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Irregular repetition slotted ALOHA with total transmit power limitation

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Dear editor,

The slotted ALOHA (SA) [1] protocol has been widely used in the multiple access networks, wherein the frame is divided into equal-length slots and all the users start their transmissions at the beginning of a slot. It should be noted that users cannot know whether other users are transmitting their packets or not. Owing to the independent transmission of users, collisions may happen, which can degrade the throughput performance. Therefore, it is necessary to manage the possible collisions rather than discard them [2–4].

In this study, a novel approach is proposed to improve the throughput of the irregular repetition slotted ALOHA (IRSA) protocol [5]. The total transmit power of all the users is considered to be the same, while the transmit power of a replica is determined by the number of replicas. Also, a simple scheme without channel fading is studied, and the channel coefficient is set to 1. It should be noted that if the channel fading coefficients can be obtained, the proposed scheme can also be employed under the fading channel condition.

(1) Intra-slot interference cancellation. Because different users can choose different degrees, the transmit power of each replica of different users can also be different. As a result, a receiver can recover packets by employing the intra-slot interference cancellation algorithm. The receiver first tries to decode the signal having the highest transmit power while treating the other signals as noise. If the signal-to-interference-noise ratio (SINR) is above the predefined threshold, the signal can be recovered successfully, otherwise, the signal is stored. After signal recovering, the receiver finds the next signal with the highest transmit power among the remaining signals. This process is repeated until all the signals are recovered. It is assumed that the proper channel coding is employed and that the user packet can be successfully decoded if the received SINR is above the predefined threshold γ.

(2) Inter-slot interference cancellation. In the inter-slot interference cancellation algorithm, each packet has a header that, contains several pointers, which are used to determine the number and position of other replicas of that packet. Whenever a clean replica is successfully decoded, the pointers are extracted, so the positions of the other replicas can be determined. This process is repeated until all the users' packets are recovered or until no more clean replicas appear.

After receiving a new MAC frame, the receiver uses two interference cancellation algorithms iteratively to recover the user packets. The receiver first finds clean replicas and employs the inter-slot IC algorithm until no clean replicas appear. Then, the intra-slot IC algorithm is employed repeatedly in each slot until no replicas can be recovered.

Decoding probability of intra-slot interference cancellation. In the iterative decoding process, it is considered that there are j unrecovered replicas in a given slot. Let $D(j)$ denote the probability that a given replica can be recovered by the intra-slot IC algorithm and let $D(j,t)$ be the probability that a given replica can be recovered by t step. Then, we have that $D(j)=\sum_{t=1}^{j} D(j,t)$.

Here, we arrange j replicas in order according to the SINR and denote them as $\mathrm{SINR}_1 \geqslant \mathrm{SINR}_2 \geqslant \cdots \geqslant \mathrm{SINR}_j$. The receiver tries to decode the signal having the highest transmit power while treating all the other signals as noise. If the SINR is higher than the given threshold γ, the signal can be recovered successfully; otherwise, signal recovery will be impossible. After signal recovering process, the receiver finds the next signal with the highest transmit power among the remaining signals. This process is repeated until t replicas can be recovered. Thus, the probability of t replicas that can be recovered by the intra-slot IC algorithm is given by

$$P_{j,t} = \Pr\{\mathrm{SINR}_1 \geqslant \gamma\ ,\ldots,\mathrm{SINR}_t \geqslant \gamma\}. \tag{1}$$

Accordingly, the probability that a given replica can be recovered is given by

$$D(j)=\sum_{t=1}^{j} D(j,t)=\sum_{t=1}^{j}\frac{(j-1)!}{(j-t)!}P_{j,t}. \tag{2}$$

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Density evolution analysis. (1) Density evolution for inter-slot interference cancellation. We denote p_i as an average erasure probability of a message sent from a slot node to the user node in the ith decoding iteration, and q_i as an average erasure probability of a message sent from a user node to the slot node in the ith decoding iteration. Then, we have

$$p_i = \sum_{d_s=1}^{M} \omega_{d_s} p_{i,d_s}, \tag{3}$$

and

$$q_i = \sum_{d=1}^{M} \lambda_d q_{i,d}, \tag{4}$$

where p_{i,d_s} and $q_{i,d}$ represent the corresponding probabilities of connecting to a degree-d_s slot node and a degree-d user node, respectively. Thus, we have $p_{i,d_s} = 1 - (1 - q_i)^{d_s-1}$ and

$$p_i = \sum_{d_s=1}^{M} \omega_{d_s} (1 - (1 - q_i)^{d_s-1}). \tag{5}$$

For a degree-d user node, the edge connected to that node can be recovered as long as one of the other $d-1$ edges can be recovered. Thus, we have $q_{i+1,d} = p_i^{d-1}$ and

$$q_{i+1} = \sum_{d=1}^{M} \lambda_d q_{i+1,d} = \sum_{d=1}^{M} \lambda_d p_i^{d-1}. \tag{6}$$

The iterative process starts at $q_0 = 1$, which means all user packets are unknown, and the iterative process ends when $q_{d+1} = q_d$.

(2) Density evolution of intra-slot interference cancellation. In this study, the power diversity is employed to recover user packets, while the limitations of clean replicas for decoding are loosened. When the intra-slot IC algorithm is employed, the density evolution equation should be revised. Based on the decoding probability of the intra-slot IC algorithm, the erasure probability p_i is calculated by

$$\begin{aligned} p_i =& 1 - \sum_{d_s=1}^{M} \omega_{d_s} \sum_{j=1}^{d_s} D(j) \binom{d_s-1}{j-1} {d_s}^{j-1} \\ & \times (1-q_i)^{d_s-j}. \end{aligned} \tag{7}$$

Thus, the density evolution can be obtained by combining (6) and (7). Then, the average erasure probability of a message sent from a user node to the slot node can be rewritten as

$$\begin{aligned} q_{i+1} &= \sum_{d=1}^{M} \lambda_d p_i^{d-1} \\ &= \sum_{d=1}^{M} \lambda_d \Bigg(1 - \sum_{d=1}^{M} \omega_d \sum_{j=1}^{d} D(j) \cdots \\ & \quad \binom{d-1}{j-1} q_i^{j-1} (1-q_i)^{d-j} \Bigg)^{d-1}. \end{aligned} \tag{8}$$

Numerical results. In this study, the numerical results of the proposed IRSA protocol are presented. Figure 1 shows the throughput of different degree distributions at $N = 200$. 'D2', 'D3', 'D4' and 'D5' represent the CRDSA with the degree of 2, 3, 4 and 5, respectively. The IRSA adopts the degree distribution function expressed as $\Lambda(x) = 0.5x^2 + 0.28x^3 + 0.22x^8$. The total transmit power is set to $P_{\text{total}} = 11$ dB, i.e., the optimal degree distribution is expressed as $\Lambda(x) = 0.43x^2 + 0.48x^4 + 0.09x^{10}$.

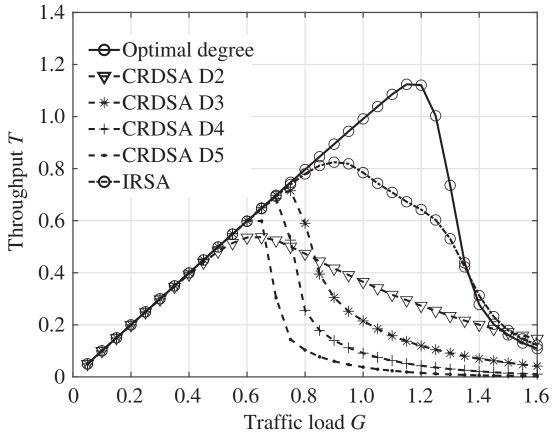

Figure 1 Impact of degree distribution on the throughput.

As can be seen in Figure 1, the performance of the optimized degree distribution outperforms the other degree distributions significantly. The peak throughput of the optimal degree distribution is higher by 36% than that of the conventional degree distribution. The reason why the CRDSA performance is poor is that the transmit power of all users is the same, so the intra-slot IC algorithm could not be applied.

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