Performance Enhancement of Radio over Multimode Fiber System using Fiber Bragg Grating for Micro and Pico Cell Applications

Shuvodip Das, Ebad Zahir

Abstract— Radio over Fiber (RoF) is a promising technology for short range transmission applications within multimode optical fiber. Typically, the RoF link employs a single mode fiber. But the signal power at the remote antenna become small due to the power loss in the electrical to optical and optical to electrical conversion process. Coupling efficiency of an electrical to optical converter can be improved with multimode fiber. But multimode fiber suffers from dispersion. Therefore, the paper proposes a simplified and efficient Radio over Multimode Fiber (RoMMF) system that can reduce the effect of dispersion by employing Fiber Bragg Grating (FBG). The performance analysis based on maximum Q-factor, minimum BER, threshold, eye height and jitter are extensively investigated. In addition, the effect of fiber length on these performance metrics is presented. Finally, a FBG based RoMMF system is proposed by providing a side-by-side comparison between the proposed and traditional system for micro and pico cell applications.

Index Terms— Bit Error Rate (BER), Dispersion, Eye height, Fiber Bragg Grating (FBG), Jitter, Optisystem, Q-factor, Radio over Multimode Fiber (RoMMF)

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1 INTRODUCTION

RADIO over fiber (RoF) refers to a technology whereby light is modulated by a radio signal and transmitted over an optical fiber link to facilitate wireless access, such as 3G and WiFi communication simultaneously from the same antenna. When radio signals are carried over multimode fiber cable then it's called Radio over Multimode Fiber (RoMMF) system. This system consists of Central Station (CS) and Base Station (BS) or Radio Access Point (RAP) connected by a multimode optical fiber link or network as shown in Fig. 1. Usually, RoF system utilizes Single Mode Fiber (SMF). [1], [2], [3]

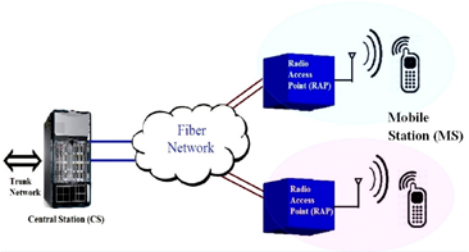

Fig. 1. RoF System Concept [3]

The choice of optical fiber in RoF system depends on applications. For short range applications, such as micro cell (less than 2 kilometer) and pico cell (about 200 meter or less), multimode fiber is preferred for its cost effectiveness and copling efficiency. Moreover, the signal power at the remote antenna is very small due to significant power loss in the electrical to optical and optical to electrical conversion process. However, coupling efficiency of an electrical to optical convertor can be improved using multimode fiber (MMF) as the core of MMF is more than five times greater in diameter than that of a SMF. The larger core enables low loss connection and facilitates simple fiber-to-fiber or fiber-to-transceiver alignment and consequently is best suited for premises of the range of micro and pico cells. [4] Moreover, deployment of multimode fiber leads to reduction in cost of the link. But Step-Index MMF (SIMMF) experiences Intermodal dispersion that degrades the performance of the system and quality of the received signals. On the other hand, Graded-Index Multimode Fiber (GIMMF) containing parabolic refractive index profile decreases modal dispersion. Dispersion is the main parameter which needs to be compensated in order to provide high level of reliability of service. Fiber Bragg Grating (FBG) is one of the most widely used element to compensate dispersion. FBG is a periodic perturbation of the effective refractive index in the core of an optical fiber that generates a wavelength specific dielectric mirror. So, FBG can be used as an inline optical filter to block certain wavelengths. [5], [7]

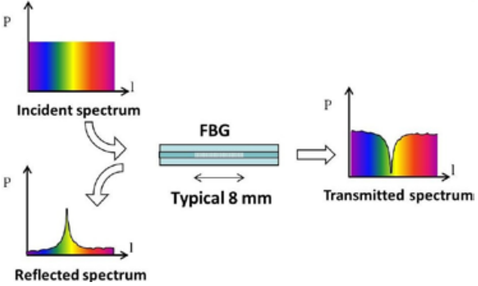

Fig. 2. Working principle of FBG [6]

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The simulation used ideal dispersion compensation FBG with user-defined group delay. The transfer function of the filter,

$$H(f) = e^{j\phi(f)} \qquad (1)$$

Where, f is the frequency dependence phase of the filter. Group delay depends on wavelength as

$$\tau(\lambda) = \frac{\lambda^2}{2\pi c}\frac{d\phi}{d\lambda} \qquad (2)$$

Where, c is the speed of light.

$$\text{Phase, } \phi = 2\pi c \int \tau(\lambda) \frac{1}{\lambda^2} d\lambda \qquad (3)\ [8]$$

In our work, we recommended the RoF link that employs a Parabolic Index Multimode Fiber (PIMMF) and FBG as inline optical filter to increase coupling efficiency and reduce dispersion. Simulation results from Optisystem 12 have been included to show the comparative performance evaluation of our proposed system containing PIMMF and FBG and traditional system without using FBG. Parameters like maximum Q-factor, minimum BER, eye height, threshold and jitter with respect to varying fiber length have been considered. Simulation results show that the proposed system exhibits acceptable performance, considering Q-factor, BER, eye pattern and jitter at maximum of 0.75 kilometer which makes the system suitable for simple, cost effective micro and pico cell applications.

2 PERFORMANCE MEASURES

Characterization of an optical transmission link which is one of the main criterions for the effective modeling of RoF system depends on the proper choice of performance metrics. Performance metrics should present a precise determination of system's limitation and measurement to improve the performance of the system. The most widely used performance measures are the Q-factor, BER, eye opening and jitter.

Q-factor is helpful as an intuitive Figure of Merit (FoM) that is directly tied to the BER. BER can be improved by either a) increasing the difference between the high and low levels in the numerator of the Q-factor or b) decreasing the noise terms in the denominator of the Q-factor.

$$Q = \frac{V_H - V_L}{\sigma_L + \sigma_H} \qquad (4)$$

V_S is the voltage sent by the transmitter and if we assume that V_s can take on one of the two voltage levels, V_H and V_L. σ_L and σ_H are the standard deviations of the noise. [9]

On the other hand, BER gives the upper limit for the signal because some degradation occurs at the receiver end. The bit error probability, P_e is the expectation value of the BER. The BER can be considered as an approximate estimate of the bit error probability. In a noisy channel, the BER is often expressed as a function of the normalized carrier-to-noise ratio (E_b/N_0), (energy per bit to noise power spectral density ratio), or E_s/N_0 (energy per modulation symbol to noise spectral density).

$$\text{BER} = \frac{1}{2}\text{erfc}(\sqrt{E_b/N_0}) \qquad (5)$$

Eye pattern or diagram is used to visualize how the waveforms used to send multiple bits of data can potentially lead to errors in the interpretation of those bits. Vertical eye opening indicates the amount of difference in signal level that is present to indicate the difference between one bit and zero bit. The bigger the difference the easier it is to discriminate between one and zero. Whereas, horizontal eye opening indicates the amount of jitter present in the signal. An open eye pattern corresponds to minimal signal distortion. Distortion of the signal waveform due to intersymbol interference and noise appears as closure of the eye diagram. [8]

Moreover, understanding of jitter is important because all digital circuits require at least one, and often several clocks for processing and handling data. As gate count and processing speeds increase, chipset designers must take into account factors such as propagation delay, skew, rise/fall times, etc to ensure adequate margins for proper operation. Jitter is one such factor. It adds uncertainty to the exact timing of an external reference clock.

Total jitter (*T*) is the combination of random jitter (*R*) and deterministic jitter (*D*):

$$\mathbf{T = D_{peak\text{-}to\text{-}peak} + 2\times n\times R_{rms}} \qquad (6)$$

In which the value of *n* is based on the bit error rate (BER) required of the link. [10]

3 METHODOLOGY AND SIMULATION SCHEMATIC

One of the main objectives of this paper is to simulate and model a FBG based RoMMF system which leads to simple and cost effective system implementation. Fig. 3 depicts the block diagram of the proposed RoMMF system.

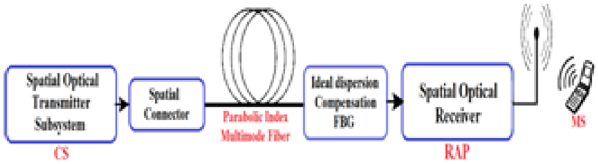


Fig. 3. Block diagram of our proposed FBG based RoMMF system

In Fig. 4, Central System (CS) is the spatial optical transmitter subsystem consisting of pseudo-random binary sequence generator (PRBS), coding/modulation block (NRZ and RZ), laser, AM modulator, DC bias and multimode generator. The central wavelength of laser is 850nm. In our proposed system, we have used wavelength which falls under A-Band and facilitates the use of lower cost Vertical-Cavity Surface-Emitting Laser (VCSEL). Optical channel that comprising spatial connector attaches signals with transverse mode profiles. To reduce the effect of dispersion, SIMMF is replaced with PIMMF having core diameter of 62.5 μm. After that ideal dispersion compensation FBG of a center wavelength of 850 nm is used as filter to block unwanted wavelengths. Radio Access Point (RAP) is the spatial optical receiver consisting of spatial aperture and optical receiver, illustrated in Fig. 5.

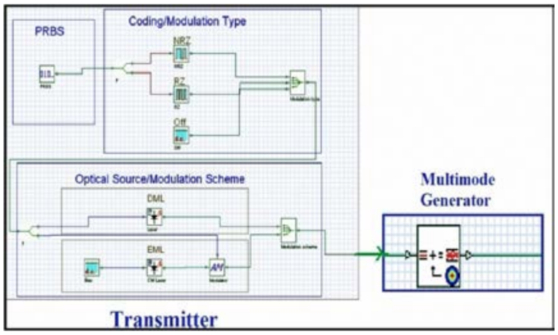


Fig. 4. Spatial optical transmitter subsystem

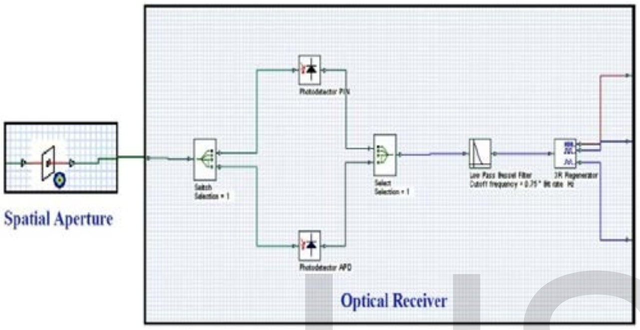


Fig. 5. Spatial optical receiver subsystem

1 Gbps data from PRBS is converted into NRZ and RZ signal sequence and the last stage of the optical transmission facilitates the user to select between an External Modulated Laser (EML) or a Directly Modulated Laser (DML). After that the RF modulated optical signal is fed to the multimode generator that attaches transverse mode profiles to the input signal. It also converts a single mode signal into a multimode signal based on the user defined power distribution. Power ratio array parameter is fixed to "1 2 3 4" that means the multimode generator generates four spatial modes per polarization (LG_{00}, LG_{22}, LG_{03} and LG_{13}). Four spatial modes then propagate through PIMMF. Parabolic refractive index helps to reduce modal dispersion. Afterward, ideal dispersion FBG having dispersion of -160 ps/nm filters out the undesired wavelengths and at output we get a 850nm concentrated output. Then the spatial aperture of spatial optical receiver subsystem couples the optical signal from the multimode fiber to the photodetector. Later, the signal is fed to the optical receiver built using a PIN photodetector, a Bessel filter and a 3R regenerator. PIN photodetector converts optical signal into electrical signal. Whereas, Bessel filter having center wavelength of 850nm attenuates signals with wavelengths other than 850nm. Finally, 3R regenerator regenerates an electrical signal. It generates the original bit sequence and a modulated electrical signal to be used for BER analysis. FBG based RoMMF system is modeled using simulation software Optisystem 12. Fig. 6 shows the simulation schematic drawn in Optisystem 12 window using various in-built blocks.

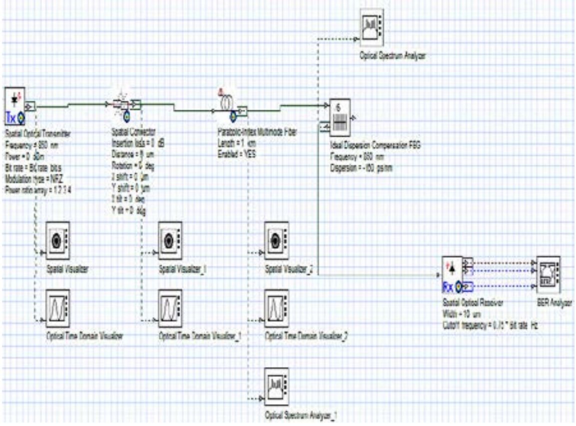
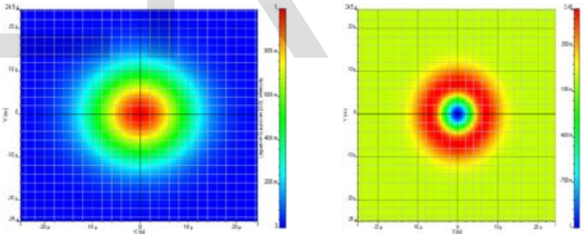


Fig. 6. Simulation schematic of proposed FBG based RoMMF system

4 SIMULATION RESULTS AND ANALYSIS

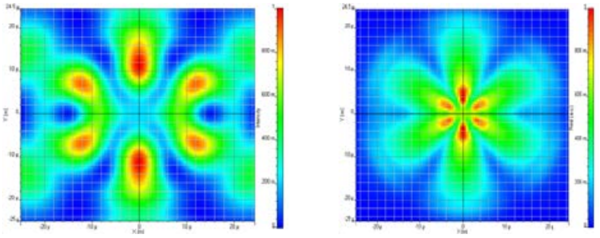
Proposed RoF system was successfully modeled and simulated using Optisystem 12 to extract simulation results. In this specific design, we have employed four types of visualizers, spatial visualizer, optical time domain visualizer, optical spectrum analyzer and BER analyzer.

Fig. 7 and Fig. 8 present the mode and weighted mode profile of optical field at the output of the a) spatial optical transmitter and b) PIMMF respectively.



(a) (b)

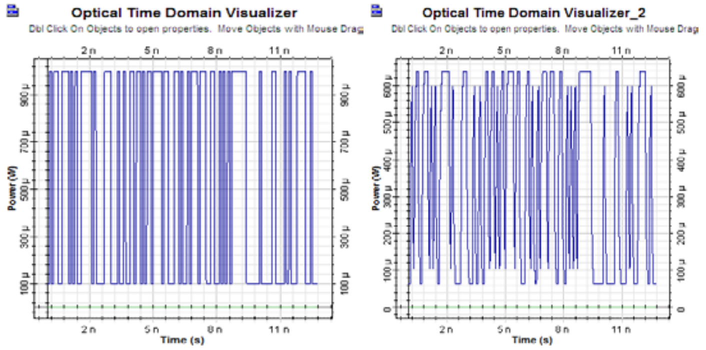
Fig. 7. Spatial visualizer displays the transverse mode at the output of the (a) spatial optical transmitter and (b) PIMMF.



(a) (b)

Fig. 8. Spatial visualizer displays the weighted mode profile at the output of the (a) spatial optical transmitter and (b) PIMMF.

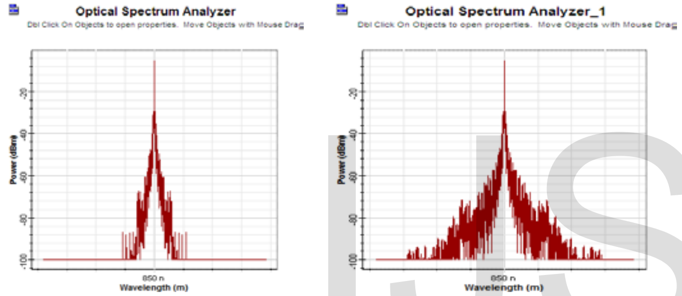
Fig. 9 illustrated the time domain representation of signal at the output of (a) spatial optical transmitter and (b) PIMMF after 0.5 km fiber length. Distortion in Fig. 9 (b) resembles the effect of attenuation and dispersion.



(a) (b)

Fig. 9. Optical time domain visualizer displays the time domain signal at the output of the (a) spatial optical transmitter and (b) PIMMF.

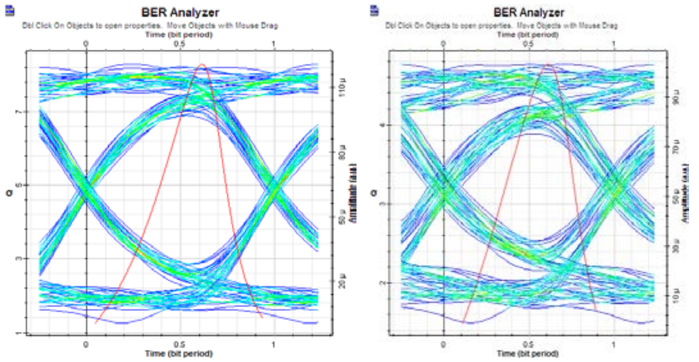
The consequence of inserting FBG is shown in Fig. 10. This figure represents the optical spectrum before and after FBG for 0.5 km fiber length. Fig. 10 (b) shows narrower spectrum concentrated on 850 nm than that of Fig. 10 (a). FBG filters out unwanted spectrum and make the resultant spectrum narrower.



(a) (b)

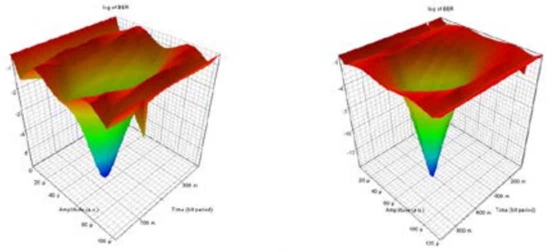
Fig. 10. Optical spectrum visualizer displays the optical spectrum a) before and b) after FBG

Fig. 11 shows the BER pattern and Q-factor after 0.5 km and 0.75 km. In the Fig. 11 (b), for 0.75 km eye width and eye closure reduced due to jitter effect and intersymbol interference.



(a) (b)

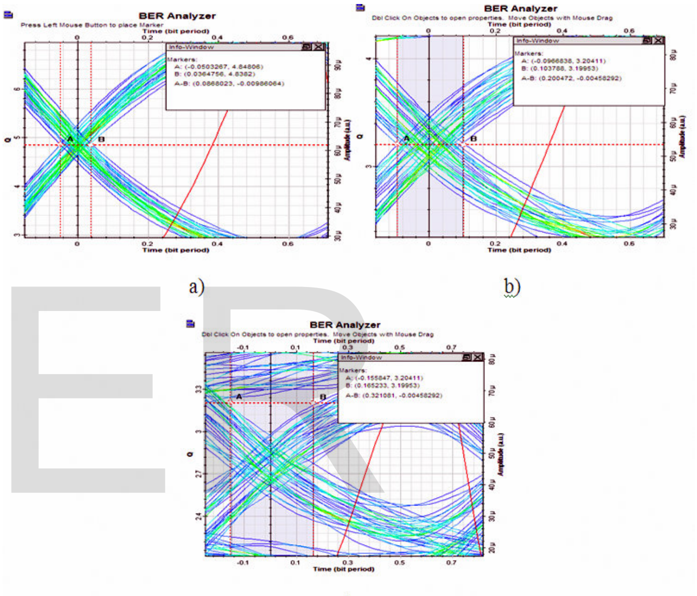
Fig. 11. Eye diagram showing BER pattern and Q-factor after (a) 0.50 km and (b) 0.75 km



(a) (b)

Fig. 12. 3D BER graph at (a) 0.5 km and (b) 0.75 km

Fig. 13 shows the total jitter of an eye diagram, measured at the eye cross point, as the difference between the time values of marks A and B. Fig. 13 (a), (b) and (c) show the jitter for 0.5 km, 0.75 km and 1km.



a) b) c)

Fig. 13. Jitter for (a) 0.5km (b) 0.75km and (c) 1km

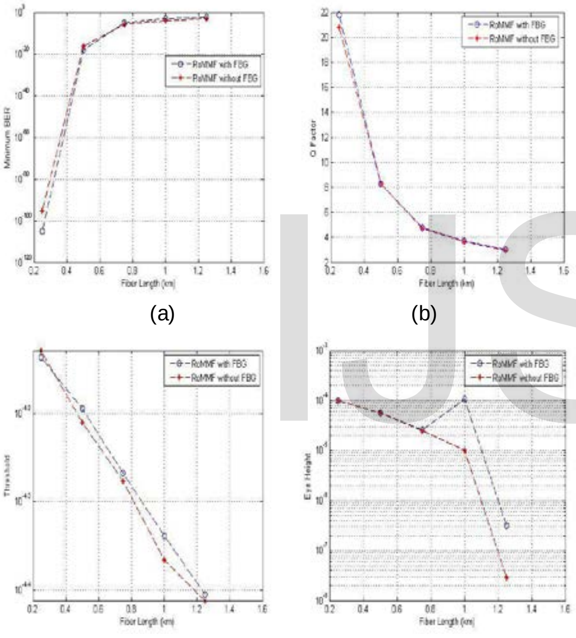
Table I: Q-factor, Minimum BER, Eye Height and Threshold for Different values of Fiber Length for RoMMF system without FBG.

No. of Samples	Fiber Length(km)	Q Factor	Minimum BER	Eye Height	Threshold
1	0.25	20.806	6.86*10^-96	0.0001001	7.4358*10^-5
2	0.5	8.27	3.72*10^-17	5.68*10^-5	6.16*10^-5
3	0.75	4.70	1.24*10^-6	2.50*10^-5	5.289*10^-5
4	1	3.68	0.0001140	1.01*10^-5	4.3*10^-5
5	1.25	2.97	0.001557	2.8786*10^-8	3.87*10^-5

Table II: Q-factor, Minimum BER, Eye Height and Threshold for Different values of Fiber Length for RoMMF system with FBG.

No. of Samples	Fiber Length(km)	Q Factor	Minimum BER	Eye Height	Threshold
1	0.25	21.8061	1.015*10^-105	0.00010013	7.301*10^-5
2	0.5	8.3127	5.764*10^-19	5.70995*10^-5	6.3842*10^-5
3	0.75	4.786	9.668*10^-6	2.59*10^-5	5.405*10^-5
4	1	3.74	0.001254	1.059*10^-4	4.58*10^-5
5	1.25	3.022	0.00524	3.17*10^-7	3.936*10^-5

Based on the simulation data extracted from Table I and Table II, Fig. 14 (a), (b), (c) and (d) have been drawn. The results shown in Fig. 14, depicts the performance of RoMMF with and without FBG considering maximum Q-factor, minimum BER, eye height and threshold with varying fiber length.



(a) (b)

(c) (d)

Fig. 14. Graph of (a) maximum Q-factor (b) minimum BER (c) Eye height and (d) Threshold against varying fiber length for RoMMF system with and without FBG

5 CONCLUSION

In this paper, we have proposed a FBG based RoMMF system and simulated the transmission of 1 Gbps data carried over 0.25 km to 1.25 km PIMMF at wavelength of 850 nm. The simulation results shown in Figure 7-13 depicted the performance of FBG based RoMMF system for different fiber lengths. Parameter metrics such as, maximum Q-factor, minimum BER, eye height, threshold and jitter have been considered. Figure 14 showed the performance comparison between RoMMF system with and without FBG. Figure 8 showed the weighted transverse mode profile at the output of spatial transmitter and PIMMF. Figure 9 (b) showed small amount of deviation in the time domain signal at the output of PIMMF due to attenuation and dispersion. Figure 10 (b) illustrated the optical spectrum after FBG and demonstrated the effectiveness of using FBG as it made the linewidth narrower by filtering out undesired wavelengths. After been transmitted for 0.5 and 0.75 km, received signal accumulated some noise as shown in the eye diagram, 3D BER graph and jitter in Figure11, 12 and 13. Eye diagram for 0.25 km and 0.5 km having wider vertical and horizontal eye opening corresponds to minimal signal distortion. Simulation results showed that with the increase of fiber length Q-factor, eye height and threshold decrease and minimum BER and jitter increases in most instances. Comparison between RoMMF system with and without FBG has been made based on the performance metrics, such as, Q-factor, minimum BER, eye height and threshold. System with FBG showed slightly better performance than that of system without using FBG. Our proposed FBG based RoMMF system displayed acceptable performance for maximum fiber length of 0.75 km. Acceptable eye diagram and low BER were achieved which implies the better performance of the system for micro and mainly for pico cell applications.

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