Multiple Access Scheme for Multi-Symbol Encapsulated Orthogonal Frequency Division Multiplexing

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Abstract :

A new multiple access scheme using Multi-Symbol Encapsulated Orthogonal Frequency Division Multiplexing (MSE-OFDM) is proposed. This is basically a time division multiple access (TDMA) technique utilizing the MSE-OFDM. The Bit Error Rate (BER) performance of the TDMA system using conventional OFDM is slightly better than that of the proposed system. This weakness is compensated as the proposed technique exhibits an improvement in bandwidth efficiency compared to the TDMA using conventional OFDM.

1. Introduction

In the recent years Orthogonal Frequency Division Multiplexing (OFDM), a digital multicarrier modulation technique has found its application in many wideband wireless systems like Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB) and High Speed Digital Subscriber Line (HDSL). OFDM has been set as the standard of air interference for Wireless LANs (802.11a and 802.11g). The reason behind this ever increasing use of OFDM is its robustness to frequency selective fading and multipath propagation which has made it a natural choice for high speed data communication in mobile environment. In spite of the growing applications OFDM suffers from some inherent drawbacks like lower bandwidth efficiency due to the Cyclic Prefix (CP) overhead, high Peak-to-Average-Power-Ratio (PAPR) and stringent requirements for time and frequency synchronisation. The Multiple-Symbol Encapsulated OFDM (MSE-OFDM) technique [2, 3] overcomes some of the above mentioned drawbacks to a great extent.

Considering the advantages of MSE-OFDM, in this paper we propose a multiple access scheme using MSE-OFDM for mobile environment. The mobile environment under consideration consists of a single Base Station (BS) or Access Point (AP) and multiple Mobile Stations (MS)

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which communicate to an external network via the BS. We propose a multiple access scheme for data transmission from the BS to different MS's. Two multiple access schemes using MSE-OFDM have been proposed in [4] and [5]. In the first case [4] a complete MSE-OFDM frame is necessary at the receiver for frequency equalisation. In the second case [5] also all OFDM symbols of a complete MSE-OFDM frame are required at the receiver for the removal of Inter Symbol Interferences (ISI) and Inter Carrier Interferences (ICI). In this case individual OFDM symbols contains data for different destination BS's. As the data destined for different MS's are put together into a single MSE-OFDM frame as proposed in [4,5] this scheme poses severe security threat. Also both the schemes are not suitable for packet transmission because in both cases continuous transmission from all sources have been proposed. In that case there will be reduction in battery life of the MS's.

The rest of the paper is organised as follows. The basics of MSE-OFDM have been described briefly in Section II. The proposed multiple access schemes using MSE-OFDM has been described in Section III. This section discusses the transmitter, receiver and the equalisation technique for the proposed multiple access scheme. The system performance has been discussed in Section IV using the simulation results. Section V concludes the paper.

2. Description of MSE-OFDM:

In MSE-OFDM technique [2, 3] a number of conventional OFDM symbols without CP are grouped together. The group of symbols are protected by a single CP. CP in this case comprises of last few samples of the last OFDM symbol. The length of CP is at least equal to the length of the Channel Impulse Response (CIR). There are two proposed variations of MSE-OFDM [2], viz., (i) CP reduced MSE-OFDM and (ii) FFT-size reduced MSE-OFDM. In CP reduced MSE-OFDM, shown in Figure 1, a number of conventional OFDM symbols are put together into a frame with a single CP. The fame is known as an MSE-OFDM frame. As there is a single CP for a group of OFDM symbols the CP-reduced MSE-OFDM exhibits an improvement of bandwidth efficiency compared to the conventional OFDM. In case of FFT-size reduced OFDM, shown in Figure 2, the size of the MSE-OFDM frame is made equal to that of a conventional OFDM symbol. Thus the size of individual OFDM symbol is much less than that of the conventional one. This implies a less number of subcarriers per OFDM symbol and hence a lower PAPR. The smaller number of subcarriers also implies higher spacing between subcarriers. The frequency synchronisation error depends on the relative frequency offset, i.e., the ratio of the actual frequency offset to the subcarrier spacing. Hence more subcarrier spacing means less frequency synchronisation error. The time synchronisation error and bandwidth efficiency in this case, however, remain unchanged compared with the conventional OFDM.

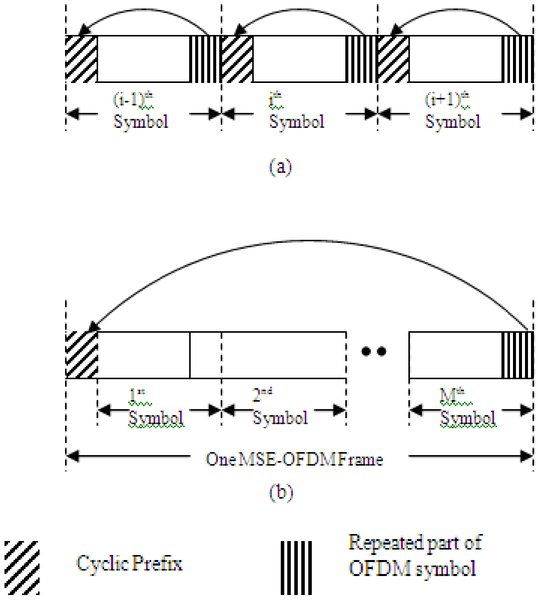

Figure 1: Structure of CP-reduced MSE OFDM. (a) Conventional OFDM symbols. (b) An MSE-OFDM frame.

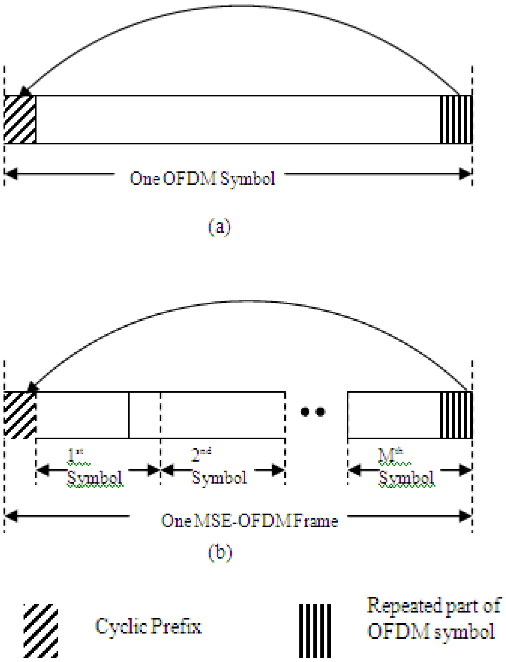

Figure 2: Structure of FFT-size reduced MSE OFDM. (a) Conventional OFDM symbols. (b) An MSE-OFDM frame.

3. Proposed Multiple Access Scheme

In this proposed system the input data packets for different users are stored into a buffer at the BS. Each user is assigned a fixed time slot in the downlink. During the time slot of a particular user the MS transmits the data packets from the buffer. For each BS a group of packets forms a complete MSE-OFDM frame. The complete frame is demodulated at the destination MS only. Several MSE-OFDM frames for all users will comprise a one multi-access frame. The packet for each MS will get transmission opportunity in its allocated slot in the multi-access frame.

In this paper we propose an MSE-OFDM system using pseudo random cyclic prefix [6]. Here the CP of each MSE-OFDM frame is replaced by a pseudo random sequence. As result OFDM symbols in a MSE-OFDM frame can be equalized individually. This in turn reduces the system complexity. The CP can also be used for addressing purpose. Different pseudo random sequences will be used for different destination MS's. At each MS the received CP will be correlated with its own assigned pseudo random sequence code. The MS that results into the highest value of correlation will be able to receive the rest of the packet. The pseudo random sequences having good auto and cross correlation properties are normally selected for cyclic prefixes. A Gold sequence or a Kasami sequence can be used in this case.

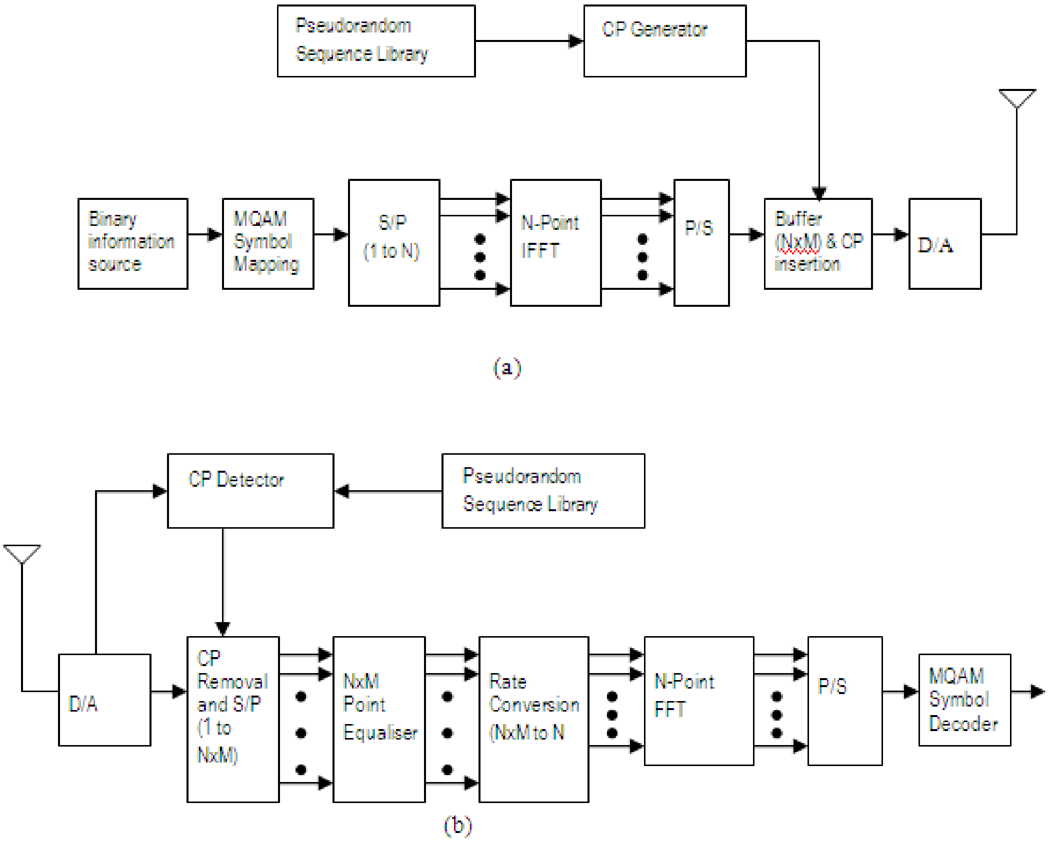

Figure 3: Block Diagrams (a) MSE-OFDM Transmitter, (b) MSE-OFDM Receiver

3.1 Transmitter

MSE-OFDM transmitter [6] is shown in Figure 3(a). In this case each OFDM symbol consists of N complex exponentials or subcarriers which are modulated by the complex data symbol X. Thus an OFDM symbol may be represented by

$$x[n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X(k) e^{j2\pi \frac{nk}{N}}, n = 0,1,2,..., N-1 \qquad (1)$$

Each MSE-OFDM frame consists of M such N-Point OFDM symbols so that the l^{th} frame of the MSE-OFDM signal can be written as

$$s_l = \sum_{k=0}^{N-1} C_{l,p}(k)\psi_1(n,k) + \sum_{i=0}^{M-1} \sum_{k=0}^{N-1} X_{l,i}(k)\psi_2(n-iN-P,k) \qquad (2)$$

where $C_{l,,p}$ is the cyclic prefix using a pseudo random sequence. The symbol i indicates the i^{th} OFDM symbol of the l^{th} frame. $\psi_1(n,k)$ and $\psi_2(n,k)$ are two multiplexing window functions corresponding to the cyclic prefix and the M information carrying OFDM symbols defined as follows

$$\psi_1(n,k) = \begin{cases} 0 & ,0 \le n \le P-1 \\ 1 & ,elsewhere \end{cases} \tag{3}$$

and

$$\psi_2(n-iN-P,k) = \begin{cases} \frac{1}{\sqrt{N}} e^{\frac{j2\pi k(n-P-iN)}{N}} & ,P \le n \le MN+P-1 \\ 0 & ,elsewhere \end{cases} \tag{4}$$

At the transmitter side of the base station data packets from various sources will be stored in the buffer from where the packets will be transmitted either in sequence of their arrival or according to some pre-defined priorities. Each data packet will comprise one complete frame of MSE-OFDM signal. The CP will be appended at the transmitter as per the destination MS address. Different CP's will be used for different mobile stations.

3.2 Receiver

In this case the transmission medium is broadcast in nature. So at the receiver of each MS it will be necessary to perform time domain correlation analysis between the received CP and a predefined pseudo random code generated within each MS. The receiver that generates the highest correlation will be able to receive the complete MSE-OFDM frame. Block diagram of the MSE-OFDM receiver is shown in Figure 3(b).

3.3 Equalisation

The equalisation technique used here is different from that of the conventional OFDM technique because of the unique frame structure of the MSE-OFDM. In this case an MN-Point equalisation is employed. Hence in this case an additional MN-Point DFT and IDFT will be required to be done before and after the frequency domain equalisation respectively. As a pseudo random sequence has been used as CP, the same sequence must also be added to the end of each MSE-OFDM frame to give the signal a cyclic look so that the received signal will be the cyclic convolution between the transmitted signal and the channel impulse response. Thus the transmitted signal in (2) can be written as a vector

$$s_l=[C_{l,p}(0),\ldots,C_{l,p}(P-1),x_{l,0}(0),\ldots,x_{l,M-1}(0),\ldots,x_{l,M-1}(N-1),C_{l,p}(0),\ldots C_{l,p}(P-1)]^T \tag{5}$$

The MSE-OFDM signal has now been modified according to accommodate the pseudo random sequence postfix. The postfix is stripped off at the receiver along with the CP.

The received signal vector r_l corresponding to the transmitted signal vector (6) can be expressed as

$$r_l = C.s_l + w_l \tag{6}$$

where w_l is an additive white Gaussian noise (AWGN) vector with the size of s_l and C is the channel matrix of size $[MN+3P-1,MN+2P]$ as given by

$$C = \begin{vmatrix} h_0 & 0 & & & & 0 \\ h_1 & h_0 & & & & \\ & & & & & \\ h_{L-1} & & h_1 & h_0 & & \\ 0 & & & & & 0 \\ & & h_{L-1} & & h_1 & h_0 \\ & & & h_{L-1} & & h_1 \\ & & & & & \\ 0 & & & & 0 & h_{L-1} \end{vmatrix} \tag{7}$$

A cyclic convolution occurs between the CP removed received signal $\tilde{s}_l$ and h so that the following transform pair holds.

$$\tilde{s}_l \otimes h + \tilde{w}_l \Leftrightarrow DFT(\tilde{s}_l).H + \tilde{W}_l = DFT(\tilde{r}_l) \tag{8}$$

where H and $\tilde{W}_l$ are the Fourier Transform of h and $\tilde{w}_l$. The size of the DFT here is MN points. It is assumed that the channel matrix is known from the channel estimation. The effect of the channel on the received signal can now be removed by a single tap frequency domain equalisation and the signal is converted back to time domain for FFT demodulation according to the following relation

$$\tilde{r}_l^{FEQ} = IDFT\left\{ \frac{DFT(\tilde{r}_l)}{H} \right\} + w_l^{FEQ} \tag{9}$$

where w_l^{FEQ} has the same statistical property as that of the AWGN. The signal $\tilde{r}_l^{FEQ}$ is broken down into M-OFDM symbols in sequence for demodulation using N-Point FFT.

4 Performance Analysis and Discussions

As already discussed, there are two different implementations of MSE-OFDM. The CP-reduced MSE-OFDM configuration shows improvement of bandwidth efficiency as there is reduction in the number of CP insertion. This system has reduced robustness in time-selective channel and hence it is suitable for static or slowly varying channels. However the FFT-size reduced MSE-OFDM configuration does not show any improvement in terms of bandwidth efficiency as the MSE-OFDM frame duration is kept the same as the symbol duration of the conventional OFDM. It is a better option in time varying channels. Our multiple access system is proposed for the time invariant channels; therefore we use the CP-reduced case. We thus get a definite improvement in terms of bandwidth efficiency of the system.

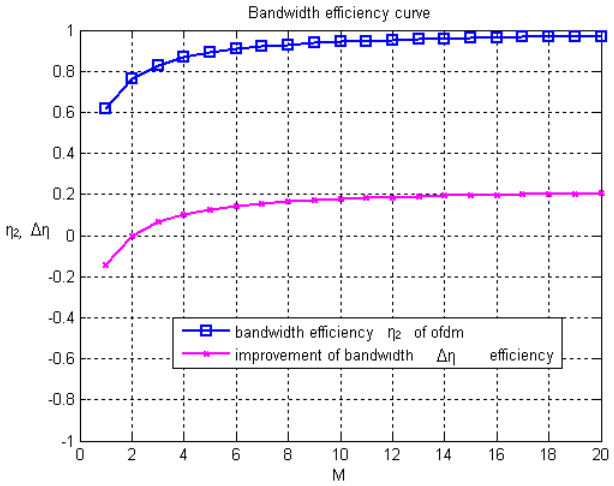

Figure 4: Bandwidth Efficiency Curve

4.1 System Complexity:

The equalization of MSE-OFDM signal has to be done on the frame basis which involves extra (*MN*+*P*)-point DFT and IDFT operations for each MSE-OFDM frame [6]. Thus $2(MN+P)\log_2(MN+P)+N\log_2 N$ number of multiplication operations are required for the MSE-OFDM scheme compared to $N\log_2 N$ multiplications necessary for conventional OFDM.

4.2 Bandwidth efficiency

We consider that each subcarrier conveys a discrete symbol taken from a two-dimensional signal space containing 2^v signal points. Then for the N-point conventional OFDM with a CP of length P the bandwidth efficiency η_1 is given by [7]

$$\eta_1 = v\frac{N}{N+P} \text{ b/s/H} \tag{10}$$

In the case of MSE-OFDM, the OFDM frame consists of MN signal points, the CP and a postfix by CP in order to introduce cyclic convolution. Hence the bandwidth efficiency is given by

$$\eta_2 = v\frac{MN}{(MN+2xP)} \text{ b/s/H} \tag{11}$$

The improvement in bandwidth efficiency is given by:

$$\Delta\eta = \eta_2 - \eta_1 = \frac{NP(M-2)}{(N+P)(MN+2xP)} \tag{12}$$

Figure 4 shows both the bandwidth efficiency of MSE-OFDM symbols and also the trend in improvement of bandwidth efficiency for different values of M. The analysis has been done taking N=64 and P=16; modulation type being BPSK. It shows that there will be improvement in bandwidth efficiency of the system with increasing the value of M. However, it can also be observed that the improvement in bandwidth efficiency approaches the saturation value of P/(N+P) = 0.2.

4.3 BER performance of multiple access MSE-OFDM system

We consider that Δk represents the relative frequency offset (ratio between actual frequency offset and subcarrier spacing) and Δn is the relative timing offset (ratio between timing offset and sampling interval). Then the bit error rate for the BPSK system for the k^{th} subcarrier in one OFDM symbol can be written as [4]

$$P_{k,e} = erfc\sqrt{\frac{E_b}{N_o + \sigma^2{}_{ICI} + \sigma^2{}_{ISI}}} \qquad (13)$$

where the variance of ICI is given by

$$\sigma^2{}_{ICI} = \sum_{l=0,l\neq k}^{N-1} X^2(l)H^2(l)\left\{\frac{\sin^2(\pi\Delta k)}{N^2\sin^2(\pi(l-k+\Delta k)/N}\right\} \qquad (14)$$

H(k) is the channel transfer function at the kth subcarrier and the variance of ISI is given by

$$\sigma^2{}_{ISI} = X^2(k)\left[\sum_{n=1}^{\infty}\frac{[(j\pi\Delta k(N-1) + j2\pi k\Delta n + j2\pi\Delta k\Delta n)/N]^n}{n!}\right]^2 \qquad (15)$$

The average bit error rate can be given as

$$P_e = \frac{1}{N}\sum_{k=0}^{N-1} P_{k,e} \qquad (16)$$

One aim of this study is to analyse the BER performance of the proposed multiple access system and also to compare it with the same using conventional OFDM system. Therefore, we conducted a set of simulations for both the cases of conventional OFDM and CP-reduced MSE-OFDM. The parameters used in simulations are N=64, P=16 and the channel impulse response (CIR) for three different users:

h1 = [1 0 0 0 0 0]
h2 =[0.9285 0 0.3714 0 0 0]
h3 =[-0.6154 0.7692 0 0.1538 0.0769]

One set simulation has been conducted for the conventional OFDM system. Here we have used a set of random bit sequences for three different users and inserted the appropriate CPs. Above three different frequency selective paths have been selected for the three users. At the receivers the frequency equalization has been performed using the appropriate transfer functions. Another set of simulation has been conducted on the same data for the proposed multiple access using MSE-OFDM. Here we have used the same set of CIRs, but the frequency equalisation has been performed after MN-point FFT on the received MSE-OFDM frame.

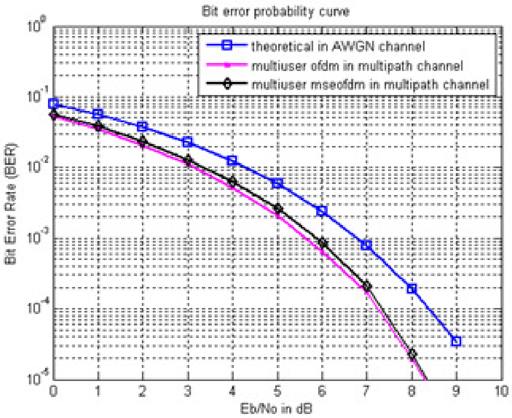

Figure 5: BER performance curve for user 1

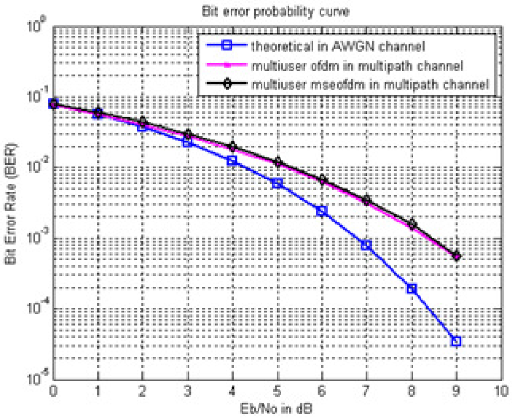

Figure 6: BER performance curve for user 2

The results of simulation are shown in Figures 5, 6 and 7. From the Figures it is observed that there is little difference in the BER performance of MSE-OFDM compared to that of the conventional OFDM. The reason behind this is that in case of MSE-OFDM the individual OFDM symbols are not separated by guard time whereas in case OFDM individual symbols are separated by the guard intervals. Thus the symbols in MSE-OFDM suffer from more ISI.

It can further be said that the better performances by both the OFDM and MSE-OFDM compared to the theoretical values are due to the channel inversion that takes place at the receiver equalizer.

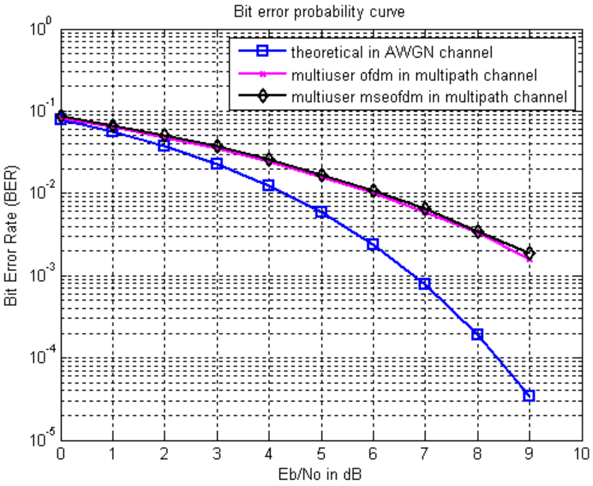

Figure 7: BER performance curve for user 3

5. Conclusions:

The proposed multiple access method is basically a time division multiple access technique. This method is obviously better than the other multi-access techniques [4, 5] because in this proposed technique every user receives its absolutely its own data packets in an MSE-OFDM frame for frequency equalization and detection during its assigned time slot. Thus the proposed scheme offers an enhance data security along with improved bandwidth efficiency and improved BER performance.

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