers, thereby reduces the spectral efficiency. For SFBC with three transmitting antennas, eight consecutive subcarriers should have same channel gain. This quasi static condition is violated under fast fading [4, 5]. Also, accurate synchronization of multiple transmitting antennas with one receiving antenna increases the complexity. Moreover, feedback signaling used for the synchronization, causes wastage of bandwidth.

Therefore, instead of using all the transmitting antennas use two antennas with best channel frequency response for every coherence period. It has been proved that antenna selection schemes offers better spectral efficiency than the conventional system with no antenna selection [14]. OTAS is expected to reduce the hardware and signal processing complexity of conventional MISO systems with no antenna selection. The following steps are executed in the OTAS scheme.

i. Calculate Frobenius norm for the channel frequency response available at each transmitter antenna [5].

$$\left\|H_I^{1,S}\right\| = \sum_{m=0}^{L-1}\left|H_I^{1,S}(m)\right|^2 \quad , for\ S = 1,2...N_T \tag{4}$$

where N_T represents the total number of transmit antennas available.

ii. Two antennas out of N_T transmitter antennas which have highest Frobenius norms are then selected as [4].

$$\{S_1, S_2\} = \arg \max_{\substack{1 \le S_1, S_2 \le N_T \\ S_1 \ne S_2}} \left\{\left\|H_I^{1,S_1}\right\| + \left\|H_I^{1,S_2}\right\|\right\} \tag{5}$$

In the conventional SFBC-SDBL system, if any one of the sub channel is bad, the average channel gain becomes less and forces the system to use lower order modulation which again reduces the QoS. To implement SFBC-SDBL always with good channel conditions OTAS scheme is combined with SFBC-SDBL scheme.

4. MA-SFBC-SDBL-OTAS Algorithm

In SDBL algorithm, the following steps are executed in sequence to identify the optimum number of bits per subcarrier.

i. Find sub channel gain H as

$$H(m) = \frac{H_I^{1,S_1}(m) + H_I^{1,S_2}(m)}{2}\ ; m = 0,1 \cdots L-1 \tag{6}$$

ii. Partition the sub carriers into P groups using

$$P = \left\lfloor \log_2 \frac{\left|H^{\max}\right|^2}{\left|H^{\min}\right|^2} \right\rfloor + 1 \tag{7}$$

where $\left|H^{\min}\right|^2$ and $\left|H^{\max}\right|^2$ are minimum and maximum sub channel gains.

iii. The lower and upper index of each group is calculated using,

$$\left.\begin{aligned} LI_i &= \frac{\left|H^{\max}\right|^2}{2^{P-i+1}} \\ UI_i &= \frac{\left|H^{\max}\right|^2}{2^{P-i}}, i = 1,2...P \end{aligned}\right\} \tag{8}$$

The subcarrier which is having the channel gain twice the other sub carrier can carry one more bit than the other subcarrier for the same energy and SNR gap. From (8), it is clear that upper index of each group is twice the lower index. Suppose the subcarriers in the first group are loaded with one bit, then the subcarriers in the second group can be loaded with two bits. For every group one more additional bit can be allocated.

iv. Identify the number of subcarriers fall in each group. The number of subcarriers fall in i^{th} group (N_i) is calculated by counting the sub carriers having channel gains between LI_i and UI_i. Same procedure is repeated to distribute L subcarriers to all P groups.

$$\sum_{i=1}^{P} N_i = L \qquad (9)$$

v. The target bits are divided and distributed based on the number of subcarriers and target bits. This creates three different cases [6]. Case 1 and Case 2 are not discussed in this paper. We concentrate on improvement of system performance in Case 3 where SDBL performance degrades

Case (1): Number of subcarriers is sufficient enough to allocate the target bits.

Case (2): The number of subcarriers is sufficiently large when compared to the target bits i.e $B_T < \sum_{i=1}^{P} i.N_i - L$.

Case (3): B_T is large i.e $B_T > \sum_{i=1}^{P} i.N_i + L(\mathrm{b}_{\max} - P)$

In this case, the number of subcarriers are not sufficient for the given target bits. Normal allocation as per Case 1 makes $B_P > b_{\max}.N_p$ which leads to more than b_{max} bits per subcarrier in the last group. To avoid this, allocate last group with $B_P = b_{\max} N_P$ and distribute the remaining target bits to other groups.

$$B_i = \begin{cases} round[(\beta + i) N_i] & ; i = 1, \ldots P-2 \\ B_T - b_{max}\, N_P - \sum_{k=1}^{P-2} B_k & ; i = P-1 \\ b_{max} N_P & ; i = P \end{cases} \qquad (10)$$

where

$$\beta = \frac{B_T - b_{\max} N_P - \sum_{i=1}^{P-1} i.N_i}{L - N_P} \qquad (11)$$

vi. After identifying the number of bits for each group, distribute them among the subcarriers available in each group using,

$$\left.\begin{aligned} b_i^u &= \left\lfloor \frac{B_i}{N_i} \right\rfloor + 1 \\ b_i^l &= b_i^u - 1 \\ N_i^u &= B_i - \left\lfloor \frac{B_i}{N_i} \right\rfloor N_i \\ N_i^l &= N_i - N_i^u \end{aligned}\right\} \qquad (12)$$

In i^{th} group, b_i^l bits are allocated to N_i^l subcarriers and b_i^u bits are allocated to N_i^u subcarriers such that,

$$B_i = b_i^u N_i^u + b_i^l N_i^l \qquad (13)$$

and

$$N_i^l + N_i^u = N_i \qquad (14)$$

5. Simulation Results and Discussion

Esfahani and Afrasiabi [6] proved that SDBL algorithm offers better performance than the conventional optimal and sub optimal algorithms. So in this work, we have not compared the performance of SDBL algorithm with other algorithms. In this work SISO-SDBL algorithm performance is set as the benchmark and we tried to improve its performance further by adding SFBC and OTAS schemes. The performance of the proposed algorithm is tested for all three cases of total target bits.

The following parameters are taken for the simulation to test the performance of the proposed algorithm. System bandwidth and subcarrier bandwidth is assumed to be 5 MHz and 39.063 kHz respectively. The total number of subcarriers is 128. M-ary QAM scheme is used to modulate each subcarrier. Based on the channel condition, M value is varied from 0 to 256. Maximum number of bits that can be loaded on a subcarrier is limited to 8 (b_{max}=8). The simulation results are repeated for 1000 different channel conditions and the average energy values are displayed. To analyze the performance of MA algorithms, energy efficiency (b/J) parameter is frequently used in the literature [17, 18]. It is the ratio between the target bits for one OFDM symbol and the total energy required to transmit the target bits. Since the SISO-SDBL algorithm perform good for Case 1 and Case 2 type of bit allocation, the results for Case 3 are given in this paper.

The channel in Fig. 2 is taken to test the performance of SISO-SDBL algorithm. To test SDBL for Case 3, we take target bits to be 832. The upper and lower index of each group, total number of bits and subcarriers allocated to each group, number of bits allocated to the individual subcarriers in each group for Case 3 is shown in Table 1. The bit allocation for Case 3 is shown in Fig. 3. All 832 bits are effectively allocated to all subcarriers. Energy allocated per subcarrier for Case 3 is shown in Fig. 4. For Case 3 of target bits, the conventional SISO-SDBL algorithm offers an average energy efficiency of 4.35 b/J for the given target bits. For Case 3, as in Table 1, subcarriers in 7th and 8th groups are loaded with 9 bits exceeding the maximum bit limit at the initial iteration. To avoid this, the algorithm has to be reiterated.

Table 1. Number of bits assigned to the number of subcarriers in each group for SISO-SDBL scheme: Case 3.

Group Index (i)	Lower Index	Upper Index	B_i	b_i^l	b_i^u	N_i^l	N_i^u	N_i
1	0.0111	0.0222	0	0	1	1	0	1
2	0.0222	0.0444	5	1	2	3	1	4
3	0.0444	0.0887	11	2	3	4	1	5
4	0.0887	0.1774	16	3	4	4	1	5
5	0.1774	0.3548	59	4	5	11	3	14
6	0.3548	0.7097	120	5	6	18	5	23
7	0.7097	1.4193	237	8	9	15	13	28
8	1.4193	2.8387	384	8	9	48	0	48

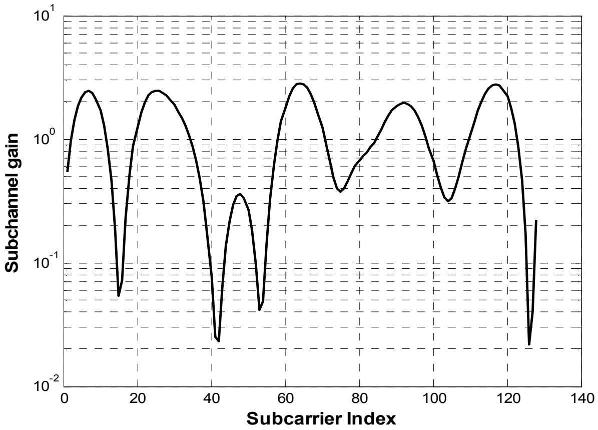

Fig. 2. Sub channel gain vs. Subcarrier index.

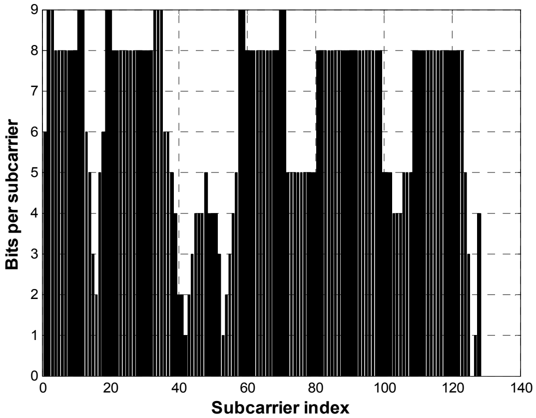

Fig. 3. Bits per subcarrier vs. Subcarrier index for SISO-SDBL scheme: Case 3.

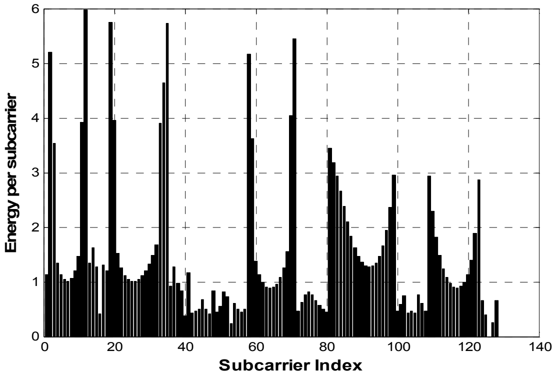

Fig. 4. Energy allocated per subcarrier vs.
Subcarrier index for SISO-SDBL scheme: Case 3.

The bit and energy allocation for SFBC-SDBL-NAS scheme is shown in Figs. 5 and 6 respectively. The sub channel gains are divided into 4 groups. The SDBL parameters obtained for SFBC-SDBL-NAS scheme is shown in Table 2. SFBC scheme introduces frequency and spatial diversity gains to the conventional SISO-SDBL system which improves the QoS. The SFBC-SDBL-NAS scheme offers an average energy efficiency of 17.97 b/J for the given target bits. To improve the performance further, OTAS scheme is coupled with SFBC-SDBL scheme. When two antennas are selected out of 4 transmitting antennas, the average energy efficiency becomes 29.78 b/J for the given target bits. The bit and energy allocation for the SFBC-SDBL-OTAS (4) scheme are shown in Figs. 7 and 8. Here the sub channel gains are divided into 3 groups. The SDBL parameters obtained for SFBC-SDBL-OTAS (4) scheme is shown in Table 3.

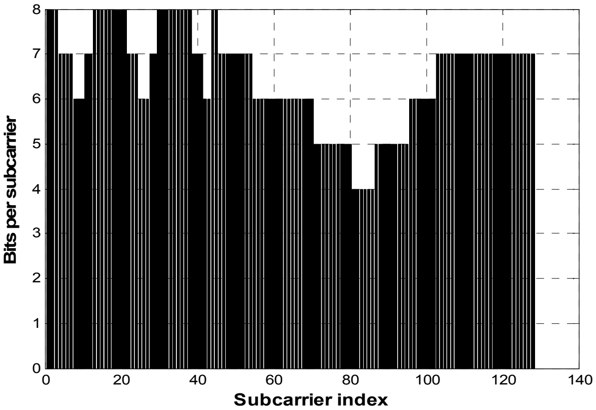

Fig. 5. Bits per subcarrier vs. subcarrier index
for SFBC-SDBL-NAS scheme: Case 3.

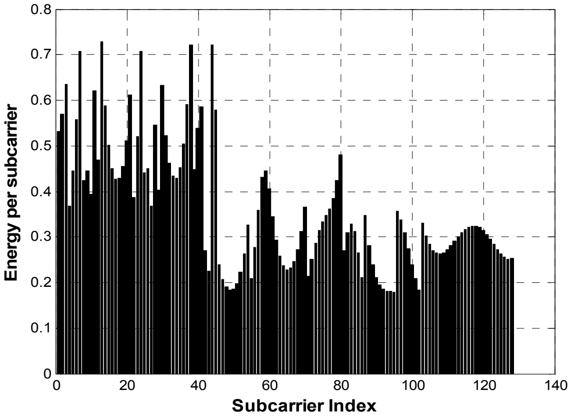

Fig. 6. Energy allocated per subcarrier vs. subcarrier index for SFBC-SDBL-NAS scheme: Case 3.

Table 2. Number of bits assigned to the number of subcarriers in each group for SFBC-SDBL-NAS scheme: Case 3.

Group Index (*i*)	Lower Index	Upper Index	B_i	b_i^l	b_i^u	N_i^l	N_i^u	N_i
1	0.4235	0.8469	44	4	5	6	4	10
2	0.8469	1.6938	135	5	6	15	10	25
3	1.6938	3.3876	224	6	7	21	14	35
4	3.3876	6.7752	429	7	8	35	23	58

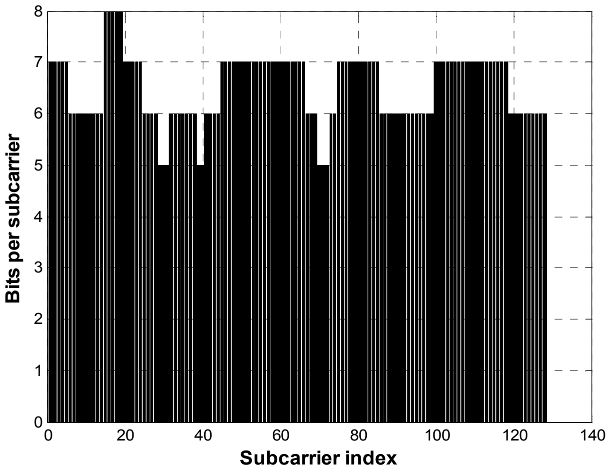

Fig. 7. Bits per subcarrier vs. subcarrier index for SFBC-SDBL-OTAS (4) scheme: Case 3.

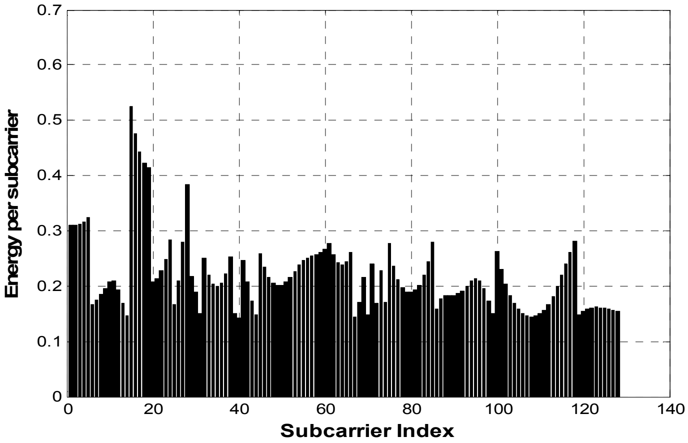

Fig. 8. Energy allocated per subcarrier vs. subcarrier index for SFBC-SDBL-OTAS (4) scheme: Case 3.

Table 3. Number of bits assigned to the number of subcarriers in each group for SFBC-SDBL-OTAS (4) scheme: Case 3.

Group Index (i)	Lower Index	Upper Index	B_i	b_i^l	b_i^u	N_i^l	N_i^u	N_i
1	1.0746	2.1491	46	5	6	8	1	9
2	2.1491	4.2982	347	6	7	52	5	57
3	4.2982	8.5964	439	7	8	57	5	62

When two antennas are selected out of 8 transmitting antennas, the average energy efficiency becomes 65.11 b/J for the given target bits. The bit and energy allocation for the SFBC-SDBL-OTAS (8) scheme are shown in Figs. 9 and 10. The sub channel gains are divided into 3 groups. The SDBL parameters obtained for SFBC-SDBL-OTAS (8) scheme is shown in Table 4.

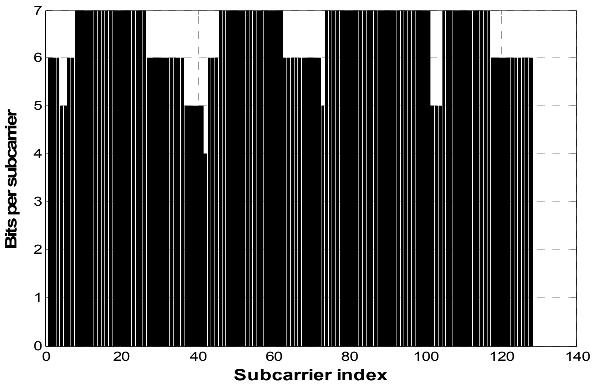

Fig. 9. Bits per subcarrier vs. subcarrier index for SFBC-SDBL-OTAS (8) scheme: Case 3

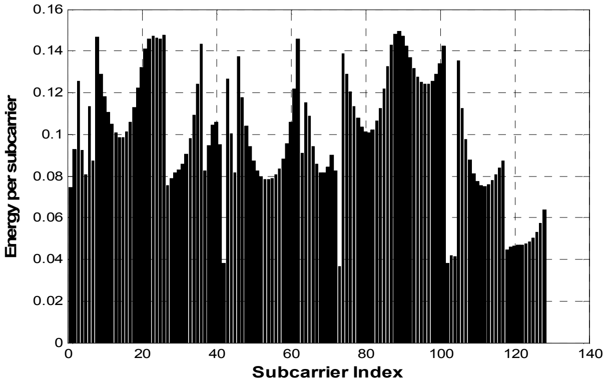

Fig. 10. Energy allocated per subcarrier vs. subcarrier index for SFBC-SDBL-OTAS (8) scheme: Case 3.

Table 4. Number of bits assigned to the number of subcarriers in each group for SFBC-SDBL-OTAS (8) scheme: Case 3.

Group Index (i)	Lower Index	Upper Index	B_i	b_i^l	b_i^u	N_i^l	N_i^u	N_i
1	2.0707	4.1413	39	4	5	1	7	8
2	4.1413	8.2827	188	5	6	4	28	32
3	8.2827	16.5654	605	6	7	11	77	88

In Fig. 11, average BER vs. SNR (dB) is compared between SISO-SDBL, SFBC-SDBL-NAS, SFBC-SDBL-OTAS (4) and SFBC-SDBL- OTAS (8) systems for Case 3. SNR is varied from 0 to 40 dB. The above mentioned systems reach a target BER of 10^{-4} at 32.2 dB, 23.6 dB, 21.4 dB and 17.5 dB respectively. It can be observed that the proposed SFBC-SDBL-OTAS (8) scheme offers 14.7 dB gain over the conventional SISO-SDBL and 6.1 dB gain over the SFBC-SDBL-NAS systems.

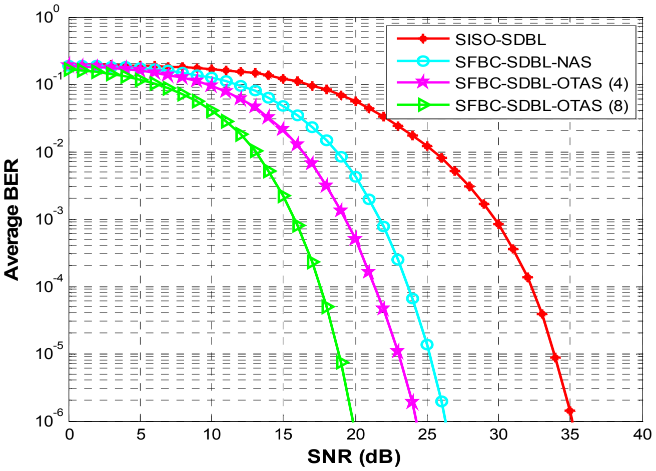

Fig. 11. Average BER vs. SNR (dB) comparison between the proposed schemes and the conventional scheme: Case 3.

In Fig. 12, average spectral efficiency (b/s/Hz) vs. SNR (dB) is compared between SISO-SDBL, SFBC-SDBL-NAS, SFBC-SDBL-OTAS (4) and SFBC-SDBL-OTAS (8) systems for Case 3. Since the proposed algorithm is MA, the average spectral efficiency increases up to certain SNR and then it becomes constant. The proposed SFBC-SDBL-OTAS (8) scheme reaches a maximum average spectral efficiency of 5.778 b/s/Hz approximately at 16 dB. SFBC-SDBL-OTAS (4), SFBC- SDBL-NAS and SISO-SDBL schemes reach the maximum value at 20 dB, 22 dB and 30 dB respectively. The proposed SFBC-SDBL-OTAS (8) scheme offers 14 dB SNR gain over the conventional SISO-SDBL scheme.

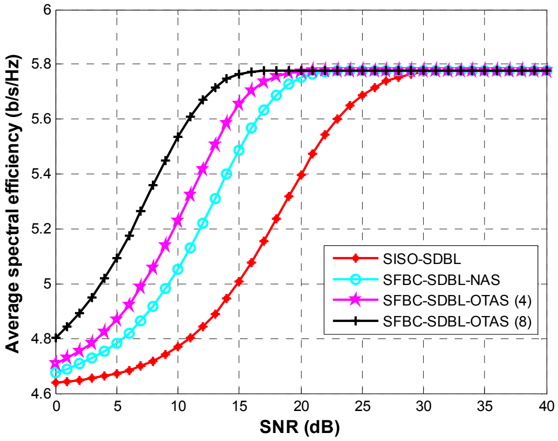

Fig. 12. Average spectral efficiency (b/s/Hz) vs. SNR (dB) comparison between the proposed schemes and the conventional scheme: Case 3.

The simulations are done with the same parameters for Cases 2 and 1. The average BER and average spectral efficiency comparisons are only displayed for Cases 2 and 1. The other results are not shown in this paper. It is obvious that since the proposed algorithm outperforms conventional SDBL for Case 3, it will naturally perform better for Case 1 and Case 2. For Case 2, the target bits are fixed to 200. In Fig. 13, average BER vs. SNR (dB) is compared between SISO-SDBL, SFBC-SDBL-NAS, SFBC-SDBL-OTAS (4) and SFBC-SDBL-OTAS (8) systems for Case 2. The above mentioned systems reach a target BER of 10^{-4} at 12 dB, 8 dB, 6.2 dB and 1.1 dB respectively. It can be observed that the proposed SFBC-SDBL-OTAS (8) scheme offers 10.9 dB gain over the conventional SISO-SDBL and 6.9 dB gain over the SFBC-SDBL-NAS systems.

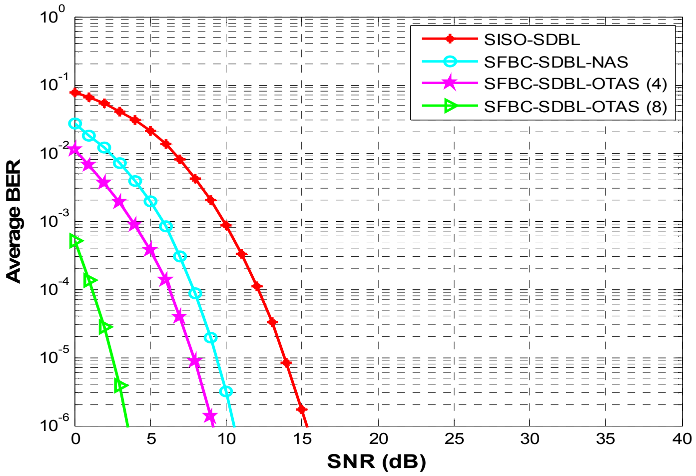

Fig. 13. Average BER vs. SNR (dB) comparison between the proposed schemes and the conventional scheme: Case 2.

In Fig. 14, average spectral efficiency (b/s/Hz) vs. SNR (dB) is compared between SISO-SDBL, SFBC-SDBL-NAS, SFBC-SDBL-OTAS (4) and SFBC-SDBL-OTAS (8) systems for Case 2. The proposed SFBC-SDBL-OTAS (8) scheme reaches a maximum average spectral efficiency of 1.389 b/s/Hz approximately at 1 dB. SFBC- SDBL-OTAS (4), SFBC-SDBL-NAS and SISO-SDBL schemes reach the maximum value at 5 dB, 8 dB and 12 dB respectively. The proposed SFBC-SDBL-OTAS (8) scheme offers 11 dB SNR gain over the conventional SISO-SDBL scheme.

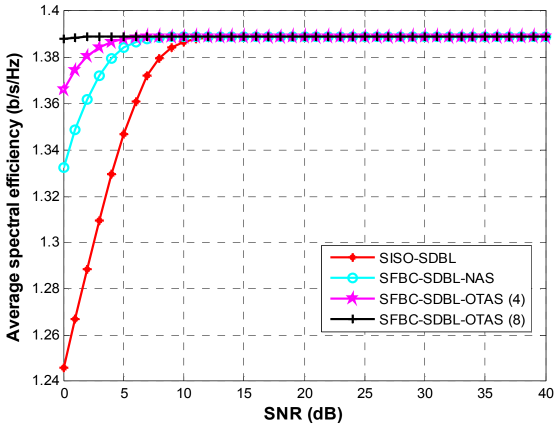

Fig. 14. Average spectral efficiency (b/s/Hz) vs. SNR (dB) comparison between the proposed schemes and the conventional scheme: Case 2.

In Fig. 15, average BER vs. SNR (dB) is compared between SISO-SDBL, SFBC-SDBL-NAS, SFBC-SDBL-OTAS (4) and SFBC-SDBL- OTAS (8) systems for Case 1. The above mentioned systems reach a target BER of 10^{-4} at 21.5 dB, 15.1 dB, 14 dB and 10.8 dB respectively. It can be observed that the proposed SFBC-SDBL-OTAS (8) scheme offers 10.7 dB gain over the conventional SISO-SDBL and 4.3 dB gain over the SFBC-SDBL-NAS systems.

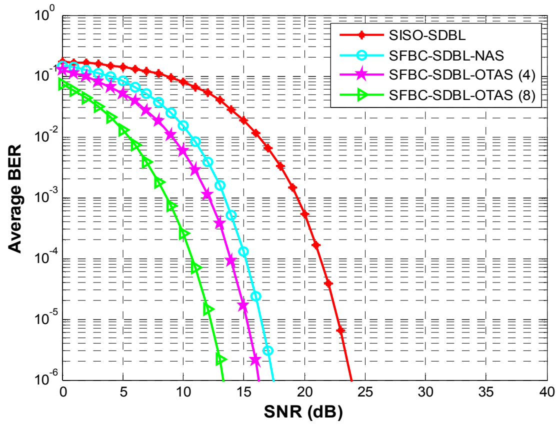

Fig. 15. Average BER vs. SNR (dB) comparison between the proposed schemes and the conventional scheme: Case 1.

In Fig. 16, average spectral efficiency (b/s/Hz) vs. SNR (dB) is compared between SISO-SDBL, SFBC-SDBL-NAS, SFBC-SDBL-OTAS (4) and SFBC-SDBL-OTAS (8) systems for Case 1. The proposed SFBC-SDBL-OTAS (8) scheme reaches a maximum average spectral efficiency of 3.556 b/s/Hz approximately at 9 dB. SFBC-SDBL-OTAS (4), SFBC-SDBL-NAS and SISO-SDBL schemes reach the maximum value at 12 dB, 14 dB and 20 dB respectively. The proposed SFBC-SDBL-OTAS (8) scheme offers 11 dB SNR gain over the conventional SISO-SDBL scheme.

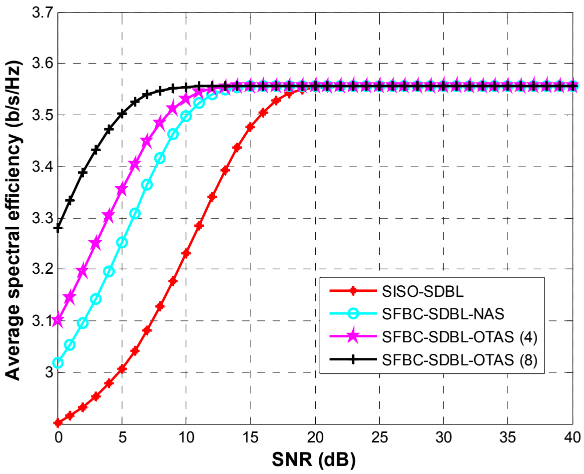

Fig. 16. Average spectral efficiency (b/s/Hz) vs. SNR (dB) comparison between the proposed schemes and the conventional scheme: Case 1.

Average energy efficiency of Case 1, 2 and 3 for various schemes is listed in Table 5. It is very clear that the proposed SFBC-SDBL-OTAS (8) scheme offers better energy efficiency for all the cases.

Table 5. Average energy efficiency (b/J) for the Cases 1, 2 and 3 using various schemes.

Schemes	Case 1	Case 2	Case 3
SISO-SDBL	20.50	81.86	4.35
SFBC-SDBL-NAS	68.26	218.87	17.97
SFBC-SDBL-OTAS (4)	103.30	327.49	29.78
SFBC-SDBL-OTAS (8)	233.52	750.75	65.11

6. Conclusion

The MA-SFBC-SDBL-OTAS scheme is proposed in this paper. The performance of the proposed algorithms is tested under various channel conditions for all the three cases of target bits.

- For all channel conditions and for all three cases, the proposed scheme offer better spectral efficiency, energy efficiency and improved BER performance than the conventional SISO-SDBL scheme.
- The performance of the conventional SDBL scheme is poor for Case 3. But after including SFBC and antenna selection schemes its performance has been improved. OTAS scheme allows the system to always choose best channels. The proposed scheme converts Case 3 problem to Case 1.

- This algorithm needs just an iteration to converge which reduces the complexity of system. Since the algorithm offers better energy efficiency, it is well suited for fixed rate wireless voice and video applications.

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