

Passive Node-Assisted Wireless Networks Forming Raptor Codes with Random Access

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Abstract—In this paper, wireless networks with passive nodes forming a pre-code of Raptor codes, also known as Raptor code-structured wireless networks (RCS-WN), are considered. In RCS-WN, the passive nodes utilize a decode-and-forward (DF) scheme and send the decoded data to the destination by using a scheduling scheme. We propose to deploy random access (RA) in passive nodes, to achieve a solution referred to as an RA-based RCS-WN (RAR-WN), and attempt to compare it with conventional wireless networks applying irregular repetition slotted ALOHA (IRSA). We investigate regular and irregular degree distributions for repetition codes to test the capacity of the proposed RAR-WN, using the extrinsic information transfer (EXIT) chart. This paper also examines the capabilities of the stopping set (both with regular and irregular degree distribution) in RAR-WN. Performance of the proposed system is evaluated in terms of EXIT chart, packet loss rate (PLR), and throughput. The results show that the proposed system is capable of achieving non-dropped throughput performance.

Keywords—EXIT chart, passive nodes, PLR, random access, Raptor codes, throughput, wireless networks.

1. Introduction

The qualities of 5G cellular communication systems have been determined in the International Telecommunication Union Recommendation (ITU-R), defining the novel approach as an enhanced mobile broadband (eMBB), massive machines-type communication (mMTC), ultra-reliable and low latency communication (URLLC) [1] solution. The development of communication techniques that involve a massive number of users supporting 5G applications mean that random access mechanisms turn out to be essential and crucial for wireless access [2]. Random access techniques are preferred, as conventional scheduling becomes difficult when the number of users connected to a given network is large.

In a random access technique, all users from whom no scheduling is required send data packets randomly, based on probability distribution, through selected time slots [3]. The problem of interference occurs when two or more users send data packets using the same time slot. These data packets, referred to as collided packets, are usually dis-

carded. In coded slotted ALOHA (CSA) [4] and irregular repetition slotted ALOHA (IRSA) [5] approaches, collided packets are resolved and stored for decoding using the successive interference cancellation (SIC) technique to improve the overall performance of the system. Both CSA and IRSA differ in terms of network encoding approaches applied. Maximum distance separable (MDS) codes are used in CSA, while repetition codes are used in IRSA. The SIC process depends on the selected time slots for sending the data packets. Practically, a pointer is used to indicate the position of each data packet in the selected time-slots. In CSA, the time slot with the packets sent in a frame is shown by a pointer. In IRSA, the pointer indicates the time slot in which a replica of the data packet is sent in the frame.

IRSA may asymptotically achieve the normalized throughput of 0.97 packets/slot [p/s] by optimizing the distribution degree of repetition codes. Normalized throughput is the probability of a packet being successfully decoded, multiplied by the traffic offered. In practice, the normalized throughput of IRSA is $T \approx 0.8$ p/s. In CSA, the maximum normalized throughput is $T = 1/e \approx 0.37$ p/s. Therefore, the fact that normalized throughput of IRSA is capable of approaching 1 p/s is very encouraging.

CSA and IRSA are interesting because random transmissions with the SIC process can be represented by bipartite graphs that resemble the codes-on-graph. Further, the authors in [6]–[8] propose the use of coded random access (CRA) in a massive multi-way relay, where repetition codes and MDS codes are exploited. Few literature examples discuss the CRA. In [9], a CRA with human priority is proposed to protect humans from machines, with repetition codes applied along with a set difference assigned to the access to each time slot per priority. On the other hand, the authors in [10] propose high-rate CRA using MDS codes with two priority groups for non-orthogonal multiple access (NOMA). In [11] and [12], the concept of CRA is further improved by applying multi-packet reception (MPR) to achieve higher throughput. The highest throughput is achieved when multi-user detection (MUD) is performed at each time slot. In this paper, no MUD or MPR are performed.

However, one of the unsolved problems in CRA is the dropped throughput performance after reaching a value that exceeds the threshold. A simple approach, known as Raptor code-structured super-dense wireless networks (RC-SWN), is proposed to achieve favorable non-dropped throughput by using passive nodes that function as pre-code Raptor codes [13]. In [14], sub-optimal degree distributions of repetition codes in Raptor code-structured wireless networks (RCS-WN) are proposed to achieve high performance in terms of non-dropped throughput. In RCS-WN, passive nodes decode and forward data to the destination with a scheduling scheme. In this paper, we propose the random access (RA) approach for accessing passive nodes in order to simplify RCS-WN, in connection with both user nodes and passive nodes.

The contributions of this paper are listed as follows:

- RA technique for passive node access in RCS-WN, known as RA-based RCS-WN (RAR-WN) is proposed, to simplify the access of RCS-WN – a solution that is crucial for analyzing the capability of serving more users or of maintaining a lower number of time slots;
- regular and irregular degree distributions for repetition codes in RAR-WN are investigated, which are not discussed in detail in [13]–[15]. Optimization of distribution degrees is important to evaluate the capacity of RAR-WN based on the extrinsic information transfer (EXIT) chart [16];
- six most important stopping sets for both regular and irregular degree distributions in RAR-WN are derived.

The rest of this paper is organized as follows. Section 2 presents structure and graphical representation of RAR-WN. Section 3 presents induced of degree distributions. The examples of the decoding strategy and EXIT chart analysis are presented in Section 4. Section 5 measures the performance of RAR-WN in terms of throughput and packet loss rate (PLR). Finally, Section 6 concludes this paper.

2. Structure and Graphical Representation

Let us consider an RAR-WN serving a massive number of users. Users $U_m = \{u_1, u_2, \dots, u_M\}$ transmit data packets to the destination (denoted as D). Figure 1 shows the structure of wireless networks without and with passive nodes $P_q = \{p_1, p_2, \dots, p_Q\}$ forming a pre-code of Raptor codes, respectively. With this condition taken into consideration, users and passive nodes are served by D in RAR-WN.

Then, RAR-WN is modeled in the manner shown in Fig. 2. The circles represent user nodes (UN), the dark circles represent passive nodes (PN), and the squares represent slot nodes (SN). RAR-WN is denoted as $\text{RAR}(\eta, Q)$, where η represents the number of users connected to each PN and Q

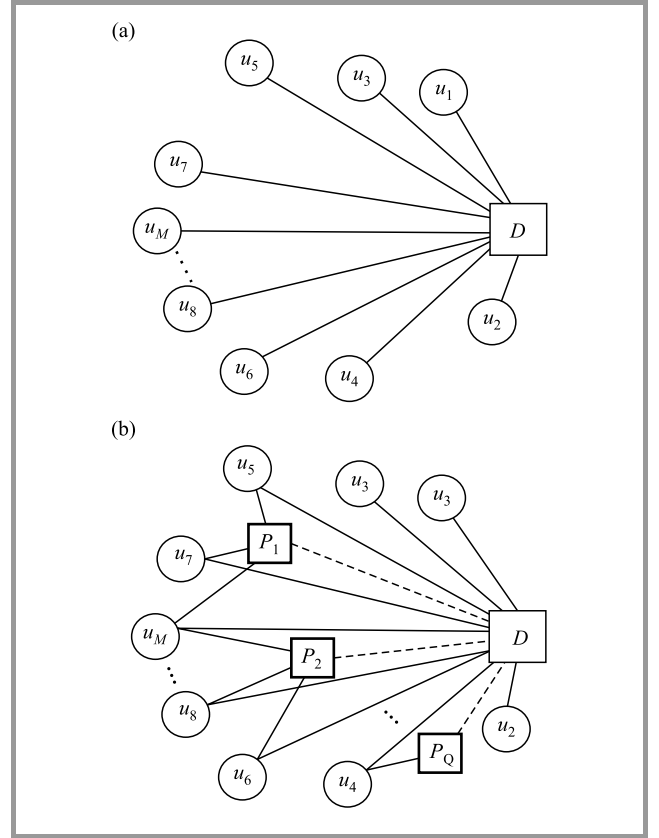


Fig. 1. The structure of wireless networks: (a) wireless networks without passive nodes, (b) wireless networks with passive nodes forming a pre-code of Raptor codes.

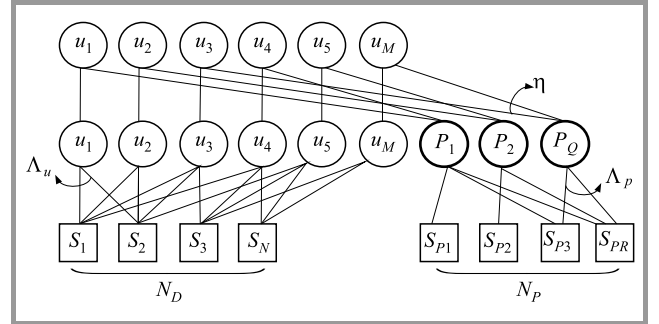


Fig. 2. Graphical representation of RAR-WN.

represents the total number of PN in RAR-WN. Each UN randomly selects a set of time slots s_n , $1 \leq n \leq N$, based on a degree distribution of repetition codes $\Lambda = \{\Lambda_u\}_{u=1}^U$, and transmits data packets via the selected time slots. D and PN receive the transmitted data packets with a different probability of collisions, because only some UNs which are connected to the PN as a pre-code of Raptor code. In PN, the data packets from connected users are decoded and forwarded to destination. The PN randomly transmits decoded data packets to D based on a degree distribution $\Lambda = \{\Lambda_p\}_{p=1}^P$ at selected time slots s_{pr} , $1 \leq r \leq R$. In this paper, we set:

$$\{\Lambda_u\}_{u=1}^U = \{\Lambda_p\}_{p=1}^P = \{\Lambda_h\}_{h=1}^H. \quad (1)$$

Degree distributions of UN and PN are defined in the set of H repetition codes denoted as $\{((n_h, k_h), \Lambda_h)\}_{h=1}^H$ and with the minimum distance of at least 2, where:

- n_h represents the number of output data packets of the h -th set of codes,
- k_h represents the number of input data packets of the h -th set of codes (for repetition codes $k_h = k = 1$),
- Λ_h represents the percentage of users that pick the h -th set of codes, where $\sum_{h=1}^H \Lambda_h = 1$ and $0 \leq \Lambda_h \leq 1$.

An example of degree distribution with $M = 4$ and $N = 4$ is illustrated as shown in Fig. 3. In this example, we assume that the first and second (u_1 and u_2) pick the $(2, 1)$ code, while the third and fourth user (u_3 and u_4) pick the code $(3, 1)$ code.

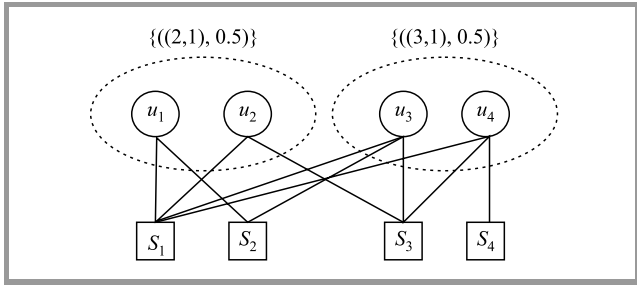


Fig. 3. An example of degree distribution with $M = 4$ and $N = 4$.

All transmissions are slot-synchronized. The channel time is divided into time slots of equal length. Channel gain of the destination, passive nodes and of all users is assumed to be perfectly known at all. Offered traffic G , as seen by each user, is defined as:

$$G = \frac{M}{(N_D + N_P)}. \quad (2)$$

3. Induced Degree Distributions

We define induced degree distributions as new distributions caused by dynamic Rayleigh fading channels, where a faded message below a threshold of P_T cannot be resolved or is considered for erasure. This phenomenon has been carefully investigated in [17] for $P_T = 0.25$, where it is found that in wireless networks, naturally the harmful degrees – degrees of $h = \{0, 1\}$, are unavoidable. However, in this paper, we assume a perfect induced degree distribution, without degrees, of $h = \{0, 1\}$, as in networks aiming to investigate the maximum performance of RAR-WN.

An example of an RAR-WN with eight users $\mathcal{U} = \{u_1, u_2, \dots, u_8\}$ and two PNs $\mathcal{P} = \{P_1, P_2\}$ is shown in Fig. 4a. The structure of RAR-WN may be seen as codes-on-the-graph, resembling the structure of Raptor codes shown in Fig. 4b. In addition, a factor graph is shown in Fig. 4c.

The degree distributions of UN, as shown in Fig. 4b and Fig. 4c, are represented by

$$\Lambda_M = \left\{ \left((1, 1), \frac{1}{8} \right) + \left((2, 1), \frac{6}{8} \right) + \left((3, 1), \frac{1}{8} \right) \right\}. \quad (3)$$

By resembling the structure of Raptor codes in [18], matrices of networks for main users ($\mathcal{G}_M$), first passive node ($\mathcal{G}_{P_1}$), and second passive node ($\mathcal{G}_{P_2}$) are shown as follows:

$$\mathcal{G}_M = \begin{pmatrix} \mathbf{1} & 1 & 1 & 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & \mathbf{1} & 0 \end{pmatrix}, \quad (4)$$

$$\mathcal{G}_{P_1} = \begin{pmatrix} 1 & 1 & \mathbf{1} & 0 & \mathbf{0} & 0 & 1 & 0 \\ 1 & 0 & \mathbf{1} & 0 & \mathbf{1} & 0 & 0 & 0 \\ 0 & 1 & \mathbf{1} & 1 & \mathbf{1} & 1 & 0 & 1 \\ 0 & 0 & \mathbf{0} & 1 & \mathbf{1} & 1 & 1 & 0 \end{pmatrix}, \quad (5)$$

$$\mathcal{G}_{P_2} = \begin{pmatrix} 1 & 1 & 1 & 0 & 0 & \mathbf{0} & 1 & \mathbf{0} \\ 1 & 0 & 1 & 0 & 1 & \mathbf{0} & 0 & \mathbf{0} \\ 0 & 1 & 1 & 1 & 0 & \mathbf{0} & 0 & \mathbf{1} \\ 0 & 0 & 0 & 1 & 1 & \mathbf{0} & 1 & \mathbf{0} \end{pmatrix}. \quad (6)$$

The rows represent time slots $\mathcal{S} = \{T_1, T_2, \dots, T_4\}$, while the columns represent users $\mathcal{U} = \{u_1, u_2, \dots, u_8\}$. A loss message caused by a deep fading is represented with light grey cells in matrices $\mathcal{G}_M$, $\mathcal{G}_{P_1}$, $\mathcal{G}_{P_2}$ and the dashed lines in Fig. 4c. The connectivity of passive nodes is represented by the dark grey cells in matrices $\mathcal{G}_{P_1}$, $\mathcal{G}_{P_2}$, and the solid lines in Fig. 4c.

The number of edges connected to a node is called a node degree. The degree distribution of a user node (UN) from the node-perspective is expressed as:

$$\Lambda(x) = \sum_{h=1}^H \Lambda_h x^h. \quad (7)$$

Furthermore, the degree distribution of user node (UN) from the edge-perspective is expressed as:

$$\lambda(x) = \frac{\Lambda(x)'}{\Lambda(1)'} = \sum_{h=1}^H \lambda_h x^{h-1}, \quad (8)$$

where Λ_h represents the probability of UN having a degree h , and H represents the maximum degree of UN.

The degree distribution of user node (SN) from the node perspective is expressed in the polynomial as:

$$\Omega(x) = \sum_{d=1}^D \Omega_d x^d, \quad (9)$$

where Ω_d represents the probability of UN having a degree d and D represents the maximum degree of SN. However, since the transmission is random (and is out of control of the system designers), the degree distribution of SN in binomial distribution is expressed as:

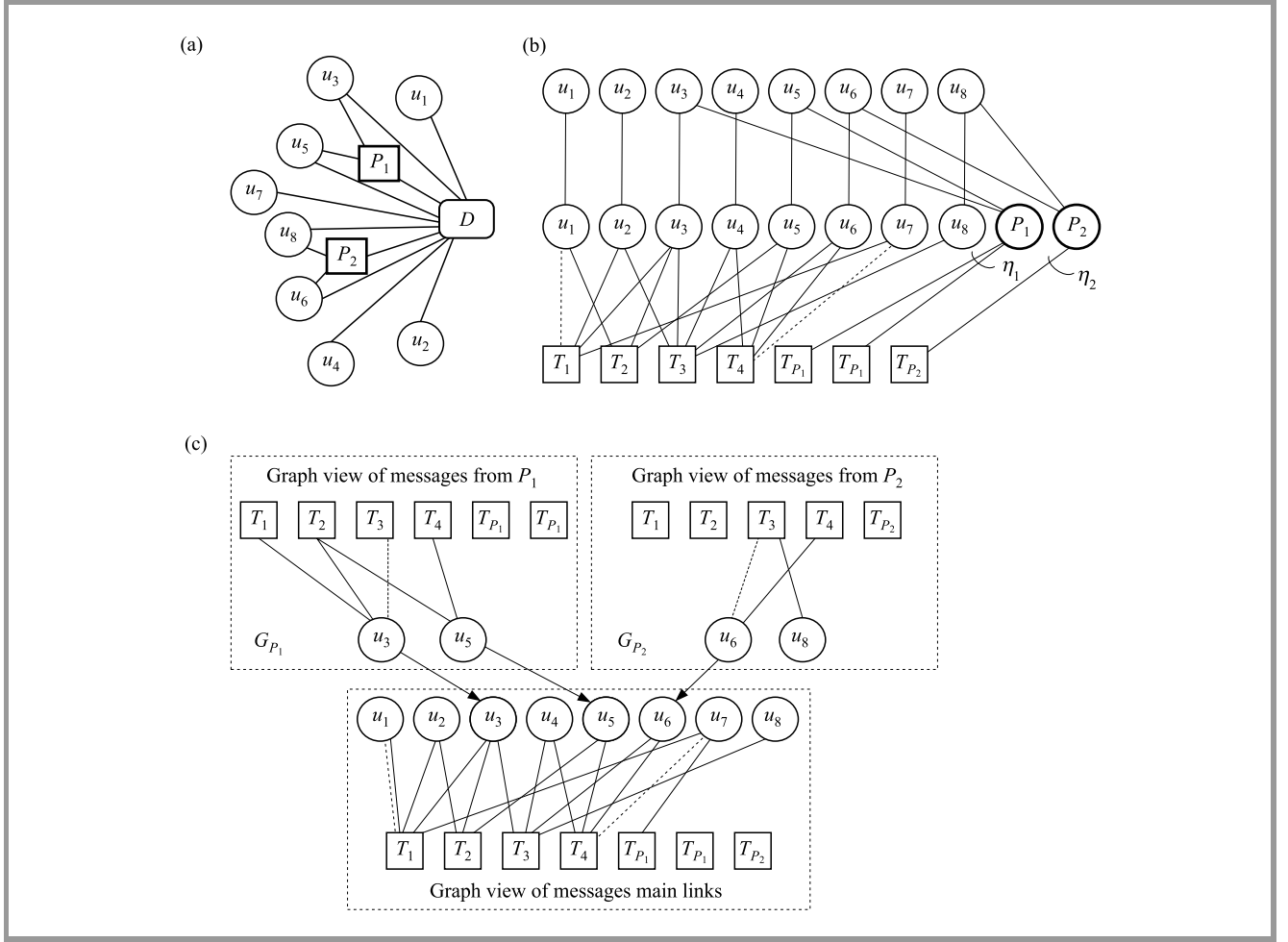


Fig. 4. Example of RAR-WN: (a) networks, (b) model, (c) factor graph.

$$\begin{aligned}\Omega(x) &= \sum_{d=1}^M \Omega_d x^d = \binom{M}{d} \left(\frac{G}{\bar{R}M} \right)^d \left(1 - \frac{G}{\bar{R}M} \right)^{M-d} x^d \\ &= \left(1 - \frac{G}{\bar{R}M} (1-x) \right)^M \approx e^{-\frac{G}{\bar{R}}(1-x)},\end{aligned}\quad (10)$$

where it is assumed that the number of users M becomes very large ($M \rightarrow \infty$) and that G remains constant. $\bar{R}$ represents the average rate of the networks:

$$\bar{R} = \frac{1}{\sum_{h=1}^H \Lambda_h x^h}. \quad (11)$$

4. Decoding Strategy and EXIT Chart

This paper considers the following degree distributions:

$$\Lambda_a = \{((2, 1), 1)\}, \quad (12)$$

$$\Lambda_b = \{((2, 1), 0.5) + ((3, 1), 0.28) + ((8, 1), 0.22)\}, \quad (13)$$

$\Lambda_a(x)$ and $\Lambda_b(x)$ are regular and irregular degree distributions, respectively. From Eq. (11), the network rate of

distribution $\Lambda_a(x)$ is $R_{\Lambda_a(x)} = \frac{1}{\Lambda_a(1)} = \frac{1}{2}$. The network rate of distribution $\Lambda_b(x)$ is $R_{\Lambda_b(x)} = \frac{1}{\Lambda_b(1)} = 0.278$. The highest asymptotic threshold $G^* = 0.932$ packets/slot is achieved even though the practical traffic is $G = 0.83$ packets/slot at PLR of 10^{-1} , which is quite high for a loss rate. The regular degree distribution is expected to be simple in practice.

This paper analyses the property of the degree distributions and their achievable offered traffic G using the EXIT chart. The probability of an edge coming out from SN is defined as p . The probability of an edge coming out from UN is defined as q . Since the number of passive nodes is denoted as Q and $(Q+1)$ graphs are involved, then internal and external erasure probabilities are defined as p^{int}, q^{int} , and p^{ext}, q^{ext} .

We consider the repetition codes as a type of practical coding schemes.

4.1. $(n_h, 1)$ Repetition Codes

A repetition code is the simplest coding scheme that is as simple as its analysis. For RAR-WN, the internal erasure probability is:

$$q^{int} = \frac{1}{\bar{n}} \sum_{h=2}^H \Lambda_h (p^{int})^{h-1} p^{ext} = \sum_{h=2}^H \lambda_h (p^{int})^{h-1} p^{ext}, \quad (14)$$

meaning that it is lower compared to that of wireless networks without PN case, because of the factor of p^{ext} . Here, λ_h is the degree of UNs from the edge perspective [19], [20]. For external q^{ext} , Fig. 4c shows that an additional edge $\mathcal{E}^e$ exists due to the connection of PN and, therefore, the external erasure probability is becoming:

$$q^{ext} = \sum_{h=2}^H \lambda_h (p^{int})^h, \quad (15)$$

which does not exist in the case of conventional wireless networks.

4.2. Decoding Algorithm

The decoding steps of PN and D are shown in Algorithm 1 and Algorithm 2, respectively.

Algorithm 1: Decoding of passive nodes

Data: Connected bipartite graphs $\mathcal{G}_{P_i}$

Result: Messages ηM are decoded.

```

for  $j=1$  until  $Q$  do
  Loop  $\mathcal{G}_{P_j}$  : Consider  $\mathcal{G}_{P_j}$  and find user  $u_i$ 
    connected to a slot node having degree  $d$ ;
  while  $\text{degree } d = 1$  is found do
    Decode message of  $u_i$ ;
    Perform SIC in all slot nodes connected to
    user  $u_i$  at graph  $\mathcal{G}_{P_j}$ ;
    Send message of  $u_i$  via  $s_{P_j}$  and subtract the
    received signals in all slot nodes connected to
    user  $u_i$  at graph  $\mathcal{G}_M$ ;
  end
end

```

Algorithm 2: Decoding of destination

Data: Connected bipartite graphs $\mathcal{G}_M$

Result: Messages M are decoded.

```

Loop  $\mathcal{G}_M$  : Consider  $\mathcal{G}_M$  and find user  $u_i$  connected to
  a slot node having degree  $d$ ;
while  $\text{degree } d = 1$  is found do
  Decode message of  $u_i$ ;
  Subtract the received signals in all slot nodes
  connected to user  $u_i$  with user  $u_i$ 's own message;
end

```

Several nodes failed during the contention period are resolved via passive nodes although the networks are overloaded.

4.3. EXIT Chart Analysis

In this paper, the equivalent parameter is defined for UN, instead of using the mutual information (MI) as used in

EXIT chart analysis. The priori and extrinsic information for the user can be expressed as Eqs. (16) and (17), respectively:

$$I_{\text{User}}^A = 1 - p^{int}, \quad (16)$$

$$I_{\text{User}}^E = 1 - q^{int}. \quad (17)$$

A similar definition is applied for SN as:

$$I_{\text{Slot}}^A = 1 - q^{int}, \quad (18)$$

$$I_{\text{Slot}}^E = 1 - p^{int}, \quad (19)$$

The decoding trajectory is used for two purposes: to confirm the accuracy of EXIT analysis, and to obtain the asymptotic maximum offered traffic G^* , where G^* is defined as the maximum G when EXIT curves of both SN and UN do not intersect each other. The EXIT curves and the corresponding decoding trajectories for distributions $\Lambda_a(x)$ and $\Lambda_b(x)$ are shown in Figs. 5 and 6, respectively.

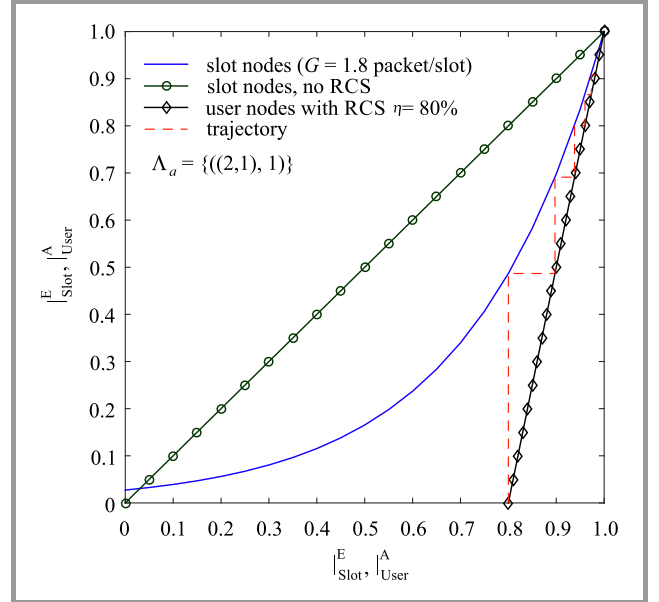


Fig. 5. EXIT projection and decoding trajectories for graphs with Λ_a at $G = 1.8$ packets/slot.

The projected EXIT curves of the UN are shown in dash-dotted lines below the EXIT curves of SN. Figure 4 shows an excellent agreement between the trajectory and EXIT curves of both SN and UN. Loss of distribution becomes higher if the gap between the UN and the SN curves is increased. A smaller gap with $\Lambda_a(x)$ is preferable to provide a higher throughput of G , as shown in Fig. 4a. Figure 4b shows a bigger gap with $\Lambda_b(x)$ resulting in smaller traffic $G = 1.8$ p/s. In addition to the indication of using EXIT curves, the trajectories also confirm a tunnel between the EXIT curves. It opens at $G = 1.8$ p/s and $G = 1.8$ p/s for $\Lambda_a(x)$ and $\Lambda_b(x)$, respectively, but the trajectories intersect for G exceeding those values.

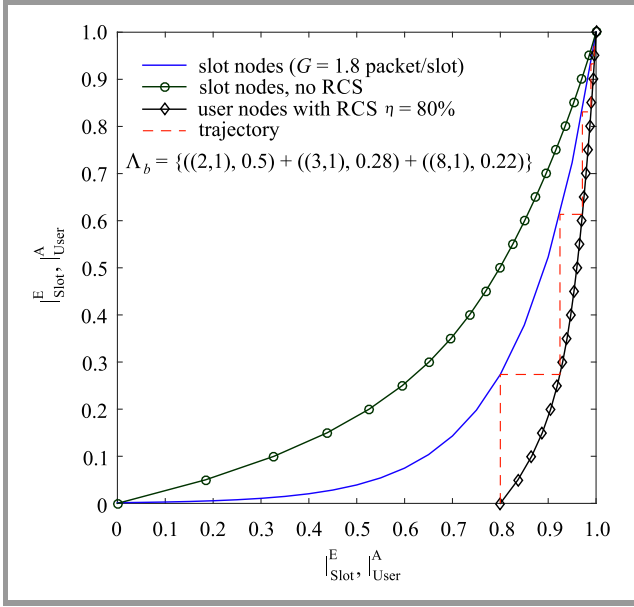


Fig. 6. EXIT projection and decoding trajectories for graphs with Λ_b at $G = 1.8$ packets/slot.

5. Performance Evaluations

This section evaluates PLR and throughput performance using a series of computer simulations with TS length N , having $N \rightarrow \infty$ ¹. The simulations are conducted under block Rayleigh fading channels to exploit the nature of broadcast messages received by destination D and PNs. PLR performance of the decoding scheme is evaluated based on a simulation.

5.1. PLR and Stopping Sets

A series of computer simulations with $N = 1000$ time slots was performed to evaluate practical PLR performance. The results are plotted in Fig. 7 for degree distributions $\Lambda_a(x)$ and $\Lambda_b(x)$. The figure shows that PLR of RAR-WN is always worse at $G < 1$, but is better at $G > 1$. The $\Lambda_a(x)$ has a faster waterfall (closer to the theoretical limit) than $\Lambda_b(x)$. Figure 7 shows PLR performance under dynamic block Rayleigh fading channels. It is found that regular degree distribution provides better PLR than irregular degree distribution, as indicated by RAR-WN Λ_a and RAR-WN Λ_b .

Among the possible stopping sets, we proved that not all stopping sets have a significant contribution to the error floor. In Table 1 six most significant stopping sets, based on their occurrence probability, for various frames N are shown, where $P_o(\cdot)$ is the occurrence probability of its argument in one graph [21]. These stopping sets limit PLR performance of RAR-WN which should be significantly reduced by the use of PNs. It is important to note that the stopping sets in RAR-WN occur only if PNs are experiencing the same stopping sets expressed by the factor $\mathcal{X}(\cdot)$ as shown in Table 1.

¹As a consequence of $M \rightarrow \infty$ and G constant is that $N \rightarrow \infty$.

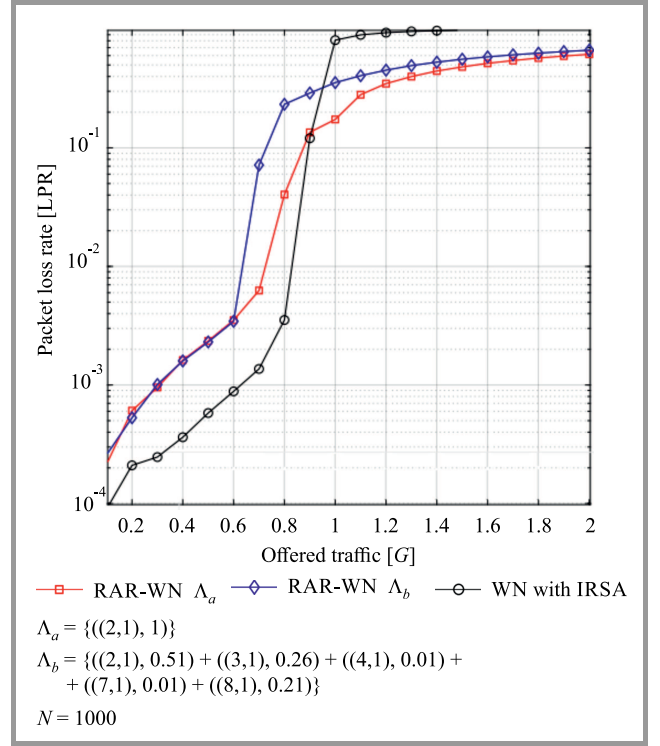


Fig. 7. PLR performances for RAR-WN (10%, 8).

Table 1
Six most important stopping sets

Set	Graph	$P_o(\cdot)$	$\mathcal{X}(\cdot)$
$\mathcal{S}_1$		$\frac{M!}{(M-2)!} \frac{\Lambda_2^2}{2!} \frac{2}{(N-1)N}$	$\binom{M}{2} \Lambda_2^2$
$\mathcal{S}_2$		$\frac{M!}{(M-3)!} \frac{\Lambda_3^3}{3!} \frac{8(N-2)}{(N-1)^2 N^2}$	$\binom{M}{3} \Lambda_2^3$
$\mathcal{S}_3$		$\frac{M!}{(M-4)!} \frac{\Lambda_4^4}{4!} \frac{288(N-3)(N-2)}{3(N-1)^3 N^3}$	$\binom{M}{4} \Lambda_2^4$
$\mathcal{S}_4$		$\frac{M!}{(M-3)!} \frac{\Lambda_2^2 \Lambda_3}{2!} \frac{24}{(N-1)^2 N^2}$	$\binom{M}{3} \frac{\Lambda_2^2 \Lambda_3}{2}$
$\mathcal{S}_5$		$\frac{M!}{(M-3)!} \frac{\Lambda_2 \Lambda_3^2}{2!} \frac{36(N-3)}{(N-2)(N-1)^2 N^2}$	$\binom{M}{3} \frac{\Lambda_2 \Lambda_3^2}{2}$
$\mathcal{S}_6$		$\frac{M!}{(M-4)!} \frac{\Lambda_2^3 \Lambda_3}{3!} \frac{288(N-3)}{(N-1)^3 N^3}$	$\binom{M}{4} \frac{\Lambda_2^3 \Lambda_3}{6}$

The occurrence probability of stopping sets for conventional networks is:

$$\dot{p}(\mathcal{S}_i) = P_o(\mathcal{S}_i), \quad (20)$$

$i \in \{1, 2, \dots, 8\}$, while for RAR-WN:

$$\ddot{p}(\mathcal{S}_i) = P_o(\mathcal{S}_i)^2 \cdot \frac{1}{\mathcal{X}(\mathcal{S}_i)}, \quad (21)$$

$i \in \{1, 2, \dots, 8\}$, where the terms $\frac{1}{\mathcal{X}(\mathcal{S}_i)}$ expresses the probability that both graphs experience the same stopping sets with $\mathcal{X}(\mathcal{S}_i)$ is obtained from the following multinomial probability:

$$\mathcal{X}(\mathcal{S}_i) = \binom{M}{v(\mathcal{S}_i)} v(\mathcal{S}_i)! \prod_{h=1}^H \frac{\Lambda_h^{v_h(\mathcal{S}_i)}}{v_h(\mathcal{S}_i)!}. \quad (22)$$

However, with regular distribution, $\mathcal{X}(\mathcal{S}_i)$ may be simplified into $\mathcal{X}(\mathcal{S}_i) = \binom{M}{v(\mathcal{S}_i)}$. PLR for conventional networks may be approximated by:

$$\dot{P}_L \approx \frac{\dot{\rho} \{2(\mathcal{S}_1)+3(\mathcal{S}_2)+4(\mathcal{S}_3)+2(\mathcal{S}_4)+(\mathcal{S}_5)+3(\mathcal{S}_6)\}}{M\Lambda_2} + \frac{\dot{\rho} \{(\mathcal{S}_4)+2(\mathcal{S}_5)+(\mathcal{S}_6)\}}{M\Lambda_3}. \quad (23)$$

Similarly, PLR for RAR-WN may be approximated by:

$$\dot{P}_L \approx \frac{\dot{\rho} \{2(\mathcal{S}_1)+3(\mathcal{S}_2)+4(\mathcal{S}_3)+2(\mathcal{S}_4)+(\mathcal{S}_5)+3(\mathcal{S}_6)\}}{M\Lambda_2} + \frac{\dot{\rho} \{(\mathcal{S}_4)+2(\mathcal{S}_5)+(\mathcal{S}_6)\}}{M\Lambda_3}, \quad (24)$$

which is definitely lower than $\dot{P}_L$ of conventional networks due to the terms $\mathcal{X}(\mathcal{S}_i)$ in Eq. (21).

The results of simulations is plotted in Fig. 7. It indicates that the stopping sets shown in Table 1 is good enough to predict the error-floor of the networks, while the traffic G indicated by the waterfall curve can be predicted using EXIT chart as the upper bound, since EXIT chart analysis assume that the frame-length N is very large.

5.2. Throughput Analysis

The considered throughput of the networks is shown in Fig. 8. Surprisingly, throughput performance of RAR-WN

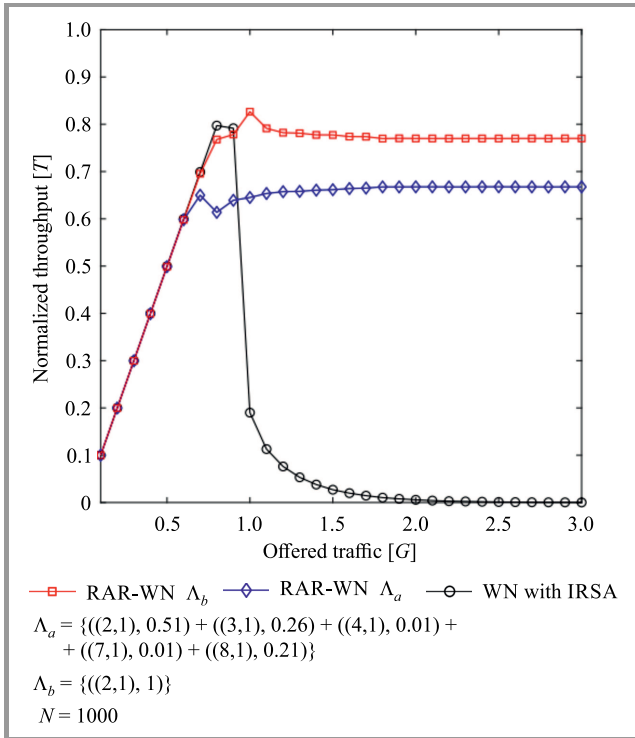


Fig. 8. Throughput performances for RAR(10%, 8).

is more stable, although the offered traffic is beyond 1 p/s. IRSA may improve throughput with the help of passive nodes in the Raptor code-structured parameter with RAR (10%, 8). RAR-WN with regular degree distribution has better throughput than RAR-WN with irregular degree distribution.

6. Conclusions

In this paper, random access-based passive nodes with regular and irregular degree distributions are developed in RAR-WN. The results show that the destination is capable of decoding more information from users by using RAR-WN. It is proved with the cross-line between SN and UN lines at I_{slot}^A and I_{user}^E close to one. Regular degree is outperform irregular degree distribution close to PLR when traffic is overloaded. RAR-WN maintains achievable throughput when wireless networks are overloaded.

Acknowledgments

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