The intelligent reflecting surface (IRS) is an emerging technique to extend the wireless coverage. In this letter, the performance of hybrid automatic repeat request (hybrid-ARQ) for an IRS-aided system is analyzed. More specifically, the outage performance of the IRS-aided system using hybrid-ARQ protocol with chase combining is studied. Asymptotic analysis also shows that the outage performance improves better than linearly by increasing number of reflectors of the IRS-aided system. The results also verify the potential of combining the ARQ scheme in the link layer of the IRS-aided system and demonstrate that very small change of path loss condition can impact the performance largely.

Introduction: Intelligent reflecting surface (IRS) is a revolutionary enabling technique to significantly improve the system performance of wireless systems. By functioning as a reconﬁgurable lens or mirror for the electromagnetic waves and intelligently reconfiguring the radio wave propagation environment, the IRS can improve system coverage especially when line-of-sight (LoS) is not guaranteed [1]. To this end, a number of research has been devoted to investigate the performance of IRS under different setups. The ergodic capacity and bit error rate (BER) performance of an IRS-aided dual-hop UAV communication system is investigated in [2]. The analysis on coverage, probability of signal-to-noise ratio (SNR) gain, and delay outage rate of IRS-aided communication system is conducted in [3]. The secrecy performance of IRS-assisted millimeter wave (mmWave) system is studied in [4]. It is well known that system performance can be further improved by resending data that has been impaired by unfavorable redundancy (IR) and hybrid ARQ with chase combining (CC) [5]. Despite the omnipresence of hybrid ARQ and great potential of IRS, a thorough literature search indicates that the performance of IRS-aided communication with hybrid-ARQ has not been investigated yet to the authors’ best knowledge. To fill the gap, we study the outage performance of IRS-aided system with hybrid-ARQ with CC in this letter.

Mathematical framework: The investigated system model for the IRS-aided system with hybrid-ARQ with CC in this letter.

Fig. 1 The IRS-aided communication system model.
accumulated SNR $\gamma_K$ at node $D$ after $K$ ARQ rounds can be written as
\[
\gamma_K = \sum_{k=1}^{K} \gamma_k = \sum_{k=1}^{K} \gamma_k \left( \frac{N}{1} \right) \alpha_k \beta_k \cdot \frac{2}{\gamma}
\]
where $\gamma_k$ is the SNRs for the link from $S$ to $D$ via IRS at the $k$-th round. The PDF and CDF of the RV $\gamma_k$ is given in (5) and (6), respectively.

The total accumulated mutual information, $I_K$, can be expressed as
\[
I_K = \log_2 \left( 1 + \gamma_K \right) = \log_2 \left( 1 + \sum_{k=1}^{K} \gamma_k \right).
\]

An outage after $K$ ARQ rounds implies that the accumulated total mutual information $I_K$ is still less than the transmission rate $R$. Mathematically, the outage probability $P_{\text{out}}(K)$ after $K$ ARQ rounds can be written as
\[
P_{\text{out}}(K) = \Pr(I_K < R) = \Pr \left( \log_2 \left( 1 + \sum_{k=1}^{K} \gamma_k \right) < R \right)
\]
\[
= \Pr(\gamma_K < \Theta) = F_{\gamma_K}(\Theta),
\]
where $\Theta = 2^R - 1$.

Arising from the fact that a noncentral-$\chi^2$ RV results from the sum of squares of several i.i.d. Gaussian RVs with non-zero mean; then the sum of several i.i.d. noncentral-$\chi^2$ RVs also has a distribution of the same type with the parameters being the sums of the corresponding parameters of the summands. Therefore, the outage probability after $K$ ARQ rounds can be expressed, after some mathematical manipulations, as
\[
P_{\text{out}}(K) = 1 - Q_m \left( \frac{N}{1} \cdot \frac{169}{\pi} \cdot \frac{\left( 16N - K^2 \right)^{\frac{1}{4}}}{\left( 16N - K^2 \right)} \right)^{\frac{1}{2}}.
\]

Asymptotic analysis: The following asymptotic expression of generalized Marcum-$Q$ function holds as $q \to 0$:
\[
Q_m(p, q) \approx 1 - q^{2m} \cdot \frac{2^m}{\Gamma(1)} \cdot \frac{\Gamma(1 + m)}{\Gamma(2m)} \cdot \exp \left( -\frac{p^2}{2} \right) + o(q^{2m}).
\]

When $N$ is sufficiently large, by utilizing the above asymptotic expression for (10), we have
\[
P_{\text{out}}(K) \approx \frac{\exp(-C_1 N)}{N^{2K}} \cdot C_2, \quad (12)
\]
where $C_1 = \frac{K^2}{2} - \frac{K^2}{4}$ and $C_2 = \left( \frac{169}{16N - K^2} \right)^{\frac{1}{2}} \cdot \left( 2^K - 1 \right) \cdot (\Gamma(\frac{K}{2}) \cdot K)^{-1}$.

The result in (12) shows that when the reflector number is sufficiently large, the following holds: $P_{\text{out}} \propto -a \cdot N - b \cdot \log(N)$, where $P_{\text{out}}$ is in log scale, $a$ and $b$ are some constants related to $K$.

Fig. 2 $P_{\text{out}}$ under varying number of ARQ round.

Numerical analysis and discussions: Figure 2 illustrates the outage performance of the IRS-aided system under different number of ARQ round. It can be seen that compared to the case where ARQ is not utilized, the hybrid ARQ scheme can greatly improve the system performance. However, with the increasing of the ARQ round, the SNR gain becomes smaller. For instance, referring to the outage probability of $10^{-3}$, the transmit SNR is lesser by around 2.4 dB by moving from $K = 2$ to $K = 3$ while the value becomes 1.6 dB when $K$ increases from 3 to 4 rounds. The performance of hybrid ARQ system over IRS-aided system cannot only be enhanced by increasing ARQ rounds, but also by the increase of reflecting elements, as shown in Fig. 3.

Fig. 3 $P_{\text{out}}$ versus varying number of reflecting elements $N$.

Fig. 4 $P_{\text{out}}$ versus varying path loss exponent $n$.

Conclusion: In this paper, we investigate the performance of hybrid ARQ with CC over the IRS-aided communication system. The results verify the potential of combining the ARQ scheme in the link layer of the IRS-aided system as well as demonstrates the sensitivity of propagation environment on the system performance.

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