Optik 125 (2014) 5893–5898

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

The queuing delay analysis at relay node based on cooperative GBN-ARQ protocols

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ARTICLE INFO

Article history:
Received 21 October 2013
Accepted 31 May 2014

Keywords:
Cooperative diversity (CD)
Go-back-N automatic repeat request protocols (GBN-ARQ)
Matrix geometric method (MGM)
Delay

ABSTRACT

In this paper, a single relay cooperative diversity network model is proposed, analyzing queuing delay of the packets at relay node. Using dynamic radio link adaptation in wireless networks, based on the character of GBN-ARQ protocol and the queuing theory, the paper solves the problem that packets wait to transmit at relay, and presents a relay node to destination node queuing analysis model for GBN-ARQ protocol with fixed feedback delay. The paper establishes Markov model of packet transmission, and the delay statistics at relay node are figured out by using matrix geometric methods.

1. Introduction

High-speed, reliable and instant data transmission are the key requirement for the wireless communication system. Using the error-control technology, link adaptation and anti-fading techniques to solve the multi-path spread, Doppler frequency shift and decline and other problems in the process of communication can guarantee the high rate, reliability and spectrum utilization of the system transmission. The core idea of the cooperative diversity technology is that every node in a wireless network has one or more partners, the partners will transmit data cooperating with other partners while transmitting their own data and achieve the sharing of transmission path, thus producing the decline of the wireless channel and improving the throughput of the wireless network [1]. Adaptive modulation and coding techniques adjust the delivery mode and transmission speed, raise the utilization ratio of spectrum depending on the current channel conditions [2]. With the automatic repeat request(ARQ) protocols, the reliability of data transmission can be guaranteed and packet error rate can be lowered [3].

Literatures [4,5] considered a transmitter node using adaptive modulation and coding at the physical layer and the automatic repeat request at the link layer to communicate with a receiver node over a wireless channel, but it does not consider the cooperative diversity techniques. Literature [6] proposed a way analyzing multi-user relay network queuing performance based on ARQ error control. Literatures [7,8] analyzed delay and throughput performance of relay network based on amplify-and-forward and decode-and-forward respectively. Literature [9] used a three-node cooperative diversity amplify-and-forward relay network as the analyzing model, analyzed queuing delay of the source node data packet over the Nakagami-m fading channels. In [10], the Markov channel model including relay link which uses select combining or max ratio combining at the receive node was equivalent to corresponding point to point channel model, and it analyzed the system delay performance under two ARQ protocols. But above paper had not considered the relay itself has data transmission, or simplified to data to forward as soon as reached relay, avoiding the relay queuing problem of data frames from the source node.

According to the above problem, this paper get a G/M/1 Markov chain using a three-node single relay cooperative diversity system as the analyzed model to model the data packet transmission status of relay. this paper models the data packet arrival process as a Bernouli process, solves the relay queuing problem of data frames from the source node, uses the matrix geometric method to statistic the delay probability of the relay data packet, finally analyze the influence of channel condition and system parameter on the delay performance.

2. System description

We presented a system model of single relay cooperative communication system in Fig. 1. In the model, S represents the source node, R represents the relay node, D represents the destination

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http://dx.doi.org/10.1016/j.ijleo.2014.07.045

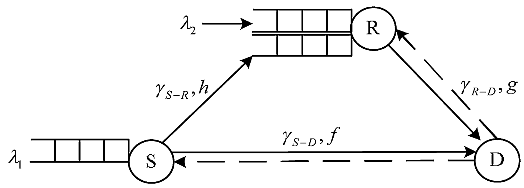

Fig. 1. Single relay cooperative communication system model.

node, each terminal is equipped with an antenna. In the figure, the solid lines represent the sending channel, dashed lines represent the feedback channel. Each channel in the system is flat Nakagami fading channel, and fading coefficient of the adjacent channel is independent, their decline factor are *f*, *h*, *g*, respectively. $\gamma_{\text{S-D}}$, $\gamma_{\text{S-R}}$ and $\gamma_{\text{R-D}}$ represents the instantaneous signal-noise ratio of S–D link, S–R link, R–D link, the channel is time-varying and we use *K* represents the change of each channel.

In the system model of this article, there are two road of the input data at the relay, one is from the source, the other is from the relay itself. Assume that the maximum rate of the packets which are sent to the relay from the sender S is *L*, so the number of the packets received from the sender S is 0–*L*. And the relay itself's new packets arrive according to Bernoulli distribution, their arrival probability is λ_2. Assume that a is the number of the packets received at the relay, and the only several possible values are 0, 1, . . ., L, $L+1$, the arrival process of the packet is a batch arrival process, we use GBN-ARQ protocol in the arrival process from relay R to destination D.

The data packets transmission occurs in fixed time scale, the number of data packets transmission in each time scale depends on the choice of the transmission mode. The destination end decodes the received packets, and then sends a feedback package including a certification package (ACK) or a negative package (NACK) to the relay. If one or more packages transmission in time slot failed, the GBN-ARQ protocol error recovery would be started. In GBN-ARQ protocol, the transmitter at the relay send packets continuously from the buffer until it tests the transmission error (NACK) in the feedback package. In this kind of transmission failure cases, GBN-ARQ retransmits all the packages from error packet.

We assume that the feedback package (such as ACK/NACK information) arrives at the relay node after *n* time slots (in this paper, we assume that the feedback channel is right). And in the ACK/NACK feedback information, the feedback channel carries the channel state information (CSI), which is used in the transfer mode of the dynamic link choice. We assume that CSI has no delay at the destination end, this assumption is reasonable over the slow fading channel whose condition is that many transmission intervals are static. We assume that the max retransmission times of a package are infinite, so in the case of finite packets are allowed to be retransmitted at the link layer, the delay this paper gets can be as an upper limit.

3. System mathematical model

The channel model used in this article is finite state Markov channel (finite state Markov channel, the FSMC) model. In this channel model, the SNR of the destination end receiver is divided into time slots with finite number. Assign $X_0(=0)<X_1<X_2<\cdots<X_{K+1}(=\infty)$ is the entrance of the receiver SNR in different channel state. When received *X* of SNR is in $X_0(=0)<X_1<X_2<\cdots<X_{K+1}(=\infty)$, it shows that the current channel state is in the *K* state. After deciding SNR entrance of the receiver, we can get a probability matrix, in which the element *k* is the transmission probability from state *k* to state *l* [12,13].

Set the data packet arrival rate at the sender and at the relay itself as λ_1 and λ_2, respectively. The maximum transfer rate from the sender to the relay is *L*, The data packets probability over the S–R link in the transmission state *k* is

$$P_{ST}=[P_0,P_1,P_2,\ldots,P_L] \tag{1}$$

Then the probability distribution of the number of data packets received at the relay from the sender within each slot is

$$P_{s1}=[(1-\lambda_1)+\lambda_1P_0,\lambda_1P_1,\ldots,\lambda_1P_L] \tag{2}$$

Among them, $0\le l\le L$, so the range of the number of new received data packets at the relay new to relay in the current time slot is 0, 1, 2, 3 ,. . ., mark its probability as $P_r(k)$, its expression is

$$P_r(k)=[P_{s1}(0)*(1-\lambda_2),\lambda_2P_{s1}(0)+P_{s1}(1)*(1-\lambda_2),\ldots,\lambda_2P_{s1}\times(L-1)+P_{s1}(L)*(1-\lambda_2),\lambda_2P_{s1}(L)] \tag{3}$$

$P_{s1}(0)$ is the first element of the array P_{s1}, which represents the probability that the number of data packets received successfully at the relay from the sender is zero. $P_{s1}(L)$ is the probability of that the data packets received is *L*.

This article mainly discussed the transmission process modeling of the data packets of GBN ARQ protocol at the relay. The time that the result of decoding each packet arrives at the transmitter of the relay is *n* time slot after sending start, if the transfer package error occurs at the time slot *t*, all the package transmitted from the time slot $t+1$ to $t+n-1$ will be abandoned. Therefore, we not only need to track the channel state (this can decide how many bags in one time slot transmit), but also to track the effective time slot (this is defined as the slot that a successful decoding transport package can be received by the destination end) [14].

Let $x(t)\ge 0$ represent the number of packages in the queue, including packets which received NACKs unsuccessfully and need to retransmit, let $0\le c(t)\le K$ track effective time slot, and represent $0\le c(t)\le K$ the channel state. We allocate the value of $s(t)$ as follows: if transmission failure occurs in an effective time slot, $s(t)$ will be equal to 1 in the next time slot. Then, it gradually reduces in the following time slot until $s(t)=0$ (effective transmission period begin again), obviously, it is $n-1$ ineffectively time slots after effective time slot. It represents that a random process is formed to a discrete time Markov chain [15].

We use a ternary group (i, j, k) to represent the state of Markov process $Y(t)$. $(i, j, k)\to(i', j', k')$ represent the system state from (i, j, k) to (i', j', k') in the adjacent time slot. Assume that *i* is fixed, we write the probability of transmission state transition $(i, *, *)\to(i+K+1-l, *, *)$ correspond to the system into the matrix block (i, j, k), $0\le l\le 2L+1$. *L* is the maximum capacity of transmission link. When $i\ge L$, the value of A_{ij} has nothing to do with *i*, we can express A_{ij} as A_i. Then, we put the probability of state transition $(i, j, *)\to(i+L+1-l, j', *)$ into the matrix block $A_{ij}(j, j')$ of the matrix block A_{ij}. Likewise, we put the transition probability $(i, j, k)\to(i+L+1-l, j', k')$ into $A_{ij}(j, j')(k, k')$, and what is needed to demonstrate that it is an element of $A_{ij}(j, j')$. In fact, the probability correspond to transition from (i, j, k) to any other state will become the $(i(K+1)n+j(K+1)+k)$th line of the state transition matrix, they are the elements of A_{ij}. Because *j* has *n* kinds of probabilities which record the invalid time slot of the channel, the channel state *k* has $K+1$ kinds of probabilities, the size of matrix block A_{ij} is $n(K+1)*n(K+1)$, the size of the matrix block $A_{ij}(j, j')$ is $(K+1)*(K+1)$.

The following example clarifies that the system transition probability is how to sort in the form of matrix, we assume that the channel state has only two probabilities, the feedback delay is two,