Forward error correction codes are commonly adopted in dual-hop relay communications, among which Luby transform (LT) codes are favorable because of their low-complexity decoder and rate adaptability to erasure channels. To alleviate the high computational cost in the primitive LT-based cooperative communications, hybrid decomposed LT (h-DLT) codes are proposed recently. By dispersing the computational cost of LT codes into the source and the relay, the computational cost of both nodes can be reduced considerably. However, there are some practical limitations. First, the nonnegative decomposition algorithm developed for h-DLT codes construction has no control of decomposition accuracy. Second, the cooperative relay communication protocol based on the original h-DLT codes can induce high communication cost. In this paper, we propose a stochastic nonnegative polynomial decomposition algorithm, which achieves robust decomposition and higher decomposition accuracy for h-DLT codes construction. Based on the new algorithm, a new type of h-DLT codes is proposed for cooperative relay communications with higher energy efficiency. Simulations are conducted to manifest the performance of the new h-DLT codes and benefits of the corresponding cooperative relay communication system. In addition, multiple design factors are investigated.