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An adaptive pilot density based data rate enhancement of mobile WiMAX

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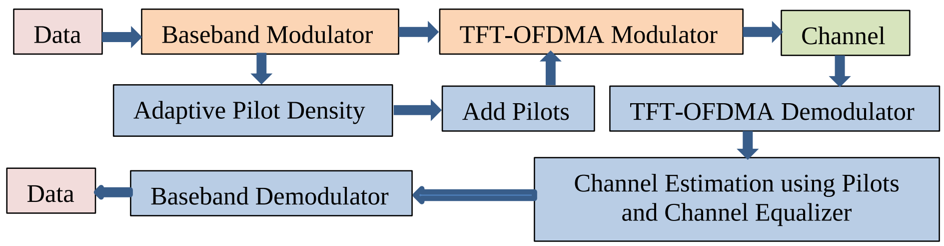
Article

ABSTRACT



Results

Baseband Modulation Scheme	Data Rate Improvement	
	(Mbps)	(%)
QPSK	1.045	7.81
16 QAM	1.68	6.25
64 QAM	2.52	6.25

Today's era demands a high data rate internet facility. Mobile WiMAX system, provides a high speed internet service. It incorporates the pilot signal at transmitter sides to get link information at receiver. Present WiMAX system is based on fixed pilot density approach. Transmission of pilot signals reduces the data rate and bandwidth efficacy of the system. This paper addresses the issue of fixed pilot density approach and suggests incorporation of variable number of pilot subcarriers based on selected baseband modulation scheme. Implemented system is assessed for bit error rate performance. Simulation results depicts that an adaptive pilot density approach gives BER performance comparable to fixed pilot density method. The system achieves a 7.81 % and 6.25 % improvement in data transmission rate when the QPSK and 16QAM, 64QAM baseband modulation schemes are chosen respectively.

Keywords: Mobile WiMAX, Orthogonal Frequency Division Multiple Access(OFDMA),Time-Frequency Training (TFT)

INTRODUCTION

Mobile WiMAX,IEEE 802.16m transmits the data in the Microwave frequency band. It works in a multipath environment. Due to the orthogonality among the subcarriers of OFDMA signal, it is spectrally efficient technique used by WiMAX. The modulation scheme plays a vital role in deciding the data rate and spectral efficiency of a communication system. IEEE 802.16m incorporates cyclic prefix OFDMA as a modulation scheme because of its bandwidth efficacy and resiliency to a multipath fading environment.[1] Present WiMAX system supports a scalable channel bandwidth. Number of subcarriers transmitted in one OFDMA symbol depends on the channel bandwidth. For a given channel bandwidth, number of subcarriers are fixed. Every OFDMA symbol contains data, pilot, DC and guard subcarriers. Pilot subcarriers are embedded into an OFDMA symbol to get channel behaviour. Transmission of pilot subcarriers reduces the number of subcarriers used for data transmission. On the other hand, transmitting more pilots helps to get more accurate information about the link behaviour and provides good BER performance. Present WiMAX system inserts large pilot tones keeping their location and power fixed. Compressive sensing (CS)based channel estimation techniques computes the link parameters with less pilot subcarriers compared to the traditional techniques. This approach works well if the signal to be estimated is sparse in certain domain. As wireless channel is sparse, a compressive sampling technique provides good channel estimation with less pilot overhead.[2]

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RELATED WORK

Various methods have been suggested and implemented for improvement of the data rate and utilization of the spectrum for the communication system. These techniques mainly focus on reducing the bandwidth wastage for pilot subcarriers. The location of pilot tones affects the accuracy of channel estimation.

The time-domain synchronous OFDM scheme reported by I. Singh et.al.[3] inserts the PN sequence as a training sequence between the OFDM symbols as a guard interval. PN sequence helps to achieve synchronization and link parameters. A large number of pilots are saved, and hence it gives an improvement in spectral efficiency by about 10 %. It needs an iterative cancellation algorithm which is highly computational complex. Its performance degrades for fast varying channels.

The Time-Frequency Training OFDM technique has been implemented by Dai et.al.[4] TFT-OFDM symbol contains PN sequence as time-domain training information. Pilots are interleaved among the OFDM data subcarriers in the frequency domain. It has only 3 % of pilot overhead, providing high spectral efficiency. It performs well in fast fading channels. It computes the link parameters based on the PN sequence and pilot tones without employing the interference cancellation algorithm. It proves to be 8.5 % more bandwidth efficient than CP-OFDM as it embeds fewer pilots. TDS-OFDM scheme is superior to TFT-OFDM in terms of spectral efficiency. The modulable orthogonal sequence (MOS) is implemented as the training sequence (TS). Grouped pilots are embedded in the OFDM symbol in frequency domain.Only 1% subcarriers are consumed as pilots. Implemented estimation shows a better performance compared to traditional methods in high-speed environments.[5] For the channel estimation, basis construction is implemented, which combines Fourier (exponential) and prolate spheroidal sequences. PN sequence padding TDS-OFDM uses a pseudorandom sequence as a guard band. The iterative algorithm subtracts PN padding and iteratively carry-outs channel estimation. The duration of the PN sequence is set to be greater than channel memory. This technique removes the residual inter symbol interference for stationary and slowly varying channels and improves spectral efficiency by 5 % and 15%[6]. The pilot tone density to be inserted in the OFDM symbol and their transmission power is decided from the channel's quality for time-varying channels. Information related to channel fading is given by the receiver and is stored at the transmitter's codebook. The pilot adaption algorithm designed for carrier aggregation OFDM system enhances the average throughput of the system.[7]

The spacing between successive pilot subcarriers is decided, keeping in mind the interpolator type, the moments of the Doppler spectrum and link's power delay profile. The proposed approach achieves a good BER performance with a pilot density of a 1.4 % for the Rayleigh channel. Pilot density is made adaptive based on the mobility of the node.[8] Equally-spaced clusters of pilots have embedded for MMSE based estimation of doubly-selective channels. Each cluster is zero-correlation-zone sequence.A cluster size of three is recommended for optimum performance.[9] A pilot reuse pattern is proposed to reduce the pilot overhead and ultimately get the better utility of the spectrum. A pilot scheduling algorithm implements a PR pattern based on the link conditions. This technique is used for Rayleigh fading channels which are spatially correlated.[10] In work by R. Ouyang et.al.,[11] an interpolation range is increased using adjacent pilot subcarriers. For channel estimation, it embeds 16.66 % of pilots in an OFDMA symbol. A pilot partly-copied channel estimation scheme is employed. This method provides good estimation accuracy for long delay multipath channels as well as the high-speed environment. A pilot reduction technique based on a neural network is proposed for a massive MIMO system. Pilot tones are unequally spaced. Pilot positions are decided considering inter-frequency and inter-antenna correlations in the channel matrix. The proposed channel estimation method performs better than a linear minimum mean square error (LMMSE) with less pilots overhead.[12] Frequent beam training issue for the user with high mobility is addressed. The author has proposed a beam training method utilizing less number of pilot symbols. The proposed technique, alongwith the CS method, provides exemplary performance in channel estimation accuracy.[13]

Overlaiding the pilots on the data subcarriers provides more subcarriers for data transmission, enhancing the spectrum utility by 25 % alongwith data rate improvement. Superimposed pilots are used for predicting channel impulse response.[14] Channel estimation is achieved using overlaid pilots arranged in an orthogonal way. The implemented technique is tested for a fast-fading environment with maximum MS speed upto100 km/h for the MIMO system.[15] A neural network based technique for reducing the pilot subcarriers is proposed for a massive MIMO system. Pilot tones are unequally spaced. A channel matrix consisting of inter-frequency as well as inter-antenna correlations is referred for deciding pilot positions. The proposed channel estimation method performs better than a linear minimum mean square error (LMMSE) with less pilots overhead.[16] Machine learning approaches and Deep learning techniques are used in variety of applications to improve the system performance. In wireless communication, MIMO technique is used to enhance the data rate.Deep learning technique is employed to increase the performance of smart antenna systems.[17] For forged image detection machine learning technique is applied.This technique provides a good accuracy.[18] For pilot optimization and calculation of channel parameters neural network is used.[19] It is concluded from the survey that Mobile WiMAX employs a fixed quantity of pilots in an OFDMA symbol.

METHODOLOGY

Various techniques have been implemented to enhance the data transmission rate and bandwidth utility of mobile WiMAX, IEEE 802.16m. Techniques to improve the WiMAX system's data transmission rate and bandwidth efficiency include utilization of spectrally efficient modulation and multiplexing scheme, channel encoding technique, more channel bandwidth, a large number of transmitting and receiving antennas, higher transmission power and higher level baseband modulation scheme. This work has implemented adaptive pilot density method and compressive sampling-based channel estimation technique to enhance the data transmission rate and bandwidth utility of mobile WiMAX, 802.16m. The work presented here focuses on designing an OFDMA scheme, a bandwidth-efficient modulation scheme with a variable size pilot pattern. Implemented system uses time-frequency training OFDMA (TFT-OFDMA) modulation scheme with an adaptive pilot density. Lower level modulation scheme such as QPSK performs better for bit error rate as compared to 16 QAM and 64 QAM for all the channel conditions. Hence number of pilots used for QPSK can be reduced. Considering this, implemented system embeds 48 pilots when 16 QAM and 64 QAM baseband modulation scheme is chosen. When QPSK technique is chosen it inserts 36 pilots in TFT-OFDMA symbol.Legacy WiMAX system embeds 96 pilots in one OFDMA symbol. Compressive sampling based channel prediction methods are able to predict the channel behaviour with less number of pilot subcarriers, if the channel is sparse. As the wireless channel is sparse, compressive sampling based channel estimation technique is used in the implemented system.At the receiver side, it has employed auxiliary subspace pursuit algorithm (A-SP), a compressive sampling technique for channel estimation. Mobile WiMAX incorporates QPSK alongwith 16 QAM and 64 QAM baseband modulation schemes. Figure.1 shows the flowchart for choosing the number of pilots based on the baseband modulation scheme selected.

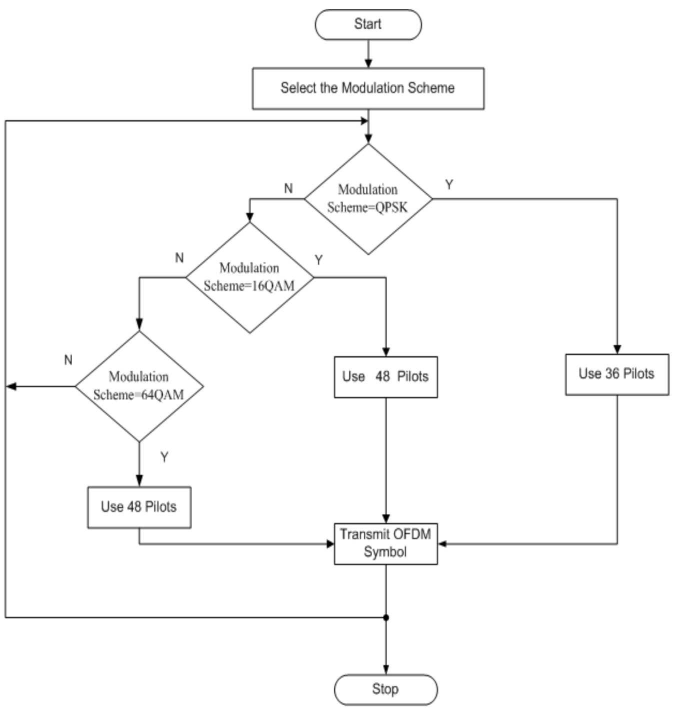

Figure 1. Flowchart for Pilot Adaption Algorithm

It gives an idea about the adaptive pilot density incorporated for WiMAX 802.16m.For 10MHz channel bandwidth,system uses 1024 FFT size. Based on the baseband modulation scheme chosen, the transmitter embeds either 48 pilots or 36 pilots in one OFDMA Symbol. Eq. 1 and 2 gives the pilot positions in the OFDMA symbol. Total 864 subcarriers are used as data and pilot tones. 18 subcarriers of 6 OFDMA symbols form one physical resource unit (PRU) unit. One group of OFDMA symbol contains six symbols. A total of seven OFDMA symbol groups are formed. Total 42 symbols are transmitted. Eq. 1 tells that pilots are inserted in every PRU unit for 16 QAM and 64 QAM modulation scheme.

$$p_{p(n,\ i)} = \sum_{k=1}^{r}\sum_{m=1}^{\mathrm{N_{sym}}}\sum_{j=1}^{\mathrm{N}_{PRUS}} p_{p(m)} + (j-1)\,\mathrm{P}_S \qquad \text{For all } j \qquad (1)$$

N_{PRUS} = Number of PRU units.

P_S = Pilot subcarrier spacing.
$p_{p(m)}$ = Pilot positions in the first PRU unit.
$\mathrm{N_{sym}}$ = Number of OFDMA symbols per PRU unit.
r = Number of OFDMA symbol groups.
n = No. of pilots in one OFDMA symbol.
i = Total no. of OFDMA symbols.
$p_{p(n,i)}$ = Pilot positions in i^{th} OFDMA symbol.
j=PRU Unit Number

Eq. 2 indicates that the PRU unit indexed with a multiple of 4 does not include the pilots. Total 36 PRU units transmit pilots when QPSK modulation scheme is used.

$$p_{p(n,i)} = \sum_{k=1}^{r}\sum_{m=1}^{\mathrm{N_{sym}}}\sum_{j=1}^{\mathrm{N}_{PRUS}} p_{p(m)} + (j-1)\,\mathrm{P}_S \qquad j \neq 4 \text{ x } a,\ a = 1 \text{ to } 12 \qquad (2)$$

Table 1 shows the pilot insertion algorithm. There are a total of 48 PRU's formed by 864 subcarriers and six symbols. If the selected modulation scheme is either 16 QAM (S=2) or 64 QAM (S=3), it inserts pilots in every PRU unit. If the selected modulation scheme is QPSK (S=1), it inserts pilots in selected PRU units. As the second method inserts 36 pilots in 36 PRU's, it furthers reduces the pilot requirement by 12 subcarriers for every OFDMA symbol. Second method utilizes 4.17 % subcarriers as pilot tones.

Table 1 Pilot Insertion Algorithm

Input: 1) Pilot subcarrier $Psub$ 2) Selected modulation scheme S 3) OFDMA symbol without pilot subcarrier $Psub$
Initialization: 1) Number of OFDMA symbols per PRU Unit $\mathrm{N_{sym}} \leftarrow 6$ 2) Number of PRU units $\mathrm{N}_{PRUS} \leftarrow 48$ 3) Pilot subcarrier spacing $\mathrm{P}_S \leftarrow 18$ 4) Pilot location for first PRU unit $p \leftarrow \{1,2,9,10,17,18\}$ 5) Number of OFDMA symbol groups r = 7 6) Total number of OFDMA symbols i = 42

Output: OFDMA symbol with pilot subcarrier $Psub$ embedded, $Symbol_{(i)}$
for k=1 to r do
for m=1 to $\mathrm{N_{sym}}$ do
for j=1 to N_{PRUS} do
if S = 1
Skip PRU units with indices having multiple of four
Find the pilot position $p_p \leftarrow p_{p(m)} + (j-1)\,\mathrm{P}_S$
insert $Psub$ at $\mathrm{p_p}$ in i^{th} OFDMA symbol
else if S = 2
Find the pilot position $p_p \leftarrow p_{p(m)} + (j-1)\,\mathrm{P}_S$
insert $Psub$ at $\mathrm{p_p}$ in i^{th} OFDMA symbol
else if S = 3
Find the pilot position $p_p \leftarrow p_{p(m)} + (j-1)\mathrm{P}_S$
insert $Psub$ at $\mathrm{p_p}$ in i^{th} OFDMA symbol
end if
end for(j)
end for(m)
end for(k)

Table 2 gives an idea about the adaptive pilot density incorporated for WiMAX 802.16m.It shows that data tones increases with decrease in the pilot tones.

Table.2 Adaptive Pilot Density

Sr. No	Baseband Modulation Scheme	Number of Pilots / OFDMA Symbol (J)	Number of Pilots / 6 OFDMA Symbol	Data Subcarriers / OFDMA Symbol (Q_d)
1	QPSK	36	216	828
2	16QAM	48	288	816
3	64QAM	48	288	816

System performance is evaluated in terms of data transmission rate. The data transmission rate of 802.16m is calculated using Eq. 3[20].

$$D_R = \frac{Q_d N_b C_r}{T_S} \text{x } M \qquad (3)$$

Where

D_R = Data transmission rate of WiMAX system (Mbps)
Q_d = Data tones in an OFDMA Symbol
N_b = Number of information bits carried by baseband modulator
C_r = Forward error correction rate
T_s =OFDMA Symol Time
M=No.of Antenna in MIMO

Results

This section gives simulation results of the implemented adaptive pilot density method. The system is tested for 1024 subcarriers with 10 MHz channel bandwidth. System performance is analyzed for a multipath fast fading environment with six taps and a maximum path delay of 20 µs. QPSK, 16 QAM, 64 QAM modulation techniques with 1/2 code rates are employed.

Figure 2 shows the BER performance of implemented WiMAX system for QPSK scheme with 30 km/h, 120 km/h, 250 km/h, and 350 km/h terminal speed. An implemented system has embedded only 36 pilots in an OFDMA symbol. It is clear from Figure 2 that to attain a target BER of 10^{-4}, WiMAX needs an SNR value of 3.28 dB, 17.5 dB, 18.59 dB, and 19.38 dB for user speed of 30 km/h, 120 km/h, 250 km/h, and 350 km/h respectively. It shows that the system performs well at a low vehicular speed of 30 km/h. System performance worsens at high terminal speed.

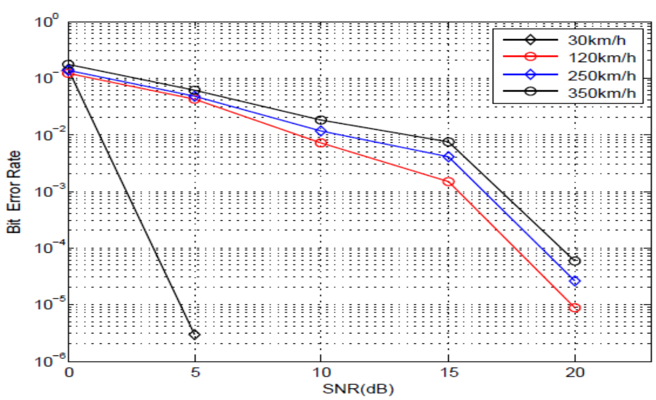

Figure 2. BER Performance of Implemented WiMAX System for QPSK Scheme for Different Vehicular Speed.

Figure 3 demonstrates the BER performance of implemented WiMAX system for 16 QAM modulation scheme with different vehicular speed. An implemented system has inserted only 48 pilots in an OFDMA symbol.Conventional WiMAX system incorporates 96 pilots in one OFDMA symbol. WiMAX needs an SNR value of 8.5 dB, 17.2 dB, 19.3 dB and 21.2 dB to accomplish a target BER of 10^{-2}, for terminal speed of 30 km/h, 120 km/h, 250 km/h and 350 km/h respectively.

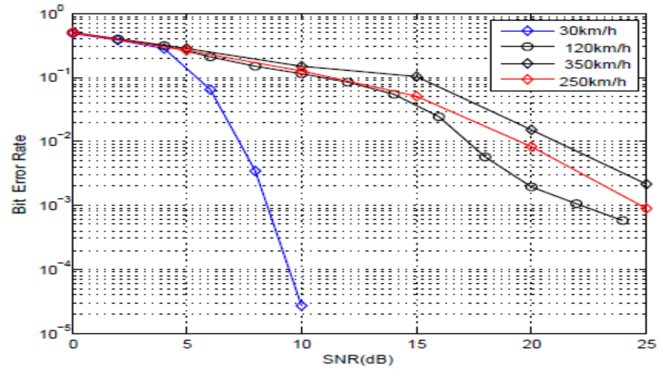

Figure 3. BER Performance of Implemented WiMAX System for 16 QAM Scheme for Different Vehicular Speed.

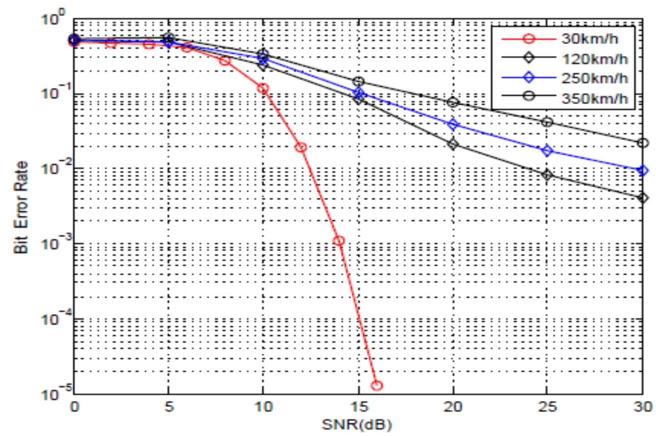

Figure 4. BER Performance of Implemented WiMAX System for 64 QAM Scheme for Different Vehicular Speed.

Figure 4 illustrates the BER performance of implemented WiMAX system for the 64 QAM modulation scheme with 30 km/h, 120 km/h, 250 km/h, and 350 km/h vehicular speed. An implemented system has used only 48 pilot subcarriers in an OFDMA data symbol.

To achieve a target BER of 10^{-2}, with 64 QAM as the baseband modulation scheme, the WiMAX system requires an SNR value of 12.5 dB, 18.75 dB and 30 dB for user speed 30 km/h, 120 km/h and 250 km/h respectively. At 350 km/h vehicular speed, the system needs more than 30 dB to provide the same BER performance.

Figures 2 to 4 show that the system performance degrades at high terminal speed. Degradation is more when a higher-level modulation technique such as 16 QAM or 64 QAM is used as compared to a lower level modulation scheme such as QPSK. There is a trade-off between data transmission rate of communication system and it's BER performance. High data rate is achieved by employing higher level modulation scheme. BER performance of all the modulation schemes degrades at high vehicular speed compared to low vehicular speed. BER performance of higher level modulation scheme is poorer as compared to lower level modulation scheme.

BER performance of mobile WiMAX degrades more at high vehicular speed for higher level modulation scheme as compared to the lower level modulation scheme. At high vehicular speed, intercarrier interference increases due to Doppler shift degrading the bit error rate performance

Table 2 compares pilot overhead between legacy fixed pilot pattern, various other research work related to WiMAX and implemented adaptive pilot pattern for mobile WiMAX, IEEE 802.16m system.

Conventional system consumes 11.11 % pilots[4,18] The implemented adaptive pilot pattern method has pilot overhead of 5.5 % when 16 QAM or 64 QAM modulation scheme is employed.For the QPSK modulation scheme, pilot overhead reduces to 4.17 %, providing additional subcarriers for data transmission. Ultimately adaptive pattern method reduces pilot requirement compared to conventional system and improves data rate and spectrum usage.

Table 3 shows the data rate comparison of 802.16m for the present fixed pilot pattern and implemented adaptive pilot pattern method.

Table 3 Data Rate Comparison

Sr No	Baseband Modulation Scheme	Number of Pilots / Symbol	Data Rate (Mbps)		Data Rate Improvement	
			Implemented System	Legacy System[1,21]	(Mbps)	%
1	QPSK	36	14.49	13.44	1.05	7.81
2	16 QAM	48	28.56	26.88	1.68	6.25
3	64 QAM	48	42.84	40.32	2.52	6.25

With the QPSK scheme, implemented system offers a data rate enhancement of 1.045Mbps. The system achieves a 7.81 % improvement in data transmission rate when the QPSK baseband modulation scheme is selected.Implemented system improves the data rate of 802.16m by 6.25 % for 16 QAM and 64 QAM. It provides a data rate improvement of 1.68 Mbps for 16 QAM and 2.52 Mbps for 64 QAM modulation techniques.

CONCLUSION

Implemented WiMAX system with adaptive pilot pattern provides BER performance comparable to that of legacy WiMAX system with fixed pilot pattern method. It uses fewer pilots than the conventional fixed pilot pattern of the mobile WiMAX system reducing the pilot overhead. This approach employs an optimum number of pilots. The adaptive strategy is used to reduce the pilot requirement based on the baseband modulation scheme. It enhances the rate of data transmission by 7.81 %. As implemented system employs variable number of pilots based on baseband modulation scheme at transmitter, system becomes little bit complex compared to traditional fixed pilot density based system.

CONFLICT OF INTEREST

The authors declare that there is no academic or financial conflict of intetest for this work.

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