Evaluating on Performance of Single-source Single-relay Sr-carq protocol in Tdma Networks with Raleigh Fading

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Abstract

This paper analyzes the performance of single-source and single-relay SR-CARQ protocol in TDMA wireless communication system. We establish its M/G/1 queuing model with vacations, and provide the expressions of its system time delay and saturation throughput. Then the analysis of theory and simulation results under the slow Raleigh fading channel show that under what conditions the SR-CARQ protocol is superior to its non-cooperative counterpart.

Keywords: *SR-CARQ, M/G/1 queuing model, Mean service delay, Throughput rate, Rayleigh fading*

1. Introduction

The proliferation of mobile wireless multi-functional devices is an important phenomenon which will shape the future Internet[1]. Some fundamental characteristics of radio medium are inherent broadcast nature or the various forms of diversity. Cooperative diversity exploiting the broadcast nature in the wireless transmission has been proposed as a promising technology to combat fading effect. Automatic repeat request (ARQ) protocols are used to guarantee reliable data delivery over the wireless channel. Up to now, the two main technologies for improving system reliability include ARQ technology and cooperative communication technology. So the study of cooperative ARQ protocol is of great importance.

In literature [2], the first delay model for single-source and single-relay cooperative SW-ARQ protocols for radio networks with TDD relaying was derived and applied to a TDMA-based network. The performance of single-source single-relay cooperative ARQ was studied through analytical model, and the performance of two cooperative ARQ protocols is compared against two non-cooperative ARQ protocols i.e., type□hybrid ARQ and type□ hybrid ARQ. However, their analysis and algorithm are only suitable for stop-and-wait ARQ (SW-ARQ) protocol, but not for continuous transmission of the Go-Back-N ARQ (GBN-ARQ) protocol or Select Repeat ARQ (SR-ARQ). Literature [3] analyzed the performance of a cooperative ARQ protocol under Poisson arrivals and time correlated Raleigh fading. The average frame latency and the probability generating function of the frame service time were compared against non-cooperative ARQ protocol. Literature [4] analyzed the performance of cooperative ARQ protocol which adopts equal gain combination over Nakagami-m channels, utilizing an approximation strategy. By approximating the product of two independent Nakagami-m random variables to the sum of two independent gamma random variables, the performance of protocol I is derived at high signal-to-noise ratio (SNR), the authors further develop the approximation for the product of two maximum Nakagami-m random variables, which is employed to obtain the performance of protocol II at high SNR.

SR-ARQ protocol is a simple method for improving data transmission performance, which only retransmitted the error data frames or data frame of overtime timer. So it is widely used for long time delay wireless data transmission as it gives the higher channel efficiency and lower delay sensitivity [5]. In this paper, we propose a new cooperative select repeat ARQ (SR-CARQ) algorithm which is suitable for the single-source single-relay wireless communication system based on TDMA (Time Division Multiple Access), where a station shares a multiple access communications channel by transmitting its messages during its dedicated time slots. We also establish the SR-CARQ's queuing model and provide the expressions of its time delay, saturation throughput and buffer occupancy at the source. Simulation results under the slow Raleigh fading channel show that, the performance of SR-CARQ is always better than non-cooperative SR-ARQ.

The remainder of the paper is organized as follows. The system model is described in Section 2, section 3 is fully devoted to the performance analysis of SR-CARQ protocols. In Section 4, the analytical results are compared with simulation results. Finally, the paper concludes in Section 5.

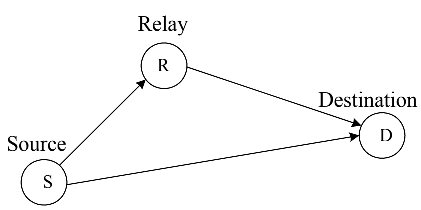

Fig. 1 Cooperative system model of three nodes

2. The System Model

We consider a wireless network with a source node S, a destination node D and a set of M relay nodes. Particularly, the source S is scheduled to transmit to destination D in the first time slot of each time frame, the destination D is scheduled to perform error detection for the received frame. One of the M relay nodes, which are scheduled to transmit during the time frame, is chosen to be R, as long as it can "eavesdrop" the transmission from S to D. Node R is the only relay assigned to help S (this paper is not addressed the selection of R). The system model illustrates in Fig. 1. Suppose this system share the same channeland using TDMA, time is divided into time frames, every system time frame is divided into M time slots, every frame length is T_F, and every time slot length is T_F/M .

3. The M/G/1 Queuing Model and Performance Index

To facilitate the later research, this paper makes the following assumptions:

(1)Feedback information (ACK/NAK) transmission is error-free;

(2)The data transmission is completely synchronic;

(3)The source S will send the information outand the process of data packet arrival will follow Poisson with the parameter of λ ;

(4) $\overline{P}_{SD}$, $\overline{P}_{SR}$ and $\overline{P}_{RD}$ respectively represent the error rate in data transmission between S to D, S to R, and R to D;

3.1 M/G/1 Queuing Model with Vacations

The queuing model for SR-CARQ is shown in Fig. 2. The server buffer has infinite capacity, and the arriving packets with Poisson arrivals obey the first-come first-served fashion. To take TDMA

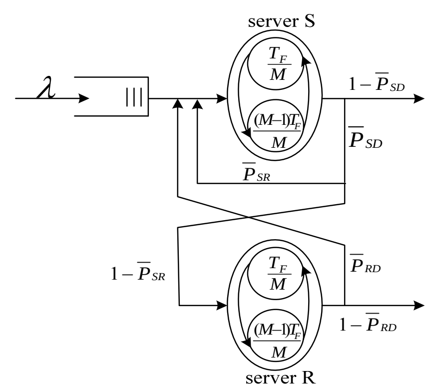

Fig. 2 The queuing model for cooperative SR-ARQ

access into account, the server has two states, i.e., working and rest. Accordingly, the server is in working state for T_F/M in every frame, and $(M-1)T_F/M$ is in the rest state. Only in the working state the server transmits data, in the rest state it is equivalent to vacations process. Under the assumption that a packet equivalent service time delay obeys general independent and identical distribution, the SR-CARQ transmission process can be approximately described as M/G/1 queuing model with vacations.

Suppose X represents the service time of data packet, V represents the vacations of the data packet, and the first and second order moments of service time and the vacations are $E(X)$, $E(X^2)$, $E(V)$ and $E(V^2)$ respectively. So the average waiting time delay of the system can be found in using Pollaczek-Khinchin formula for the M/G/1 queuing model with vacations [6]

$$W = \frac{\lambda E(X^2)}{2(1-\rho)} + \frac{1}{2}\frac{E(V^2)}{E(V)} \quad (1)$$

Where $\rho = \lambda \overline{X} = \lambda E(X)$.

By Little formula [6], it is possible to obtain the system mean service time delay

$$T = E(X) + W - \frac{(M-1)T_F}{M} \quad (2)$$

The maximum throughput rate and the buffer occupancy at S are

$$Th = 1/E(X), \quad N = \lambda T \quad (3)$$

3.2 Performance Index Solution

The packet error rate of direct link {S, D} of SR-CARQ is $P_\omega = \overline{P}_{\mathrm{SD}}$; the error rate of SR-CARQ is $P_\sigma = \overline{P}_{\mathrm{SD}}(\overline{P}_{\mathrm{SR}} + (1-\overline{P}_{\mathrm{SR}})\overline{P}_{\mathrm{RD}})$; t_c represents the mean propagation delay and processing delay from S to D; the length of every packet is the same as every time slot length, is T_F/M, the number of packet retransmission is k, the sliding window width is N. So the equivalent service delay is $\frac{T_F}{M}N + \frac{T_F}{M}k + (k+1)t_c$. Then we can obtain that

$$E(X) = \sum_{k=1}^{\infty}\left[\frac{T_F}{M}N + \frac{T_F}{M}k + (k+1)t_c\right]$$
$$\cdot P_\omega \cdot (1-P_\sigma)P_\sigma^{\,k-1} + \frac{T_F}{M}N \cdot (1-P_\omega)$$
$$= P_\omega(\frac{T_F}{M}N + t_c) + \frac{P_\omega P_\sigma(\frac{T_F}{M} + t_c)}{1-P_\sigma}$$
$$+ \frac{T_F}{M}N \cdot (1-P_\omega)$$

$$E(X^2) = \sum_{k=1}^{\infty}\left[\frac{T_F}{M}N + \frac{T_F}{M}k + (k+1)t_c\right]^2$$
$$\cdot P_\omega \cdot (1-P_\sigma)P_\sigma^{\,k-1} + (\frac{T_F}{M}N)^2 \cdot (1-P_\omega)$$
$$= \frac{2P_\omega \cdot P_\sigma[N \cdot (\frac{T_F}{M})^2 + t_c \cdot \frac{T_F}{M} \cdot (N+1) + t_c^{\,2}]}{1-P_\sigma}$$
$$+ \frac{P_\omega \cdot P_\sigma(\frac{T_F}{M} + t_c)^2 \cdot (1+P_\sigma)}{(1-P_\sigma)^2}$$
$$+ (\frac{T_F}{M}N)^2 \cdot (1-P_\omega)$$
$$+ P_\omega[(\frac{T_F}{M}N)^2 + 2t_c \cdot \frac{T_F}{M}N + t_c^{\,2}]$$

Since each packet in a frame accounts for only one time slot, if no packet arrives at the start of time slot, the server can not begin to transmit packets until the same time the slot in the next frame comes. So the channel will suspend (vacation) a frame (M time slots) for every packet, accordingly the vacations is T_F. Therefore, $E(V^2)/E(V) = T_F$.

Using the expressions for $E(X)$, $E(X^2)$ and $E(V^2)/E(V)$ respectively, it is possible to obtain the packet mean service time delay T from Eq. 2, the maximum throughput rate Th and the average number of data packets N in the queue from Eq. 3. Although the expressions of T, Th and N are very complicated, they are functions of parameters T_F, M, N, λ, P_ω, P_σ and t_c. That is

$$T = f(T_F, M, N, \lambda, P_\omega, P_\sigma, t_c)$$

4. Analytical and Simulation Results

4.1umption on Channel with Rayleigh Fading

Path loss and fading affect the transmission of the data frames. Frequency-flat, slow Rayleigh fading is assumed. The instantaneous SNR from node i to j is [2]

$$\gamma_{ij} = \frac{E_{b_i}}{N_0} \cdot K \cdot d_{ij}^{-\beta} \cdot \delta_{ij}^2 \quad (\{i, j\} = \{S, D\}, \{S, R\}, \{R, D\}) \tag{4}$$

Where the meanings of the parameters in (4) are described in the following:

E_{b_i} is the transmitted energy per bit at node ;

N_0 is the noise spectral density of the additive white Gaussian noise (AWGN) channel;

K is the path loss for an arbitrary reference distance;

d_{ij} is the distance from i node to j (normalized to the reference distance);

β is the path loss exponent;

α_{ij} is the Rayleigh distributed random variable to model the Rayleigh fading magnitude from node i to j;

α_{ij}^2 has an exponential distribution with mean $E[\alpha_{ij}^2] = 1$ ($\forall i, j$) .

In this paper, we assume that system can use the type of BPSK modulation, the corresponding average bit error rate is [7]

$$P(\gamma_{ij}) = Q(\sqrt{2\gamma_{ij}}) \approx \frac{1}{2} e^{-\gamma_{ij}} \tag{5}$$

Using the error rate $P(\gamma_{ij})$ in Eq. 5 and the value of Rayleigh fading, we can obtain the simulation results of packet mean service time delay, the maximum throughput rate and buffer occupancy from the form Eq. 2 and Eq. 3.

4.2 Ulation Results

The system parameters are set as follows: T_F =1, M =8, N =8, λ =0.05. Suppose the case of link is the symmetrical uplink, i.e., $\gamma_{RD} = \gamma_{SD}$, let γ_{SR} =10dB. Fig. 3, Fig. 4 and Fig. 5 show how $SNR_{S,D}$ affects T , Th and N of the two systems. Simulation results in the following three figures are shown that the superiority of the SR-CARQ over non-cooperative SR-ARQ protocol, especially in the low SNR condition and high arrival rates in TDMA wireless networks.

In Fig. 3, we can see that the mean delay T in two systems of SR-ARQ and SR-CARQ is decreasing with the increase of $SNR_{S,D}$. When $SNR_{S,D}$ <5dB, the trend of decreasing of T in SR-CARQ is relatively flat with the increase of $SNR_{S,D}$, this phenomenon explain that when the quality of channel situation is poor we can choose the SR-CARQ to reduce the delay and improve the performance of system.

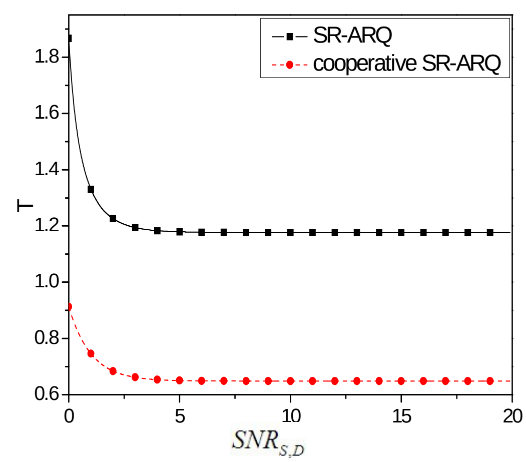

Fig. 3 T vs. $SNR_{S,D}$ (dB)

The simulation results in Fig. 4 show that the rate of SR-CARQ is always better than non-cooperative SR-ARQ. Also, the throughput rate of SR-CARQ and non-cooperative SR-ARQ are 0.493 and 0.976, when $SNR_{S,D}$ =3dB; It is clear from Fig. 5, that the buffer occupancy curve of SR-CARQ is always below the non-cooperative counterpart.

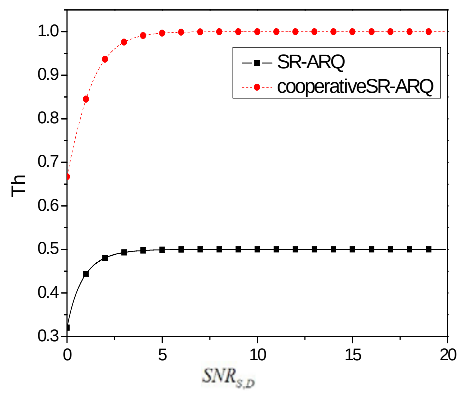

Fig. 4 Th vs. $SNR_{S,D}$ (dB)

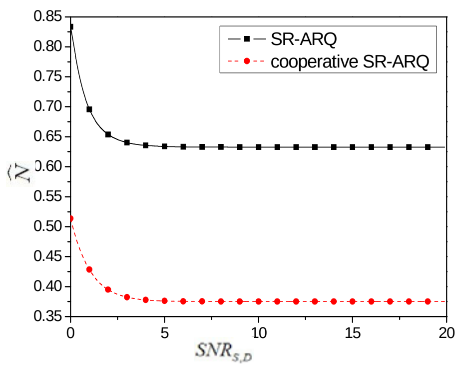

Fig. 5 N vs. $SNR_{S,D}$ (dB)

5. Conclusion

We derived the delay model for single-source single-relay SR-CARQ protocol in TDMA wireless networks, and analyzed its performance by using queuing theory in terms of time delay, saturation throughput and the buffer occupancy. Analytical and simulation results under the slow Rayleigh fading showed that, the performance of SR-CARQ outperformed non-cooperative SR-ARQ. This work is expected to provide a theoretical basis for studying advanced cooperative ARQ protocol.

In the cooperative versions of ARQ (C-ARQ), other nodes than the sender or the destination play a role in the packet retransmission/recovery process. There are many proposals of C-ARQ, which differ on whether they are devised as a cross-layer mechanism between layers 1 and 2 (physical and link layers) , they are pure layer 2 mechanisms, or they are a cross-layer mechanism between layers 2 and 3 (link and network layers); on whether they are devised for cellular, sensor, infra-structured WLAN, ad-hoc or mesh networks; or on whether they use or not, frame combining. Performance analysis of C-ARQ protocols has yielded many interesting results in the literature. i.e., Le and Hossain [8] design an analytical model for a general C-ARQ scheme in cluster-based multi-hop networks, while coherent maximal-ratio combining (MRC) is adopted to facilitate the analysis. The analytical model [8] is very useful to research the performance of C-ARQ scheme deeply. Especially in [2], many interesting and open questions, which can improve C-ARQ scheme's application in engineering, have been presented in its last section. For example, how to consolidate and generalize the initial findings in this field How will double-source C-ARQ scheme work? What happens if source and relay share the same channel and collisions may occur? How are relays selected and how are other nodes notified of the selection made? Next, we will pay much attention to these open questions.

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