Performance Analysis of Single Relay Cooperative ARQ protocol under Time Correlated Rayleigh Fading Channel

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***Abstract*—In this paper, we analyze the performances of a cooperative ARQ protocol under Poisson arrivals and the time correlated Rayleigh fading channel environment. A two dimensional discrete time Markov chain is formulated for the analysis. Using the steady state analysis of the Markov chain, the average frame latency and the moment generating function of the service time of a frame are derived. We validate our analytical results by comparing them with simulation results. From our analysis, we show that the cooperative ARQ protocol outperforms the non-cooperative protocol. In addition, we see that the effect of time correlation of the fading channel is not negligible.**

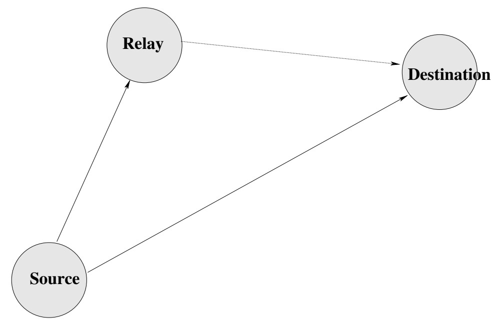

Fig. 1. A single source node and a single relay node cooperation.

I. Introduction

Next generation wireless networks such as the fourth generation wireless system are required to support quality of service (QoS) such as spectral efficiency and delay requirement. To meet these requirements, new advanced schemes are needed and performance analysis of these schemes is also important to check their validity.

Different from the channels in wired networks, wireless channels in wireless networks have main two features - fluctuation and fading in received signal strength and inherent broadcast nature of signal. Various diversity schemes are used to alleviate fading effect and to improve performance. In this paper, we consider a cooperative system utilizing spatial diversity. Although the broadcast nature of the wireless channel has been treated traditionally as interference because simultaneous transmitted signals from nodes are collided, it is possible to exploit the characteristic by overhearing transmission from source node to destination node. After a node who is willing to help the source node eavesdrops the transmission from the source node, the helping node, generally called relay node, transmits a replica or a mixture of its data frame and the eavesdropped data frame to the destination for reliable communication. This method is known as cooperative communication which depicted in Fig. 1.

There have been a number of works about cooperative communications, e.g. [1] - [4]. Most of these researches have mainly focused on the PHY layer and little attention has been paid to the performances of upper layers. So, we consider the MAC layer performance of the cooperative system and particularly concentrate on a cooperative ARQ protocol.

Recently, a few works have studied the performance of cooperative ARQ protocols, but they are not based on mathematical frameworks. [5] - [8] propose different cooperative ARQ protocols and show some gains in terms of spectral efficiency and packet error rate. [9] compares performances of possible and several cooperative ARQ protocols based on simulation. Regarding the analysis of QoS such as delay constraint and throughput, [10] analytically shows that the cooperative ARQ protocol dramatically reduces the average service time and the jitter of service time compared with a conventional ARQ protocol under saturated condition. [11] considers frame latency as well as service time when the fading channel is uncorrelated, and shows that not only the service time but also the frame latency in the cooperated ARQ protocol are much smaller than those in the conventional ARQ protocol. Motivated by the above two papers [10], [11], we develop an analytical model of the cooperative ARQ protocol under unsaturated traffic condition and a correlated fading channel, which is a generalization of [10] and [11]. Furthermore, we analyze not only average service time and frame latency but also the probability generation function of the service time by utilizing queueing techniques such as Markov renewal theory and Little's theorem. The main contributions of the paper are the following.

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1) Our analytical model considers unsaturated traffic condition, while the model in [10] considers saturated traffic condition. Note that the unsaturated traffic condition is more meaningful in practice. Hence, our model can predict the actual performance in practice.
2) The model in [11] considers uncorrelated fading channel. However, our model considers correlated fading channel, which is more practical.
3) We develop a novel two dimensional Markov chain to analyze the performance of the cooperative ARQ protocol. Base on the Markov chain, we can obtain the service time distribution and analyze the delay performance and the effect of the correlation in the fading channel.

The rest of this paper is organized as follows. In Section II, the fading channel model is given and then the cooperative ARQ protocol is explained. Section III provides our analytical model for the cooperative ARQ protocol. The performance analysis based on our analytical model is given in Section IV. Validation of our analytical model through simulation studies is given in Section V. We give our conclusions in Section VI.

II. System Model

For simplicity, we call the cooperative ARQ protocol and conventional ARQ protocol the *Coop-ARQ* protocol and the *Non-Coop-ARQ* protocol, respectively.

A. Fading channel model and frame transmission

We consider a wireless network consisting of a source node, a destination node and a relay node as in Fig. 1. All the wireless channels of SD, SR and RD[1] are assumed to be flat and correlated Rayleigh fading channel and independent. For frame transmissions, time is divided into slots of equal size. In our model, time instants at slot boundaries are indexed by $t = 0, 1, 2, \cdots$. For the flat Rayleigh fading, the success-failure process of frame transmissions can be modeled as a Markov process as follows [12]. Let $\epsilon_i(t)$ be the success-failure process of channel i at slot boundary t for $i = SD, SR, RD$. Then for a given channel reception power threshold Pth_i and fading complex envelope of channel i, $g_i(t)$, we have

$$\epsilon_i(t) = \begin{cases} G, & \text{if } |g_i(t)|^2 > Pth_i, \\ B, & \text{otherwise}, \end{cases}$$

for $i = SD, SR, RD$. States G and B mean success and failure of the transmission, respectively. Since the channel is assumed to be invariant during a slot, $\epsilon_i(t)$ only depends on the channel states at slot boundaries. For channel i, let a_i and b_i be the state transition probabilities of $\epsilon_i(t)$ such that

$$a_i = \Pr\{\epsilon_i(t+1) = G | \epsilon_i(t) = B\}$$
$$b_i = \Pr\{\epsilon_i(t+1) = B | \epsilon_i(t) = G\}$$

The state transition probability matrix $P^{(i)}$ of the process $\epsilon_i(t)$ with state space $\{G, B\}$ can be written as

$$P^{(i)} = \begin{bmatrix} 1-b_i & b_i \\ a_i & 1-a_i \end{bmatrix} \tag{1}$$

[1]SD,SR and RD are abbreviations of 'Source to Destination', 'Source to Relay' and 'Relay to Destination', respectively.

The derivation of exact values of transition probabilities in $P^{(i)}$ can be found in [13].

B. Coop-ARQ protocol

In the *Coop-ARQ* protocol, if the source node has a frame to transmit, it transmits the frame to the destination node. If the transmitted frame is successfully received by the destination, the destination will send an ACK to the source announcing the success of the transmission. Otherwise, the destination will NAK to the source reporting the failure of the transmission. While the source node transmits the frame, the relay node can eavesdrop the transmission from the source to the destination. If the relay node catches correctly the transmitted frame and the failure of the transmission from the source to the destination, it retransmits the replica in the next slot instead of the source. In the *Coop-ARQ* protocol, if the relay node successfully retransmits the frame, the destination node informs the successful reception to both nodes. However, if the frame sent by the relay node is also erroneous, the destination sends a NAK. In this case, since the channel between the relay node and the destination node may still remain in the fading state, it is better that the source node retransmits the frame. So, in the *Coop-ARQ* protocol, this retransmitting procedure is initiated by the source node. Accordingly, the retransmitting scheme mentioned above is carried out repeatedly until the successful reception of the frame to the destination. For the sake of simplicity in the protocol operation, the relay node abandons the frame after the cooperation takes place.

III. Markov Chain for ARQ protocols

In this section a Markov chain for the *Coop-ARQ* protocol is developed. Before the development of the Markov chain, the following common assumptions for the *Coop-ARQ* protocol are made.

- The arrivals of frames to the source node follow the Poisson process.
- There is a buffer in the source node which accommodates arriving frames.
- The source node starts to transmit a frame only at the beginning of a slot.
- The time duration of transmitting a frame and receiving an ACK or a NAK of that frame is within one slot. So, the source and relay node know the success or failure of the frame transmission at the end of the slot where the frame transmission is performed.
- There is no limit in the number of retransmission trials.
- The time slots of all nodes in the network are synchronized.
- During a slot, the channel state is assumed to be invariant. So, the success of a frame transmission only depends on the channel state of the slot boundary where the transmission starts.
- ACK and NAK frames from the destination node are decoded correctly by the source and relay nodes.

The following parameters are also used to develope the Markov chain for the *Coop-ARQ* protocol.

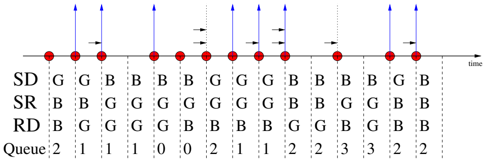

Fig. 2. The operation of the Coop-ARQ protocol. Circle marks on the time axis denote embedded points of the Markov chain. An upward vertical arrow means a departure of frame at that time instant and a right horizontal arrow means an arrival to the source node. Queue denotes the queue length at the source node.

- T_s: time duration of a slot.
- λ: arrival rate of frames per second.
- α_m: the probability of arriving m frames during one slot.
- β_m: the probability of arriving m frames during two slots.

Since we assume that the frame arrivals follow the Poisson process with rate λ, α_m and β_m are represented by arrival rate λ and slot duration T_s as follows:

$$\alpha_m = \frac{e^{-\lambda T_s}(\lambda T_s)^m}{m!},$$
$$\beta_m = \frac{e^{-2\lambda T_s}(2\lambda T_s)^m}{m!}.$$

For the analysis, we develop an embedded two dimensional Markov chain consisting of the number of frames in the source node and the channel states between nodes. Embedded epochs of the Markov chain are defined by slot boundaries which satisfy the following conditions:

- The initial time, i.e, $t = 0$, is an embedded epoch of the Markov chain.
- If the source node does not have any frames to transmit in a slot, then the end of the current slot is an embedded epoch of the Markov chain.
- If a frame transmission by the source node is successful in a slot, then the end of the current slot is an embedded epoch of the Markov chain.
- If a frame transmission by the source node fails in a slot, then the end of following slot to the current slot is an embedded epoch of the Markov chain.

Embedded points of the Markov chain are shown in Fig. 2.

Let $q_C(k)$ denote the number of frames in the source node just after k-th embedded epoch and $Ch_C(k)$ be the channel state process of the *Coop-ARQ* protocol at the k-th embedded epoch. Let k^* be the actual time instant of the k-th embedded epoch. Then the states of $Ch_C(k)$ are defined as given in Table I. With this novel definition we can construct a two dimensional Markov chain later. The detailed reason is omitted here due to the space limitation. Let E and F be the transition probability matrices of $Ch_C(k)$ when $q_C(k) = 0$ and $q_C(k) \geq 1$, respectively. Note that the (i, j)-th element of matrix E denotes the transition probability from channel state i to j when there are no frames in the source node and the (i, j)-th element of matrix F denotes the transition probability from channel state i to j when there is at least one frame to transmit in the source node. Then E and F can be represented by elements of matrices $P^{(SD)}, P^{(SR)}, P^{(RD)}$ defined in (1). [2]

TABLE I
STATE DIAGRAM OF $Ch_C(k)$

	$\epsilon_{SR}(k^*)$	$\epsilon_{RD}(k^*)$	$Ch_C(k)$
$\epsilon_{SD}(k^*) = G$	G	G	1
	G	B	2
	B	G	3
	B	B	4
	$\epsilon_{SR}(k^*)$	$\epsilon_{RD}(k^*+1)$	$Ch_C(k)$
$\epsilon_{SD}(k^*) = B$	G	G	5
	G	B	6
	B	G	7
	G	B	8

The two-dimensional stochastic process $\{q_C(k), Ch_C(k)\}$ forms a Markov chain. Transition probabilities of $\{q_C(k), Ch_C(k)\}$ can be obtained as follows:

$$\Pr\{q_C(k+1) = j, Ch_C(k+1) = l | q_C(k) = i, Ch_C(k) = k\} = \begin{cases} \alpha_j E_{k,l}, & \text{if } i = 0, \\ \alpha_{j-i+1} F_{k,l}, & \text{if } i \geq 1, 1 \leq k \leq 4, \text{ and } j \geq i-1, \\ \beta_{j-i+1} F_{k,l}, & \text{if } i \geq 1, k = 5, \text{ and } j \geq i-1, \\ \beta_{j-i} F_{k,l}, & \text{if } i \geq 1, 6 \leq k \leq 8, \text{ and } j \geq i, \\ 0 & \text{otherwise,} \end{cases} \quad (2)$$

where $E_{k,l}$ and $F_{k,l}$ denote the (k, l)-th elements of matrices E and F, respectively. The state transition matrix P^C of the Markov chain $\{q_C(k), Ch_C(k)\}$ can be obtained by (2). It is straightforward to show that P^C follows the transition matrix of an M/G/1 type queue.[3]

Let $\pi^C_{i,j}$ denote the steady state probability that the Markov chain $\{q_C(k), Ch_C(k)\}$ is in state (i, j). Note that $i \geq 0$ and $1 \leq j \leq 8$. Let $\pi^C \triangleq \left(\pi^C_{0,1}, \pi^C_{0,2}, \cdots, \pi^C_{0,8}, \pi^C_{1,1}, \cdots\right)$ be the steady state probability vector for the Markov chain $\{q_C(k), Ch_C(k)\}$. The steady state probability vector π^C can be obtained by the matrix analytic method in [14].

IV. PERFORMANCE ANALYSIS

In this section the analysis of frame latency and service time of the network for the *Coop-ARQ* protocol is presented by using the Markov chain developed in the section III. The definitions of performance metrics that will be derived in this section are as follows:

- T_C: the service time of a frame in the *Coop-ARQ* protocol, i.e, the time duration between the time instant of a *new* frame transmission and the time instant of a successful reception at the destination node of that frame. Here *new* means that the transmission is not a retransmission.
- L_C: the frame latency in the *Coop-ARQ* protocol, i.e, the time duration between the time instant of a frame arrival at the source node and the time instant of a successful

[2]Closed expressions of matrices E and F are omitted due to the space limitation.

[3]The detailed expression of the matrix P^C is omitted due to the space limitation

reception at the destination node of that frame. So, L_C is the actual delay of a frame.

Throughout this section, we assume that the Markov chain $\{q_C(k), Ch_C(k)\}$ is in steady state.

A. *average service time $E[T_C]$ and probability mass function of T_C*

To get the average service time of a frame in the *Coop-ARQ* protocol, the channel state probability at a new frame transmission instant should be derived. Let $\hat{p_j}$ denote the stationary distribution of the channel state (the state of the process $Ch_C(k)$) at a new frame transmission instant in the *Coop-ARQ* protocol for $1 \le j \le 8$. The set of time slots where a new frame transmitted is a subset of the set of embedded epoches of the Markov chain $\{q_C(k), Ch_C(k)\}$. A tagged embedded epoch, say the k-th embedded epoch, is a slot boundary at which a new frame is transmitted if one of the following mutually exclusive conditions are satisfied:

- $\{q_C(k-1), Ch_C(k-1)\} = (0, j)$ for $1 \le j \le 8$ and there are at least one arrival just before the k-th embedded epoch.
- $\{q_C(k-1), Ch_C(k-1)\} = (1, j)$ for $1 \le j \le 5$ and there are at least one arrival just before the k-th embedded epoch.
- $\{q_C(k-1), Ch_C(k-1)\} = (i, j)$ for $i \ge 2$ and $1 \le j \le 5$.

Let M be the probability of the above conditions. The values of $\hat{p_j}$ for $1 \le j \le 8$ can be obtained by conditioning on the above events. The closed form expression of M and $\hat{p_j}$ are given in (3) and (4), respectively. The detailed derivation is omitted due to the space limitation.

Let $\hat{t}$ be an arbitrary embedded point where a new frame transmission begins. The probability generation function $G^{T_C}(z)$ of T_C can be obtained as follows:

$$\begin{aligned}
&G^{T_C}(z) \triangleq E\left[z^{T_C}\right] \\
&= \sum_{j=1}^{8} E\left[z^{T_C} | Ch_C(\hat{t}) = j, q_C(\hat{t}) \ge 1\right] \hat{p_j} \qquad (5) \\
&= \sum_{j=1}^{4} z\hat{p_j} + z^2\hat{p_5} + \sum_{j=6}^{8} E\left[z^{T_C} | Ch_C(\hat{t}) = j, q_C(\hat{t}) \ge 1\right] \hat{p_j}
\end{aligned}$$

The above equation (5) follows from the observation that $1 \le Ch_C(\hat{t}) \le 4$ implies the successful transmission of the new frame by the source node and $Ch_C(\hat{t}) = 5$ implies the successful transmission of the new frame by the relay node. From the fact that $Ch_C(k)$ is a Markov chain, we have

$$\begin{aligned}
&E\left[z^{T_C} | Ch_C(\hat{t}) = j, q_C(\hat{t}) \ge 1\right] \\
&= \sum_{l=1}^{4} z^3 F_{j,l} + z^4 F_{j,5} \qquad (6) \\
&+ \sum_{l=6}^{8} z^2 F_{j,l} E\left[z^{T_C} | Ch_C(\hat{t}+1) = l, q_C(\hat{t}+1) \ge 1\right]
\end{aligned}$$

for $6 \le j \le 8$. Since the Markov chain $\{q_C(k), Ch_C(k)\}$ is in steady state, the following equation holds.

$$\begin{aligned}
&E\left[z^{T_C} | Ch_C(\hat{t}+1) = l, q_C(\hat{t}+1) \ge 1\right] \qquad (7) \\
&= E\left[z^{T_C} | Ch_C(\hat{t}) = l, q_C(\hat{t}) \ge 1\right]
\end{aligned}$$

Combining (5), (6) and (7) gives the probability generating function $G^{T_C}(z)$ for the service time T_C of a frame. The average service time $E[T_C]$ can be obtained as follows:

$$E[T_C] = \left. \frac{d}{dz} G^{T_C}(z) \right|_{z=1}$$

The probability mass function of T_C can be also derived using the probability generating function $G^{T_C}(z)$ as follows:

$$\Pr\{T_C = k\} = \left. \frac{d^k}{dz^k} \frac{G^{T_C}(z)}{k!} \right|_{z=0} \qquad (8)$$

B. *the average frame latency $E[L_C]$*

To get the average frame latency, the probability of having n frames in the source node at an arbitrary slot is analyzed. Then the average frame latency can be obtained by applying Little's theorem. First, we derive the steady state probability that *an arbitrary slot boundary* is in state (i, j). Let $\mu_{i,j}$ be the actual sojourn time in state (i, j). Then we have the following equations:

$$\mu_{i,j} = \begin{cases} 1, & \text{if } i = 0 \\ 1, & \text{if } i \ge 1, 1 \le j \le 4 \\ 2, & \text{if } i \ge 1, 5 \le j \le 8 \end{cases}$$

Let $S_C(k)$ be the sojourn time (in slots) at the k-th embedded points. Then we see that $\{q_C(k), Ch_C(k), S_C(k)\}$ becomes a semi-Markov process. Let $\tilde{\pi}^C_{(i,j)}$ denote the steady state probability that an arbitrary slot boundary is in state (i, j). By Markov renewal theory [15], we have the following equation for $\tilde{\pi}^C_{i,j}$:

$$\tilde{\pi}^C_{(i,j)} = \frac{\pi^C_{(i,j)} \mu_{i,j}}{\sum_{k,l} \pi^C_{k,l} \mu_{k,l}}$$

Note that $\tilde{\pi}^C_{(i,j)}$ is not the probability that i frames are in the source node at an arbitrary slot boundary. There are some chances that the arbitrary slot boundary is not an embedded point of $\{q_C(k), Ch_C(k)\}$. In this case, the number of frames in the source node can be different from the number of frames denoted by the state because there are some new frame arrivals between the last embedded point and the arbitrary slot boundary.

Let $\hat{q}_n$ be the probability that n frames are in the source node at an arbitrary tagged slot boundary. Then $\hat{q}_n$ can be expressed as follows by conditioning on the state of the semi-Markov process at the tagged slot boundary.

$$\hat{q}_n = \sum_{j=1}^{8} \sum_{i=0}^{\infty} \tilde{\pi}^C_{(i,j)} f_n^{(i,j)}, \qquad (9)$$

where $f_n^{(i,j)}$ denotes the conditional probability that n-frames are in the source node at the tagged slot boundary, given

$$M = (1 - e^{-\lambda T_s}) \sum_{k=1}^{8} \pi_{0,k}^C + \left[(1 - e^{-\lambda T_s}) \sum_{k=1}^{4} \pi_{1,k}^C + (1 - e^{-2\lambda T_s}) \pi_{1,5}^C \right] + \sum_{i=2}^{\infty} \sum_{k=1}^{5} \pi_{i,k}^C \quad (3)$$

$$\hat{p_j} = \frac{1}{M} \left[(1 - e^{-\lambda T_s}) \sum_{k=1}^{8} \pi_{0,k}^C E_{k,j} + \left[(1 - e^{-\lambda T_s}) \sum_{k=1}^{4} \pi_{1,k}^C F_{k,j} + (1 - e^{-2\lambda T_s}) \pi_{1,5}^C F_{5,j} \right] + \sum_{i=2}^{\infty} \sum_{k=1}^{5} \pi_{i,k}^C F_{k,j} \right] \quad (4)$$

that the state of the semi-Markov process at the tagged slot boundary is in state (i, j).

For $i = 0$ or $i \geq 1$, $1 \leq j \leq 4$, the tagged slot boundary is an embedded point of the Markov chain $\{q_C(k), Ch_C(k)\}$. Then the number of frames in the source node at the tagged slot boundary is equal to the number of frames denoted by the state. That is,

$$f_n^{(i,j)} = \begin{cases} 1, & \text{if } n = i, \\ 0, & \text{otherwise}, \end{cases} \quad (10)$$

for $i = 0$ or $i \geq 1$, $1 \leq j \leq 4$.

For $i \geq 1$, $5 \leq j \leq 8$, the tagged slot boundary is an embedded point with probability $\frac{1}{2}$. If the tagged slot boundary is an embedded point, then the value of $f_n^{(i,j)}$ is determined by the same way as in (10). On the other hand, when the tagged slot boundary is not an embedded point, the number of frames at the tagged slot boundary is increased by the number of newly arriving frames just before the tagged slot boundary. So, we have the following equation:

For $i \geq 1$, $5 \leq j \leq 8$,

$$f_n^{(i,j)} = \frac{1}{2} I\{n = i\} + \frac{1}{2} I\{n \geq i\} \alpha_{n-i}, \quad (11)$$

where $I\{\cdot\}$ denotes the indicator function. Combining (9), (10) and (11), we can obtain the closed form of $\hat{q}_n$.

Let $E[N_C]$ be the average number of frames in the source node. The value of $E[N_C]$ can be obtained as follows:

$$E[N_C] = \sum_{n=0}^{\infty} n \hat{q}_n \quad (12)$$

The average frame latency of the *Coop-ARQ* protocol $E[L_C]$ can be derived from (12) by using Little's theorem as follows:

$$E[L_C] = \frac{E[N_C]}{\lambda T_s}$$

V. MODEL VALIDATION AND PERFORMANCE RESULTS

To validate our analytical model for the *Coop-ARQ* protocol and compare its performances with those of the *Non-Coop-ARQ* protocol, we simulate a simple *ad-hoc* network as shown in Fig. 1. In the simulation, a slot duration is set to 5 ms. In our model, Pth_{SD}, Pth_{SR} and Pth_{RD} indicate the channel qualities of SD, SR and RD, respectively. In this study, we set $Pth_{SD} = -3(dB)$ and $Pth_{SR} = Pth_{RD} = Pth_{SD} - 10log_{10}(4)(dB)$ which means that the relay node is located at the middle point between the source and destination node. Moreover, the channels of SD, SR and RD are assumed to be independent. For simplicity, we denote the maximum Doppler shift as f_D.

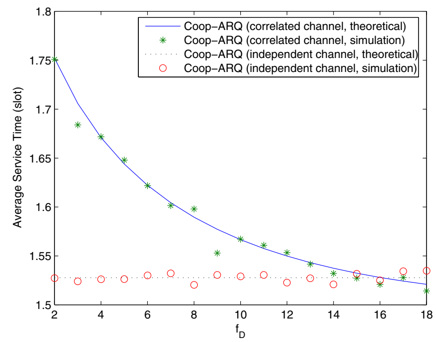

Fig. 3. Service time of the *Coop-ARQ* protocol with correlated channel and the *Coop-ARQ* protocol with independent channel when $\lambda = 30$.

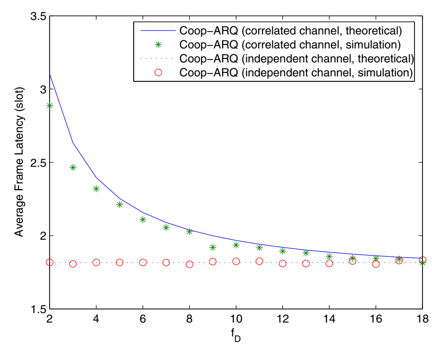

Fig. 4. Frame latency of the *Coop-ARQ* protocol with correlated channel and the *Coop-ARQ* protocol with independent channel when $\lambda = 30$.

We first examine the effect of the correlation in the channel on performance. When $\lambda = 30$ is set, Fig. 3 and Fig. 4 consider the *Coop-ARQ* protocol and plot the changes in the average service time and the average frame latency as f_D increases. In the correlated channel, the average frame latency of the *Coop-ARQ* protocol dramatically increases as f_D decreases. This implies that the more correlated the fading channel is the worse performance the *Coop-ARQ* protocol has. Moreover we see that the performances under the correlated channel converge to those under the independent channel as f_D increases. This is because, as f_D increases, the channel becomes less correlated and eventually independent.

Next, to investigate the effect of the correlation in detail, we plot the service time distribution from (8) in Fig. 5 and it indicates that long service times appear more when $f_D = 2$ than when $f_D = 18$. Note that long service times increase the latencies of other frames. So, we see that a smaller value

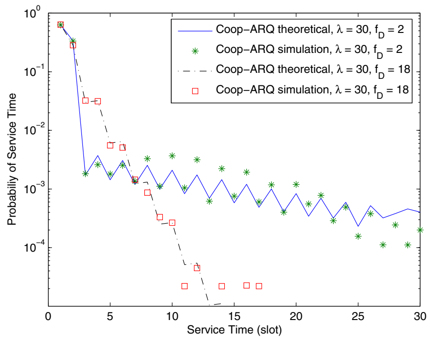

Fig. 5. Service time distribution of the *Coop-ARQ* protocol when $\lambda = 30$.

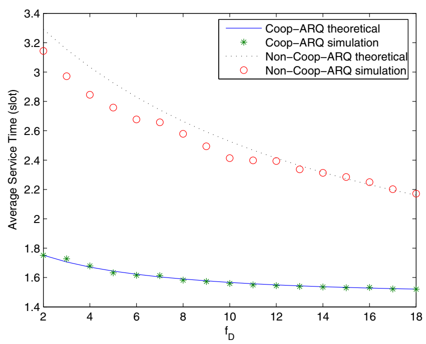

Fig. 6. Service time of the *Coop-ARQ* protocol and the *Non-Coop-ARQ* protocol over f_D when $\lambda = 30$.

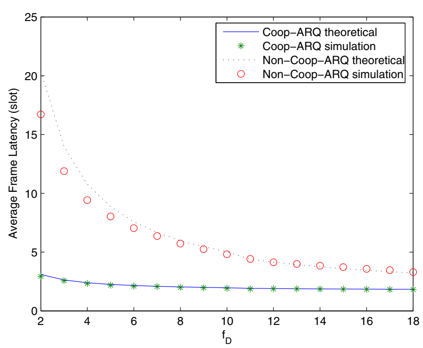

Fig. 7. Frame latency of the *Coop-ARQ* protocol and the *Non-Coop-ARQ* protocol over f_D when $\lambda = 30$.

of f_D results in the higher average frame latency which is in accordance with our previous result.

When $\lambda = 30$ is set, Fig. 6 and Fig. 7 compare the performances of the *Coop-ARQ* protocol and *Non-Coop-ARQ* protocol as f_D varies. As seen in the figures, for all f_D values, the performances of the *Coop-ARQ* protocol are better than those of the *Non-Coop-ARQ* protocol. This means that the *Coop-ARQ* protocol still has benefits under the time correlated fading channel.

VI. Conclusion

In this paper, we develop an analytical model for a cooperative ARQ protocol operating under the time correlated Rayleigh fading channel, which is an extension of [10] and [11]. Based on the model, we obtain the moment generating function of service time and the average frame latency. From the analysis the performances of the *Coop-ARQ* protocol are shown to be superior to those of the *Non-Coop-ARQ* protocol. We also find the effect of time correlation in the fading channel is not negligible, and accordingly should be considered in the system design.

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