

# Performance Analysis of Slotted ALOHA Systems with Energy Harvesting Nodes and Retry Limit Using DTMC Model

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**Abstract**—We analyze performance of slotted ALOHA systems with energy harvesting nodes and retry limit. We assume that the capacities of data and energy buffer at a node are one packet and  $E$  packets, respectively, and that one data packet transmission consumes one energy packet. The data and the energy packet arrival processes are modeled by independent Bernoulli processes. Under these assumptions, we develop a node-centric two-dimensional discrete time Markov chain model. Based on the equilibrium point analysis, we derive the fixed point equation with respect to the ratio of nodes transmitting a data packet. The accuracy of numerical results derived from the fixed point equation is verified by computer simulation. The numerical results indicate that throughput, the offered traffic and the discard probability roughly depend on the minimum of the data packet generation probability and the energy packet generation probability.

## I. INTRODUCTION

**E**NERGY harvesting techniques have been attracting researchers' interest in minimization of nodes by removing batteries. For example, in Wireless Sensor Networks (WSNs), a huge number of such battery-less tiny nodes may be dispersed in a wide area. Each node may harvest their energy from environment. When a huge number of nodes with bursty traffic contend with one another for a common communication channel such as WSNs, a Medium Access Control (MAC) protocol plays an important role which can greatly influence performance of networks with or without the use of energy harvesting techniques [1].

Performance of MAC protocols with energy harvesting nodes has been extensively investigated in the literature. Moradian and Ashtiani [2] analyzed the maximum stable throughput of slotted ALOHA systems consisting of finite number of energy harvesting nodes. They constructed a node-centric two-dimensional Discrete-Time Markov Chain (DTMC) model with  $(j, x)$ , where  $j$  is the number of energy packets in the energy buffer and  $x$  is the elapsed time for the next retransmission. Foss et al. [3] discussed stability conditions of slotted ALOHA systems with infinite population of energy

harvesting nodes from the system-centric viewpoint of a queuing network. The system is described by a two-tuple  $(q, v)$ , where  $q$  and  $v$  are the total number of data and energy packets in the system, respectively. Bae [4] analyzed the delivery ratio of slotted ALOHA systems with energy harvesting nodes under delay constraints. A node-centric two-dimensional DTMC model  $(W, E)$  was constructed, where  $W$  is the elapsed sojourn time of the leading data packet in the data buffer and  $E$  is the number of energy packets in the energy buffer. Notice here that no retry limit of unsuccessful data packet is considered in the above literature [2], [3].

In this paper, we analyze performance of slotted ALOHA systems consisting of energy harvesting nodes with retry limit [5] using a node-centric two-dimensional DTMC model. Then, the performance is analyzed in terms of throughput, average transmission delay and discard probability of data packet due to excessive retransmission trials.

## II. SYSTEM MODEL

Consider a slotted ALOHA system consisting of  $N$  energy harvesting nodes contending for a common channel. Each node is equipped with not only a single data packet buffer but also an energy packet buffer of  $E$ -packet capacity. From the single-buffered assumption each node can store only one data packet. The length of data packet to be transmitted is assumed to be fixed to the unit length. The time axis is divided into slots which suffices for a single data packet transmission. The propagation delay between nodes and the common receiver is negligible. A data packet arrives independently at each node with probability  $\lambda$  in a slot. A node harvests an energy packet with probability  $\epsilon$  in a slot. A node can transmit a data packet with probability  $p$ , if its energy buffer is not empty. One energy packet is consumed when a node transmits a data packet. We consider neither capture effects nor channel noise, so that a data packet transmission succeeds, only if no other data packets are transmitted simultaneously. All data packets involved in collision are to be retransmitted, until the number of retransmission trials including the first transmission reaches to the retry limit  $L$ . As an example, a system model with two energy harvesting nodes is depicted in Fig. 1.

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## **Table of Contents Aloha Systems Instructions**

1. Understanding the eBook Aloha Systems Instructions
  - The Rise of Digital Reading Aloha Systems Instructions
  - Advantages of eBooks Over Traditional Books
2. Identifying Aloha Systems Instructions
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Aloha Systems Instructions
  - User-Friendly Interface
4. Exploring eBook Recommendations from Aloha Systems Instructions
  - Personalized Recommendations
  - Aloha Systems Instructions User Reviews and Ratings
  - Aloha Systems Instructions and Bestseller Lists
5. Accessing Aloha Systems Instructions Free and Paid eBooks

- Aloha Systems Instructions Public Domain eBooks
  - Aloha Systems Instructions eBook Subscription Services
  - Aloha Systems Instructions Budget-Friendly Options
6. Navigating Aloha Systems Instructions eBook Formats
    - ePub, PDF, MOBI, and More
    - Aloha Systems Instructions Compatibility with Devices
    - Aloha Systems Instructions Enhanced eBook Features
  7. Enhancing Your Reading Experience
    - Adjustable Fonts and Text Sizes of Aloha Systems Instructions
    - Highlighting and Note-Taking Aloha Systems Instructions
    - Interactive Elements Aloha Systems Instructions
  8. Staying Engaged with Aloha Systems Instructions
    - Joining Online Reading Communities
    - Participating in Virtual Book Clubs
    - Following Authors and Publishers Aloha Systems Instructions
  9. Balancing eBooks and Physical Books Aloha Systems Instructions
    - Benefits of a Digital Library
    - Creating a Diverse Reading Collection Aloha Systems Instructions
  10. Overcoming Reading Challenges
    - Dealing with Digital Eye Strain
    - Minimizing Distractions
    - Managing Screen Time
  11. Cultivating a Reading Routine Aloha Systems Instructions
    - Setting Reading Goals Aloha Systems Instructions
    - Carving Out Dedicated Reading Time
  12. Sourcing Reliable Information of Aloha Systems Instructions
    - Fact-Checking eBook Content of Aloha Systems Instructions
    - Distinguishing Credible Sources
  13. Promoting Lifelong Learning
    - Utilizing eBooks for Skill Development

- Exploring Educational eBooks
- 14. Embracing eBook Trends
  - Integration of Multimedia Elements
  - Interactive and Gamified eBooks

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