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ENHANCED BANDWIDTH EFFICIENCY IN WIRELESS OFDMA SYSTEMS THROUGH ADAPTIVE SLOT ALLOCATION ALGORITHM

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ABSTRACT

WiMAX (Worldwide Interoperability for Microwave Access), a new wireless technology promises to deliver both high data rates and long range coverage. In wireless communication channel, the effect of multipath fading is reduced by the use of OFDM transmissions. Adaptive subcarrier allocation methods exploit the multiuser diversity, which leads to improvement in performance by assigning subcarriers to users based on the channel conditions. In this paper, three algorithms are discussed to achieve bandwidth efficiency and fairness. The two algorithms named, fair allocation, proportional allocations are compared with static multiple access method. Performance is compared in terms of Signal to Noise Ratio (SNR) and throughput.

Keywords: OFDMA, dynamic slot allocation, fair allocation, proportional allocation.

1. INTRODUCTION

WiMAX, a new wireless technology promises to deliver both high data rates and long range coverage. The IEEE 802.16 is a family of standards defining the physical and medium access control layer for metropolitan area network and is referred as WiMAX. It is a wireless communications standard designed to provide data rate of 30 to 40 Megabit-per-seconds, [1] with the 2011 update providing up to 1 Gbps for fixed stations. When compared to 3G, WiMAX offers higher peak data rates, greater flexibility, and higher average throughput and system capacity. Another advantage is its ability to efficiently support more symmetric links-useful for fixed applications [2]. Emerging markets are hungry for fixed broadband services; however characteristics of ADSL limit the even distribution of fixed broadband services to encompass urban and rural areas. Of late, WiMAX has surfaced to substitute ADSL in these markets and the results are encouraging. Vertical applications present a huge new market opportunity for WiMAX operators. WiMAX is not the only wireless technology that can support vertical applications, but it is particularly well suited to delivering them because of its high capacity, low per-bit cost, and Quality of Service (QoS), and security capabilities [2 - 5].

Orthogonal frequency division multiple access is one of the key techniques applied in physical layer for the IEEE 802.16 which partitions the available bandwidth into different narrow band subcarriers. OFDMA is a new promising wireless access technology based on OFDM, which realizes multiple accesses by providing each user with a fraction of the available number of subcarriers. A key issue in high data rate transmission in wideband over multipath fading channels is to require technique to be able to combat inter symbol interference. OFDM enables the base stations to transmit data with a high bandwidth on a broad frequency band by separating it into multiple orthogonal subchannels on which data symbols are transmitted in parallel. By adding cyclic prefix to each OFDM symbol, the inter-symbol interference can be avoided. In multiuser scenario upon a multicarrier system, a subcarrier in deep fading for one user may be of good quality for other users. By assigning the subcarriers to the appropriate user the spectral efficiency can be improved.

To improve the total channel capacity adaptive modulation scheme is proposed [6]. Usually the users near the base stations see high channel gains so that they are assigned higher order modulation and higher code rates. The users far away from the base stations are assigned lower order modulation and lower order coding rates.

In this paper two algorithms are proposed for improving the bandwidth efficiency. They are proportional allocation algorithm and fair allocation algorithm. In WiMAX, physical layer the accessing technique which is followed at first is Time Division Multiple Access (TDMA) which is also called as static technique. In OFDMA the subcarriers are allotted in such a way that equal bandwidth is allotted to each user. This is called as Fair allocation. In this paper fair allocation is discussed with reduced complexity. The static and fair allocation algorithms are compared in terms of number of subcarriers assigned to each user and throughput.

The paper is organized as follows. In Section 2, the system model is presented. Section 3 introduces the different subcarrier allocation strategies. Section 4 deals the simulation results and, finally, in Section 5 some conclusions are drawn.

2. SYSTEM MODEL

The system model used in this paper is shown in Figure-1. In this paper, an OFDMA system for mobile wireless MANs, based on IEEE 802.16e standard [7], is considered. In OFDM communication systems, the available spectrum is divided into a large number of subcarriers. Adaptive modulation schemes are adopted to transmit data information on these subcarriers by resorting

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to the use of the inverse discrete fourier transform (IDFT) in transmission and the discrete fourier transform (DFT) at the receiving end. In particular, we focus here, on an OFDM-based wireless communication system [8], where *K* users can communicate with the base station, by using a set of subcarriers, under the form of slot, or sub channel: in particular, accordingly to [7], we suppose that a slot is formed by a group of adjacent subcarriers of 2 subcarriers. Within a frame, different subchannels, i.e., different sets of slots (groups of contiguous subcarriers in the time-frequency domain) are assigned to users. We have considered frame duration *TF* equal to 8 ms and a 1024 FFT for a 10 MHz channel according to the SOFDMA.

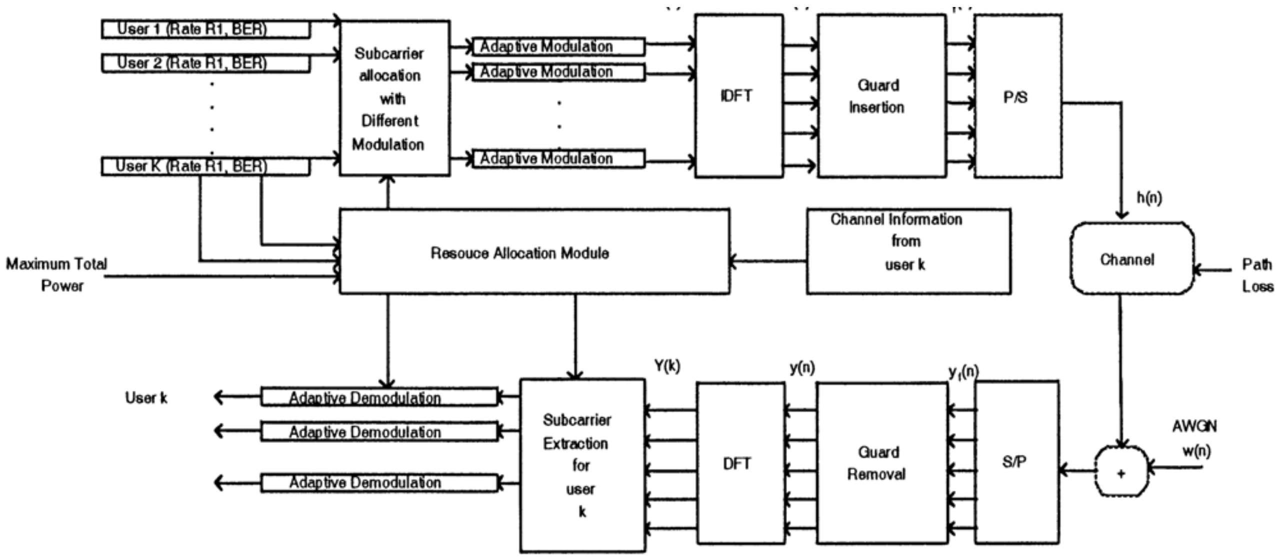

Figure-1. Orthogonal frequency division multiple access system.

(Scalable OFDMA) concept [9]: the subcarrier spacing is a fixed parameter in all the systems with different bandwidth. For allocating the defined number of subcarriers, the transmitter has to know about the channel state information (CSI) which is measured through channel estimation strategy. A feedback is given from the receiver to the transmitter about CSI by considering the parameters affecting the feedback efficiency.

3. SLOT ALLOCATION STRATEGIES

The adaptive subcarrier allocation algorithms discussed in this paper are based on the estimation of the channel capacity belonging to slots. By means of CSI, it is possible to foreseen the channel capacity for a user if that slot is assigned to it.

The channel capacity of a subcarrier in the OFDMA multiplex can be expressed as:

$$C_{p,\,OFDMA=}(1/N_s)*C_p = (1/N_s)\,Bp \log_2(1+E_s/N_0) \qquad (1)$$

Where, E_s/N_0 is the signal energy to noise ratio and N_s is the number of sub carriers.

By introducing the effect of the multipath- fading, the capacity of an *N* × *M* rectangular slot (*N* contiguous carriers in the frequency domain per *M* OFDM symbols) becomes,

$$C_{slot}(\alpha_{slot}) = N*M/\,N_s\,B_p \log_2(1+(E_s/N_0)\,\alpha^2_{slot}) \qquad (2)$$

Where α_{slot} denotes the mean value of the multipath channel coefficient.

In this paper, an ideal channel estimation in assumed, i.e., the exact value of $SNR^k(i, j)$ is known at the receiving site. The amount of the channel assigned to a given user is related in our case to the overall number of slots assigned to it.

$$C^k_{slot}(i,j) = N*M/\,N_s\,B_p \log_2(1+SNR^k(i,j)) \qquad (3)$$

The maximum capacity value assigned to each user is,

$$C_{maxk} = \sum_0^{A-1}\sum_0^{B-1} C^k_{slot}(i,j)\; for\; k = 1,2,\ldots.K \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4$$

The capacity assigned to the k[th] user by certain slot allocation algorithm can be defined as:

$$C_k = \sum_0^{A-1}\sum_0^{B-1} x^k(i,j)\,C^k_{slot}(i,j) \qquad \ldots\ldots\ldots\ldots(5)$$

Where

$$x^k(i,j) = \begin{cases} 1\; slot\,(i,j)\, assigned\, to\, k^{th} \\ 0\; slot\,(i,j)\, not\, assigned\, to\, k^{th} \end{cases} user \qquad \ldots\ldots\ldots(7)$$

3.1. Fair allocation

The first allocation algorithm considered in this paper represents a generalized version of that proposed in [10]. The main modification introduced here is that of considering the slot allocation instead of single carrier allocation. The problem to be solved in an optimal manner is to allocate slots to users in order to maximize the minimum of all users' assigned capacity C_k (i.e., user's throughput).

Let, s (i, j): the slot of frequency index I and time index j; S: the set of free slots; S_k: the set of slots assigned to the k^{th} user; R_k: the capacity assigned to the k^{th} user;
The fair allocation algorithm results to be:

(i) Initialization

a) $R_k \leftarrow 0$ for k=1, ……, K;
b) $S_k \leftarrow \emptyset$ for k=1, ……, K;
c) S$\leftarrow \{s(i,j): i = 0, \dots, A-1, j = 0, \dots, B-1\}$;

(ii) For k=1, …., K;]

a) Find a slot s(i,j) Є S so that $SNR^k_{i,j} \geq SNR^k_{n,m}$ for wach slot index (n,m) for which at least a free slot in S exists;
b) $S_k \leftarrow S_k \cup \{s(i,j)\}$;
c) $S \leftarrow S - \{s(i,j)\}$;
d) $R_k \leftarrow R_k + C_{SLOT^k_{i,j}}$;

(iii) While S$\neq \emptyset$:

a) Find the user k so that $R_k \leq R_u$ for each user u;
b) Find the slot s(i,j) $\in S$ *so that* $SNR^k_{i,j} \geq SNR^k_{n,m}$ for each slot index(n,m) for which atleast a free slot in S exists;
c) $S_k \leftarrow S_k \cup \{s(i,j)\}$;
d) $S \leftarrow S - \{s(i,j)\}$;
e) $R_k \leftarrow R_k + C_{SLOT^k_{i,j}}$;

The algorithm, after an initialization phase, assigns to a given user a slot within the frequencies in which that user has the best channel conditions. The slot to assign is selected among the ones that provide the best SNR to that user.

3.2. Proportional allocation

The main drawback of the fair allocation algorithm is the user with best channel condition obtains a lower number of slots with respect to the user with worst channel condition. To avoid this drawback, a different allocation strategy is proposed here by assuming that users with the best channel conditions obtain a larger amount of capacity.

(i) Initialization

a) Compute $C_{max,k}$ *for* $k = 1, \dots, K$ accordingly to (6)
b) $R_k \leftarrow 0$ for k=1, ……, K;
c) $S_k \leftarrow \emptyset$ for k=1, ……, K;
d) S$\leftarrow \{s(i,j): i = 0, \dots, A-1, j = 0, \dots, B-1\}$;

(ii) For k=1, …., K;

a) Find a slot s(i, j) Є S so that $SNR^k_{i,j} \geq SNR^k_{n,m}$ for wach slot index (n, m) for which at least a free slot in S exists;
b) $S_k \leftarrow S_k \cup \{s(i,j)\}$;
c) $S \leftarrow S - \{s(i,j)\}$;
d) $R_k \leftarrow R_k + C_{SLOT^k_{i,j}}$;

(iii) While S$\neq \emptyset$:

a) Find the user k so that $\frac{R_k}{C_{max,k}} \leq \frac{R_u}{C_{max,u}}$ for each user u;
b) Find the slot s(i, j) $\in S$ *so that* $SNR^k_{i,j} \geq SNR^k_{n,m}$ for each slot index(n, m) for which atleast a free slot in S exists;
c) $S_k \leftarrow S_k \cup \{s(i,j)\}$;
d) $S \leftarrow S - \{s(i,j)\}$;
e) $R_k \leftarrow R_k + C_{SLOT^k_{i,j}}$;

The difference between this algorithm and the previous one is the user selection: in this case, the selected user is the one who has the minimum ratio between the actual capacity value and the maximum obtainable capacity value.

4. SIMULATION RESULTS AND DISCUSSIONS

The simulation process is performed in the Matlab environment and the results are discussed. The parameters considered in simulation are reported in Table-1.

Table-1. Simulation parameters.

Parameter	Specification
Carrier frequency	3.5GHz
Bandwidth	10MHz
Maximum Doppler deviation	408Hz
Maximum delay spread	2.51 μ sec
Guard interval	1/8 of OFDMA symbol duration

In this process, ITU-R Vehicular Channel Model A, with 6 Paths is considered and the parameters used are listed in Table-2 below.

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Table-2. ITU-R vehicular channel model A, with 6 paths.

Tap	Relative delay (ns)	Average power (dB)	Doppler spectrum
1	0	0	Classic
2	310	-1.0	Classic
3	710	-9.0	Classic
4	1090	-10.0	Classic
5	1730	-15.0	Classic
6	2150	-20.0	Classic

The results of the two algorithms are compared with non adaptive method. The spectrum of the OFDMA signal is given below in Figure-2.

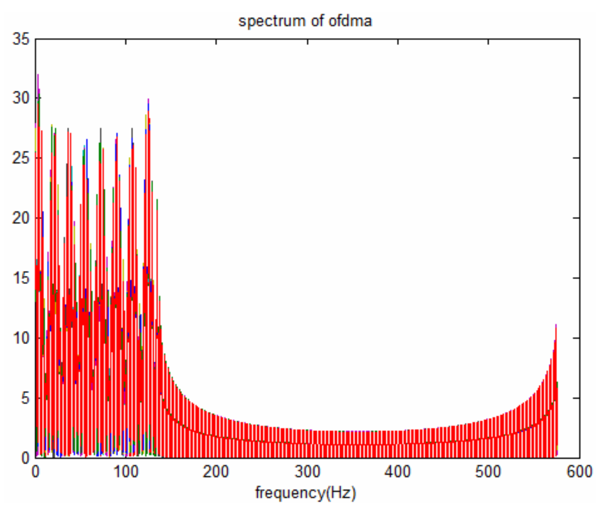

Figure-2. Spectrum of OFDMA.

Two users are considered in this paper and the spectrum of user 1 and user 2 is given in Figure-3 and Figure-4, respectively.

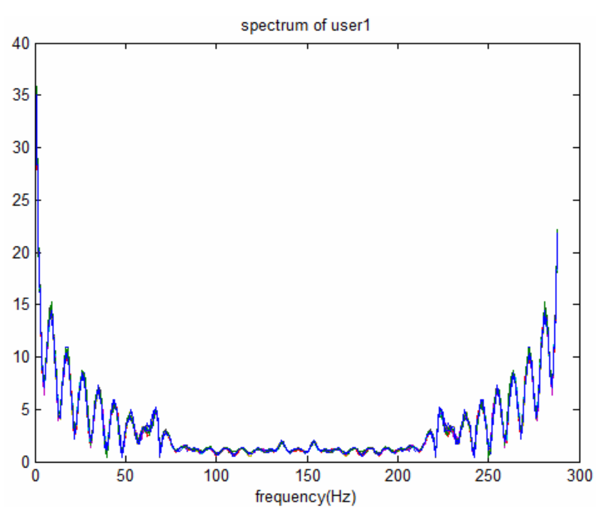

Figure-3. Spectrum of user1.

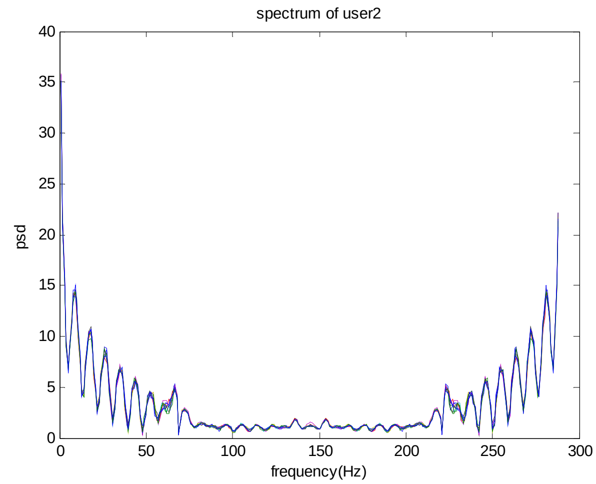

Figure-4. Spectrum of user 2.

The number of subcarrier of fixed, fair and proportional allocation algorithms with pathloss are compared and shown in Figure-5. The subcarriers for each user are constant in fixed algorithm and it is allocated based on channel condition in fair algorithm.

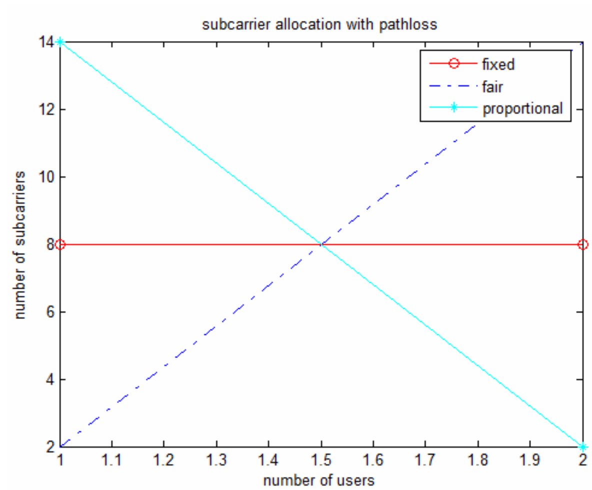

Figure-5. Subcarrier comparison with pathloss.

Throughput of fixed, fair and proportional allocation algorithms without pathloss are compared and shown in Figure-6.

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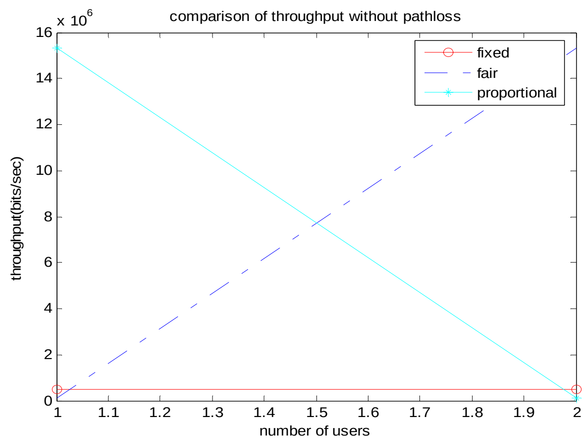

Figure-6. Throughput comparison without pathloss.

The pathloss effect is also considered. The pathloss model is based on [11], [12] with pathloss value, in dB, given by

$$PL = L + 10 \cdot \gamma \cdot \log_{10}(D/D0),\ D>D0$$

where D is the user distance from Base station, D0 is the reference distance (set to 100 meters), γ is the pathloss exponent (set to 4.375 accordingly to an urban environment) and L equal to 20 $\log_{10}(4\pi D0/\lambda)$ is the pathloss value at the reference distance (with respect to the wavelength λ) that, in this case, is equal to 83.32 dB.

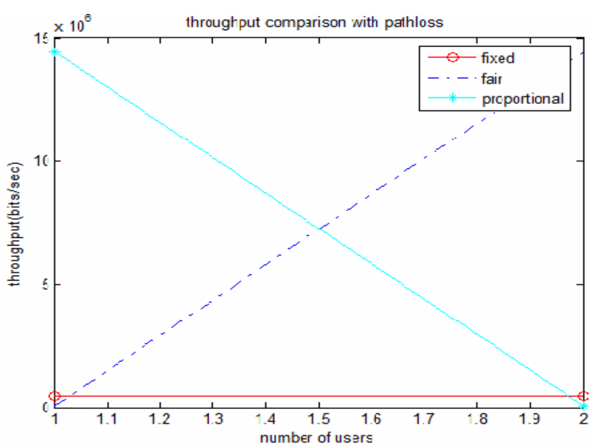

Figure-7. Throughput comparison with pathloss.

For various users without and with path loss, the signal to noise ratio is measured and it is shown in Figure-8 and Figure-9, respectively.

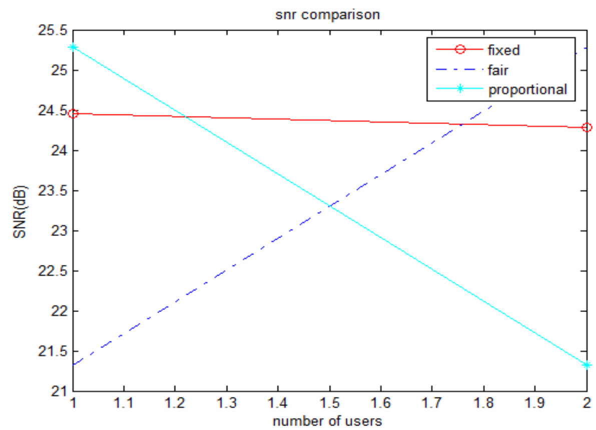

Figure-8. SNR comparison without pathloss.

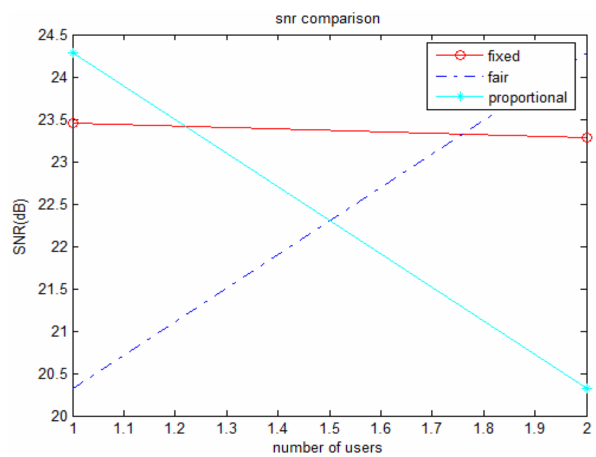

Figure-9. SNR comparison with pathloss.

The SNR in dB Vs throughput in Mbps for various algorithms are summarized and tabulated in Table-3 for both with and without path loss.

Table-3. SNR Vs throughput.

Name of the algorithm	Without path loss				With path loss (-3dB)			
	User1		User2		User1		User2	
	SNR	Throughput	SNR	Throughput	SNR	Throughput	SNR	Throughput
Fixed	24.439	0.5045	24.23	0.4905	23.4394	0.4733	23.235	0.4592
Fair	20.355	0.0970	25.29	15.454	19.3550	0.0890	24.295	14.517
Proportional	25.295	15.4540	20.35	0.0970	24.2950	14.517	19.355	0.0890

CONCLUSIONS

This paper has considered an OFDMA system in which resources are shared in an adaptive manner. The two algorithms are proposed and compared with the non adaptive method. These algorithms are based on the estimation of the channel capacity belonging to the slots to be assigned. The first proposed method, the fair allocation scheme is better for users far from the BS. This is mainly due to the fact that the fair allocation tries to allocate the subcarrier in a fair way while in the other case the subcarrier are allocated in order to maximize the overall cell capacity that is done by damaging the most far users. The second proposed method, named proportional allocation scheme, assigns different amounts of capacity to users, proportionally to the channel conditions seen by each user. The proposed algorithm permits to achieve a better trade-off between fairness and bandwidth efficiency respect to the fair allocation.

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