Power Allocation for Incremental-Selective Decode-and-Forward Cooperative Communications over Rician Fading Channels

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Abstract— In this paper we consider a relaying communication system over Rician fading channels. In this system we assume simple Incremental-Selective Decode-and-Forward (ISDF) protocol, which is jointly combining incremental and selective DF relaying protocols. In this protocol, storage or retransmission of the first phase signal are not allowed. We analyze the symbol error rate (SER) performance of the recommended protocol with M-PSK modulation. We evaluate the performance of the protocol in the frequency nonselective slow Rician fading channels .Using the approximation of the SER expression, the optimal power allocation is investigated. Our results show that at least 50% of total power must be used by direct link and the reminder can be used by the relay. In addition, the results indicate that the power allocation coefficient just depend on the quality of source-relay channel and the quality of relay-destination.

Keywords*— *Decode and forward; incremental relaying; selective relaying; power allocation; Rician Fading channels;

I. Introduction

The performance of mobile agents is limited by severe variations in signal attenuation due to multipath fading. To deal with this problem, some kinds of diversities have to be used. For instance multi input- multi output (MIMO) technology uses spatial diversity to overcome deep fading however, agents such as mobile handsets, sensor network nodes and etc., due to size, power or other constraints, can not utilize multiple antennas [1-2].

Cooperative diversity is a transmission scheme, which cooperative users share their resources to form virtual antenna arrays to obtain spatial diversity for achieving diversity gains through the relay channel [3-4].

Main cooperative signaling techniques are categorized in two schemes as follows. The first is amplify and forward protocol, in which the relay receives a noisy version of the signal transmitted by source and then amplifies and retransmits this noisy signal. Regarding cooperative diversity, second commonly used protocol for the transmission between the source and the destination through the relays is the decode-and-forward (DF) protocol, in which the relays first decode the received signal then encode and retransmit it to the destination[5].

Laneman et. al. also proposed several relaying protocols such as selective DF and incremental DF [5].

By implementation of a limited feedback from the destination terminal, (e.g., a single bit indicating the success or failure of the last direct transmission attempt) we use relaying process when it is needed. If the source-destination channel's SNR is sufficiently high, the feedback indicates success of the direct transmission, so the relay does nothing. If the source-destination channel's SNR is not sufficiently high for successful direct transmission, the feedback requests the relay to perform decode-and-forward operation on what has been received from the source [5]. Performance of incremental relaying scheme has been investigated in [6]. In another work incremental relaying with selection a relay from multiple relay is also considered[7].

Another protocol is the selective DF relaying scheme, which the relay node can decode the received signal and then check correctness of decoding, including cyclic redundancy check (CRC) digits or signal-to-noise ratio (SNR) levels. If the symbol is correctly decoded, the relay will forward it to the destination, otherwise, the relay will remain silent [5]. Power allocation for this protocol over Nakagami-m fading channels has been investigated in [8-9] and for Rayleigh fading channels power allocation has been investigated in[10].

To improve performance of incremental DF relaying scheme, a new relaying scheme has been proposed and its error probability performance over Rayleigh channels has been analyzed. The new scheme jointly combines the incremental and selective DF relaying protocols, and so it is called incremental-selective DF relaying [11].

In this paper, we analyze the SER performance of the incremental and selective DF cooperative scheme over Rician fading channels. In our other work [12] we evaluate the SER performance of the incremental and selective DF relaying protocols over Rayleigh fading channels.

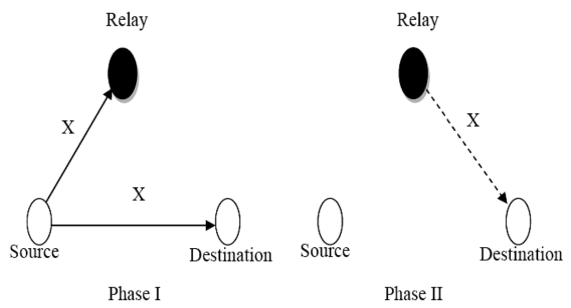

Figure 1. protocol of relaying data in two phase

In our model a feedback from destination indicates success of the direct transmission in contrast with model based on the SNR threshold. The exact SER expression for M-PSK modulation has been derived. Moreover, the optimal power allocation is investigated based on the derived approximated SER expressions. Note that only a partial CSI is required for determination of how much power should be allocated to the source and the relay to optimize the SER performance.

This paper is organized as follows. In Section II, system model and the relaying protocol are developed. The SER performance is derived in Section III and it is approximated in high SNR regime. In Section IV, optimal power allocation is explained for the ISDF protocol. Numerical and simulation results are presented in Section V. Finally, the conclusions are given in section VI.

II. SYSTEM MODEL

In this section we describe protocol and channel model. A wireless network with a single-user relay channel having one source, a single relay, and one destination node is considered.

A. Protocol and Channel model

Fig.1 describes the communication via a relay in two phases. The source broadcasts data in phase one. In this phase the destination and the relay listen to the channel. They try to decode the signal. If destination decodes the message then destination broadcasts a bit to indicate correctness of decoding. So in the second phase, the source transmits another symbol, otherwise, if the relay decodes the message in the first phase, and the destination could not decode message, so the decoded message will be send to the destination via relay else, relay remains silent.

The relay system is assumed to operate over independent Rician fading channels. If the channel's gain for links are h so the magnitude of h is Rician distributed with the probability density function (PDF) given by [13]

$$P_h(\alpha) = \frac{2(K+1)e^{-K}\alpha}{\Omega} e^{-\frac{(K+1)\alpha^2}{\Omega}} I_0(2\alpha\sqrt{\frac{K(K+1)}{\Omega}}) \qquad (1)$$

where ($\Omega = E[h^2]$) is the average fading power of the channel and K is the Rician K-factor defined as the ratio of the power of the LOS component to that of scattered components and is the zeroth order modified Bessel function of the first kind.

All the channels coefficients (h_{sd}, h_{sr}, h_{rd}) are independent of each other. We also assume that all the additive white Gaussian noise (AWGN) terms in the three links ($S \to D$, $S \to R$ and $R \to D$)are zero mean with equal variance N_0 (i.e., $n \sim \mathcal{N}(0, N_0)$).

B. Input–Output Relation and Signal-to-Noise Ratio

The source transmits the signal (x) with normalized power. Without loss of generality, the signal power is normalized to unity ($E\{|x|^2\} = 1$).The transmitted power of the source is assumed to be p_1 and that of the relay to be p_2. Therefore the received signal at the destination may be written as

$$y_{sd} = \sqrt{p_1} h_{sd} x + n_{sd} \qquad (2)$$

where h_{sd} is the channel gain for the source-destination link and n_{sd} is the additive white Gaussian noise with zero mean and variance N_0 for the source-destination link. The received signal at the relay may be written as

$$y_{sr} = \sqrt{p_1} h_{sr} x + n_{sr} \qquad (3)$$

where h_{sr} is the channel gain for the source-relay link and n_{sr} is the additive white Gaussian noise with zero mean and variance N_0 for the source-relay link.

If the second phase happens, the received signal in the second phase at the destination terminal may be written as

$$y_{rd} = \sqrt{p_2} h_{rd} x + n_{rd} \qquad (4)$$

where h_{rd} is the channel gain for the relay-destination link and n_{rd} is the additive white Gaussian noise with zero mean and variance N_0 for the relay-destination link. Whenever the relay and the destination know channel state information, signal to noise ratios in the first phase are

$$\gamma_{sd} = \frac{p_1|h_{sd}^2|}{N_0},\ \gamma_{sr} = \frac{p_1|h_{sr}^2|}{N_0} \qquad (5)$$

For DF cooperation, we do not assume any storage or retransmission of the first phase transmitted signal to the destination. Therefore signal to noise ratio at the destination in the second phase can be written as

$$\gamma_{rd} = \frac{p_2|h_{rd}^2|}{N_0} \qquad (6)$$

where SNRs in Eq. (5) and Eq. (6) are distributed according to a noncentral-χ2 distribution which is given by

$$p_{\gamma_i}(\alpha) = \frac{(K+1)e^{-K}}{\bar{\gamma_i}} e^{-\frac{(K+1)\alpha}{\bar{\gamma_i}}} I_0(2\sqrt{\frac{K(K+1)\alpha}{\bar{\gamma_i}}}) \qquad (7)$$

In the following section we derive SER of the system based on the channel's SNR which is shown in this section.

III. SYMBOL ERROR RATE

In this section, we analyze the SER performance of the incremental–selective DF over Rician fading channels.

A. *Exact Symbol Error Rate*

In [13] SER for direct link is calculated for M-PSK modulation using moment generating function (MGF) that is written as fallows

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$$\psi(\gamma) = \frac{1}{\pi}\int_0^{\frac{(M-1)\pi}{M}} \mathcal{M}_\gamma(\frac{-b}{sin^2(\phi)})d\phi \quad (8)$$

where $b = sin^2\frac{\pi}{M}$ and γ is the channel's SNR. The moment generating function $\mathcal{M}_\gamma$ is defined as

$$\mathcal{M}_\gamma(s) = \int_0^\infty p(\gamma)e^{s\gamma}d\gamma \quad (9).$$

When the SNRs are in the form $\frac{p_i|h_j^2|}{N_0}$ and h_j's have Rician distribution, their MGF functions can be written as [13]

$$\mathcal{M}_\gamma\left(\frac{-b}{sin^2(\phi)}\right) = \frac{(K+1)\sin^2\phi}{(K+1)\sin^2\phi+b\bar{\gamma}} e^{-\frac{Kb\bar{\gamma}}{(K+1)\sin^2\phi+b\bar{\gamma}}} \quad (10)$$

so the symbol error rate can be written as

$$SER = \psi(\gamma_{sd})\psi(\gamma_{sr}) + \psi(\gamma_{sd})\psi(\gamma_{rd})(1-\psi(\gamma_{sr})) \quad (11)$$

Substituting Eq. (10) and Eq. (8) into Eq. (11) we get an integral Equation (12) that should be solved numerically[10].

where ($\bar{\gamma}_{sr}$, $\bar{\gamma}_{sr}$, $\bar{\gamma}_{sr}$) are the average SNR of corresponding channels which can be written as

$$\bar{\gamma}_{sd} = \frac{p_1\Omega_{sd}}{N_0}, \bar{\gamma}_{sr} = \frac{p_1\Omega_{sr}}{N_0}, \bar{\gamma}_{rd} = \frac{p_2\Omega_{rd}}{N_0} \quad (13)$$

where $\Omega_{sd}, \Omega_{sr}, \Omega_{rd}$ are the average fading powers of corresponding channels. To obtain a closed form equation for the SER, in the next section we derive an approximation of Eq. (12).

B. *Approximated Symbol Error Rate*

The SER expression involves very complex integrals that are difficult to evaluate. With assumption of large SNR Value (i.e.$\gamma \gg (K+1)$), we can approximate Eq. (10) with

$$\mathcal{M}_\gamma\left(\frac{-b}{sin^2(\phi)}\right) \cong \left(\frac{b\bar{\gamma}}{(K+1)\sin^2\phi}\right)^{-1} e^{-K} \quad (14)$$

therefore Eq. (8) can be rewritten as

$$\psi(\gamma) \cong \frac{1}{\pi}\int_0^{\frac{(M-1)\pi}{M}}\left(\frac{b\bar{\gamma}}{(K+1)\sin^2\phi}\right)^{-1} e^{-K} = \frac{Ae^{-K}}{b\bar{\gamma}} \quad (15)$$

where A is defined as

$$A = \frac{1}{\pi}\int_0^{\frac{(M-1)\pi}{M}} sin^2\phi \; d\phi = \frac{M-1}{2M} + \frac{sin\left(\frac{2\pi}{M}\right)}{4\pi} \quad (16)$$

We also assume that the SNR value for the source relay channel is sufficiently large, therefore the symbol error at the relay is very low, and thus the approximated overall SER may be written as

$$SER_{app} \cong \frac{A^2e^{-(K_{sd}+K_{sr})}}{b^2\bar{\gamma}_{sd}\bar{\gamma}_{sr}} + \frac{A^2e^{-(K_{sd}+K_{rd})}}{b^2\bar{\gamma}_{sd}\bar{\gamma}_{rd}} \quad (17)$$

where K_{sd}, K_{sr}, K_{rd} are the Rician K-factor of corresponding channels. We will show that the SER approximation is valid in the high SNR regime.

IV. OPTIMAL POWER ALLOCATION

After that, we discuss the power allocation problem for the DF cooperative network. Note that only partial CSI is required for determination of how much power should be allocated to the source and the relay nodes to optimize the performance. This derivation is based on SER approximation given in Eq. (17) for M-PSK signals over Rician fading channels.

Under the total power constraint, i.e., $(p_1 + p_2 = P)$ where $p_1 = \beta P$ and $p_2 = (1-\beta)P$ the approximated SER expression can be modified as

$$SER_{app} \cong \frac{C}{\beta^2} + \frac{D}{\beta(1-\beta)} \quad (18)$$

where $C = \frac{A^2 N_0^2 e^{-(K_{sd}+K_{sr})}}{b^2P^2\,\Omega_{sd}\,\Omega_{sr}}$ and $D = \frac{A^2e^{-(K_{sd}+K_{rd})}}{b^2P^2\,\Omega_{sd}\,\Omega_{rd}}$ and β is the power allocation coefficient. Using the optimization theoretic arguments, it is not difficult to show that the optimum power allocation coefficient can be derived as

$$\begin{cases} \beta = \frac{1-4\frac{C}{D}+\sqrt{1+8\frac{C}{D}}}{4\left(1-\frac{C}{D}\right)} & \frac{C}{D} \neq 1 \\ \beta = \frac{2}{3} & \frac{C}{D} = 1 \end{cases} \quad (19)$$

where

$$\frac{C}{D} = \frac{\Omega_{rd}}{\Omega_{sr}} e^{-(K_{sr}-K_{rd})} \quad (20)$$

From Eq. (19), this fact can be seen that the optimum power coefficient does not depend on the quality of the source-destination channel. In the first phase if the destination have been decoded message then we do not need relay (i.e., $p_2=0$ or $\beta=1$). But if the destination could not have decoded the message we need relay to send a clean copy of the message to the destination. In this case we allocate some of power to the relay.

$$SER = \left(\frac{1}{\pi}\int_0^{\frac{(M-1)\pi}{M}} \frac{(K+1)\,sin^2\phi}{(K+1)\,sin^2\phi+b\bar{\gamma}_{sd}} e^{-\frac{Kb\bar{\gamma}}{(K+1)sin^2\phi+b\bar{\gamma}_{sd}}}\,d\phi\right) \times \left(\frac{1}{\pi}\int_0^{\frac{(M-1)\pi}{M}} \frac{(K+1)\,sin^2\phi}{(K+1)\,sin^2\phi+b\bar{\gamma}_{sr}} e^{-\frac{Kb\bar{\gamma}}{(K+1)sin^2\phi+b\bar{\gamma}_{sr}}}\,d\phi\right) + \left(1-\frac{1}{\pi}\int_0^{\frac{(M-1)\pi}{M}} \frac{(K+1)\,sin^2\phi}{(K+1)\,sin^2\phi+b\bar{\gamma}_{sr}} e^{-\frac{Kb\bar{\gamma}}{(K+1)sin^2\phi+b\bar{\gamma}_{sr}}}\,d\phi\right) \times \left(\frac{1}{\pi}\int_0^{\frac{(M-1)\pi}{M}} \frac{(K+1)\,sin^2\phi}{(K+1)\,sin^2\phi+b\bar{\gamma}_{sd}} e^{-\frac{Kb\bar{\gamma}}{(K+1)sin^2\phi+b\bar{\gamma}_{sd}}}\,d\phi\right) \times \left(\frac{1}{\pi}\int_0^{\frac{(M-1)\pi}{M}} \frac{(K+1)\,sin^2\phi}{(K+1)\,sin^2\phi+b\bar{\gamma}_{rd}} e^{-\frac{Kb\bar{\gamma}}{(K+1)sin^2\phi+b\bar{\gamma}_{rd}}} \times d\phi\right) \quad (12)$$

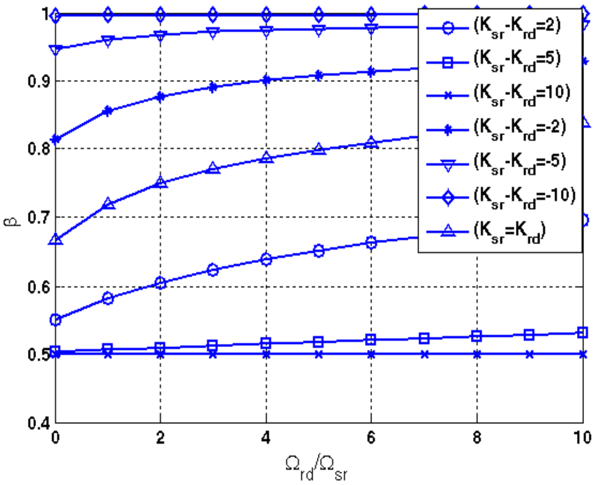

Figure 2. Optimum Power Allocation Coefficent for Rician fading in different K.

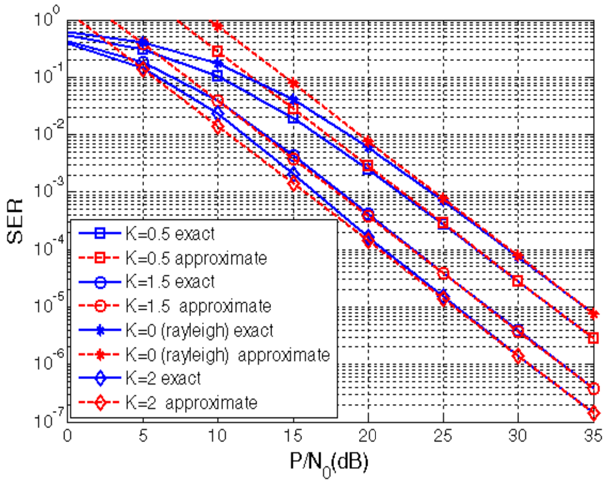

Figure 3. Approximated and exact SER versus SNR in symmetric Rician fading ($\Omega_{sr} = \Omega_{sd} = \Omega_{rd} = 1$).

The allocated power to the relay depends on proportional relation of the source-relay channel's quality and the relay-destination channel's quality.

If the link quality between the source and the relay is very good (i.e., $\Omega_{sr} \gg \Omega_{rd}$ or $K_{sr} \gg K_{rd}$) the optimum power coefficient tends to 0.5. On the other hand, the relay can always decode the transmitted symbol correctly, so the decoded symbol at the relay is almost the same as that at the source. We may consider the relay signal as a clean copy of the source signal, so we put power on them almost equally.

If the link quality between the source and the relay is bad, it is difficult for the relay to decode the transmitted symbol correctly. Thus, forwarding role of the relay is not important and it makes sense to put all the power at the source. When $\Omega_{sr} \ll \Omega_{rd}$ or $K_{sr} \gg K_{rd}$, optimum power coefficient tends to 1. Therefore the optimum power coefficient changes in the interval [0.5 1].

We can see that the optimum ratio of the transmitted power p_1 at the source divided to the total power P is less than 1 and greater than 2/3, while the optimum ratio of the power p_2 used at the relay divided to the total power P is larger than 0 and less than 1/3, i.e.,

$$0.5 < \frac{p_1}{P} < 1 \quad , \quad 0 < \frac{p_2}{P} < 0.5 \qquad (21).$$

For the special scenario that distribution of the link between source and relay is the same as that of the relay-destination link (In the case $\Omega_{sr} = \Omega_{rd}$ and $K_{sr} = K_{rd}$) relay's links have the same quality thus transmission via relay is not optimum and so the direct link with greater allocated power is the best choice.

Note that the Rician distribution spans the range from Rayleigh fading ($K = 0$) to no fading (constant amplitude) ($K = \infty$).

V. Evaluation And Simulation

Computer simulations are conducted to verify accuracy of the analytical results for the incremental selective DF protocol. All the channel models are Rician fading, and we assume that the relay and the destination can check whether the decoding result is correct. Without loss of generality we performed simulation for 8-PSK modulation. Power is optimally allocated to the source and the relay.

Fig.2 shows the optimum power allocation coefficient in the incremental-selective relaying for different K Rician factor. It can be seen that in the ISDF, the power allocation coefficient changes in the interval 0.5 to 1. When the source-relay channel suffers weaker fading, β tends to 0.5, otherwise, β tends to 1. When the source-relay channel suffers severe fading (K=0, Rayleigh fading) it is better to use all of the power in the direct link.

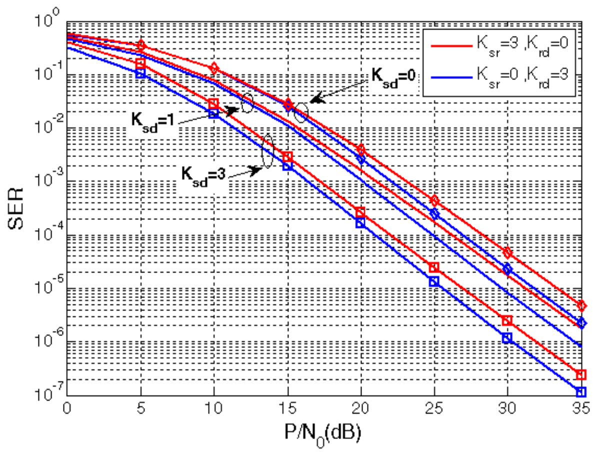

Figure 4. SER versus SNR in Asymmetric Rician fading channels ($\Omega_{sr} = \Omega_{sd} = \Omega_{rd} = 1$).

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In Fig.3 the symbol error rate is shown for two sets of average fading powers. The exact SER and the approximated SER for different K-Rician factor are displayed. In Fig.3 we assume symmetric channel i.e., all the channels are have the same distribution (have same K) but the average fading powers may be different. The exact SER and the approximated SER are the same in the moderate and high SNR regime. With increasing K, the SER are decreased. In the case K=0 (Rayleigh distribution) we have greater SER.

In Fig.4 we assume asymmetric channels i.e., channels have different distribution (each channel have self K-Rician factor). Also in this case the exact SER and the approximated SER are the same in the moderate and high SNR regime. With increasing K, the SER are decreased. In the case K=0 (Rayleigh distribution) we have greater SER. Fig.4 also shows that the SER of scenario which the source-relay channel suffers Rayleigh fading and the relay-destination suffers Rician fading outperforms of scenario which the source-relay channel suffers Rician fading and the relay-destination suffers Rayleigh fading.

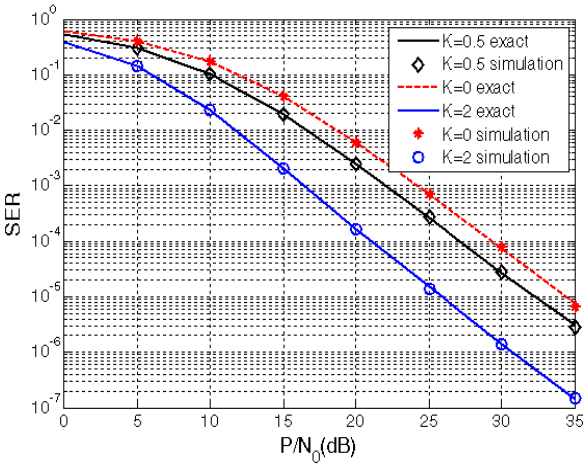

Figure 5. Simulation and exact SER versus SNR in symmetric Rician fading channels ($\Omega_{sr} = \Omega_{sd} = \Omega_{rd} = 1$).

The simulation is carried out to examine the correctness of derived expressions for the SER in Eq. (12). Fig.5 shows that the exact SER same as the simulation curve for different K-Rician factor i.e., the simulation results coincide to the exact results.

VI. Conclusions

The main objective of this work is to derive SER expression for incremental selective relaying over independent Rician fading channels. For ease of usage, we have also provided an approximate expression for the SER. Moreover the optimal power allocation is investigated based on the derived approximate SER. The performance of incremental selective relaying at Rician fading channels for different K-Rician factor in both symmetric and asymmetric relay channel are examined.

It should be noted that at least 50% of total power must be used by the direct link and the reminder can be used by the relay. Moreover, the results indicate that the power allocation coefficient just depends on the quality of the source-relay channel and the quality of the relay-destination channel.

Also the results indicate that the SER of the scenario which the source-relay channel suffers Rayleigh fading and the relay-destination suffers Rician fading outperforms scenario which source-relay channel suffers Rician fading and the relay-destination suffers Rayleigh fading.

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