# Energy Dissipation Balance Scheme in Dynamic Ad Hoc Networks

**Yuheng Fang, Jianyi Shi, Zhuo Sun, Song Kong and Sese Wang**

**Abstract** In order to balance energy allocation to extend the lifetime of dynamic ad hoc networks, the Relay Node Backup Power Control (RNBPC) scheme is proposed using Markov decision process. Through theoretical proof and simulations, an expected energy-balanced network can be achieved by collecting information of transmission probability of every node in the network and predict the future transmission situation in preprocess period. During preprocess period, we initialize the network by the combination of two proved schemes. Once we find the nodes which have heavy communication task, evaluated by the transmission probability, then the scheme searches the feasible backup relay node to share the communication task to avoid energy running out too quickly. Simulation results show that the RNBPC scheme can relieve traffic nodes and then balance the energy dissipation of every node as well to extend the lifetime of the whole network.

## 1 Introduction

Recent years, mobile ad hoc networks (MANETs) have become the major short-distance wireless networks, especially when the Internet of Things has been emerging. Most of the sensors and communication ends in MANETs have power dissipation

Y. Fang (✉) · J. Shi · Z. Sun · S. Kong · S. Wang
Key Laboratory of Universal Wireless Communications,
Beijing University of Posts and Telecommunications, Beijing, China
e-mail: yhfang@bupt.edu.cn

J. Shi
e-mail: Shijianyi@bupt.edu.cn

Z. Sun
e-mail: zhuosun@bupt.edu.cn

S. Kong
e-mail: kongsong@bupt.edu.cn

S. Wang
e-mail: buptyt@bupt.edu.cn



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sensing due to the lack of sustainable and stable energy supply, for the reason of that battery cannot be recharged once the network starts working. Therefore, power consumption control and energy saving schemes are very important for MANETs to improve network stability and prolong the lifetime of whole communication system.

Traditional power control schemes have been proposed to reduce the interference and energy consumption in MANETs. Many adaptive power control schemes have been proposed, mainly including the centralized and distributed methods. Centralized optimizations require a centralized controller, which assists to collect the information of all the rest of the nodes and adjusts the transmission power for each of them. But the obvious defect is the extra power which would be wasted when the centralized controller is collecting the information and this will also result in network latency.

Many research works put the efforts on distributed power control schemes. In Ref. [1], a distributed power control algorithm, DTRNG, was put forward based on the Relative Neighborhood Graph (RNG) [2]. The DTRNG aims to minimize the total transmission power while maintaining the connectivity of the network. The DTRNG first searches the neighbor nodes and determines the minimal transmission power by reducing the power gradually for every node. Then the DTRNG algorithm removes the largest edge of each triangle of RNG to reduce the transmission power and keep the network connected. Furthermore, the DTRNG is developed to be the DTCYC algorithm, which removes the largest edge of each circle when the DTRNG work has done. Therefore, the DTCYC is more efficient in saving energy and can thus prolong the lifetime of the network.

However, the DTCYC algorithm only focuses on the total transmission power and has not taken the influence of dynamic communication environment into consideration. Therefore, the DTCYC algorithm is not suitable when delay-sensitive applications need to be transmitted across the multi-hop wireless networks. An autonomic and distributed joint routing and power control scheme was proposed in Ref. [3], which enables the nodes to autonomously determine their routing and transmission power to maximize the network utility in a dynamic environment. In this method, the problem was formulated as a Markov decision process. According to the state transition probability, a distributed scheme, which can find the optimal policy through reinforcement learning when the dynamics are unknown, is presented for only a restricted braid topology.

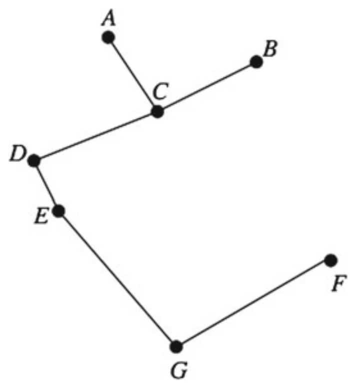
Energy consumption is an important performance metric for wireless sensor networks, and in many cases wireless transmission is the major factor, which largely depends on the distance between transceivers. In Ref. [4], a precise model based on probabilistic distance distributions using the geometric properties of grid-based clustering is presented. An optimal power control scheme for mobile ad hoc networks, which optimizes the hop count according to the distance between the source and the destination nodes for improving the network's capacity, is proposed in Ref. [5]. Considering that the total length of the path segments is usually much larger than the Euclidean distance between the source–destination pair in the multi-hop routing methods, which results in more total power consumption of the involved mobile nodes. In Ref. [6], an adaptive and distance-driven power control (ADPC) scheme, which determines the optimal number of relay nodes and the best position of these relay nodes, is proposed. The ADPC algorithm first computes the optimal number and the sites of relay nodes between the source and the destination nodes. Then the ADPC scheme searches feasible relay nodes around the optimal virtual relay-sites and selects one link with the minimal total transmission energy consumption for data transmission. The ADPC scheme can both save energy and reduce the end-to-end latency of the transmission.

## 2 Problem Formulation

In DTCYC algorithm, we can achieve the minimal total power consumption in mobile ad hoc networks. However, this algorithm does not take the realistic communication situation into consideration. Given that if Node A communicates to Node F most frequently in Fig. 1, according to DTCYC algorithm, we only have the communication route: ACDEGF. Obviously, this link is not the best route to transmit data packets from Node A to Node F, when comparing to the link: ACF, on the efficient of saving energy. Another problem is that if the total probability of Node A transmits data to Node F and Node B communicates to Node G is over 50 % or more higher, Node C would be the most frequent relay node in communication and thus the power consumption of Node C would be the highest, so its lifetime would be the shortest. And once one relay node dies, the whole system would have a disaster in further communication.

In Ref. [6], an adaptive and distance-driven power control scheme was proposed by means of distance research in random geometrics. According to the ADPC scheme, the optimal number of relay nodes and the optimal location of each node for data transmission can be obtained when a distance is given. Furthermore, we can choose an optimal communication route between source–destination pair by searching around the optimal location. The search range is a circle with the virtual relay-site

**Fig. 1** Application of DTCYC algorithm



(OVS) as the center and r as the radius. This scheme can help find the optimal communication route. However, the ADPC scheme also encounters the problem that the DTCYC has been facing with, the Node C would also become the most frequent relay node. Therefore, the ADPC also has not taken the case that one or more specific nodes would bear heavy task on forwarding data, which would shorten the node's lifetime, into careful consideration.

Considering that transmission probability in a network usually keeps a distribution over the restricted range, which can be figured out by statistics. In this paper, we introduce a scheme to improve the performance of ADPC scheme using Markov decision process, called Relay Node Backup Power Control (RNBPC) scheme. The simulation results demonstrate that the RNBPC algorithm achieves a more optimal performance in saving total energy in a dynamic environment.

## 3 Relay Node Backup Power Control Scheme

Now the problem to be solved in this paper can be stated as: Given a mobile ad hoc network, assume that the nodes transmission probability can be described as a matrix **P**, then the total power consumption could be optimized using Markov decision process (MDP) based on the DTCYC algorithm and the ADPC scheme.

In this section, we put forward a distributed scheme to balance energy allocation and optimize the total power consumption. We first use DTCYC algorithm to start the communication inside the network and record every node's neighbor nodes. Then we use ADPC scheme to determine the optimal route of source–destination pairs and update the record table of each node. Second, we collect the information of every node's transmission probability during a certain period T and then use the collection to initialize the transmission probability matrix **P**. Finally, we analyze **P** to determine whether some nodes have excessive communication task. If these nodes do exist, we use matrix **P** to pick up a backup node for these nodes to get a relief in communication. Through the Relay Node Backup Power Control (RNBPC) scheme, we achieve an optimal energy consumption balance for nodes in the network, which would greatly extend the lifetime of the network.

### 3.1 *Initialize Transmission Probability Matrix P Using the DTCYC Algorithm and the ADPC Scheme*

In our scheme, initializing the transmission probability matrix **P** correctly is very important. At first, the situation of the network is not known, especially when the network is dynamic. We first choose the DTCYC algorithm to determine and record each node's theoretical minimal transmission power while maintaining the connectivity of the network. However, the DTCYC algorithm does not help us to select an optimal route between source and destination nodes, except the minimal total power consumption. Subsequently, we choose the ADPC scheme to get an optimal route for each node's transmission. After the calculation, the record table for every node should get updated with the optimal route information. Then we run the network according to the records for a certain period T. During this period, we collect the transmission statistics. When T runs out, we use the statistics to initialize the matrix **P**. The above process can be described as Transmission Probability Matrix Initialization (TPMI) algorithm.

According to the DTCYC algorithm, we can adjust transmission power $p_1, p_2, \ldots, p_n$ to minimize total power consumption $\sum_{i=1}^{n} p_i$ while maintaining the connectivity of the network. Then, the ADPC scheme helps us to choose the optimal route in the topology that the DTCYC algorithm has built. According to mathematical proof in Refs. [1] and [6], we achieve a balance between total power consumption and optimal route. Finally, we choose a time threshold T, which should be determined by practical situation, to run the network to collect transmission information. Therefore, the initialization algorithm is convincing in maintaining low power consumption.

### *3.2 Determine Backup Nodes for Traffic Relay Nodes*

Once we get the transmission probability matrix **P**, which can be stated as formulation (1), then we can predict the transmission probability of next period.

$$\mathbf{P} = \begin{bmatrix} \mathrm{p}_{11} & \cdots & \mathrm{p}_{1n} \\ \vdots & \ddots & \vdots \\ \mathrm{p}_{n1} & \cdots & \mathrm{p}_{nn} \end{bmatrix} \tag{1}$$

The variable $p_{ij}$ presents the data forwarding probability between Node i and Node j, where Node i is the transmitter and Node $j$ is the receiver.

Considering the theory of Markov decision process, once we do a matrix multiply, we get $\mathbf{P} \times \mathbf{P}$ or $\mathbf{P}^2$, thus we can achieve the transmission probability of next period. According to the meaning of $\mathbf{P}^2$, we can figure out the transmission probability of Node i in next stage by just adding the probability of $i$th column together. Thus, we can predict the transmission situation of every node in the next period T. We introduce a variable marked as $p_0$, which presents the threshold to determine whether the state of one node is overloaded. If $p_i > p_0$, then we claim that Node i has too much communication task, which would break the balance of the overall energy consumption. Then we search the route table of Node $i$ to find a suitable backup node, which should be much less busy and its communication probability is far under the threshold. If we find one, we use it as a backup for Node $i$ to reallocate the communication task between Node $i$ and this node to achieve a communication power consumption balance. In Fig. 2, for example, we set $p_0$ to 35 % and assume that Node C has heavy communication task, and then we choose Node D as the backup node for Node C

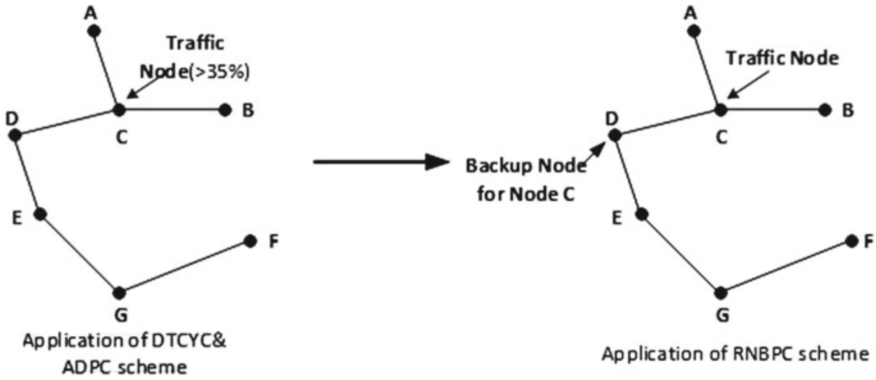



**Fig. 2** Finding backup node for traffic node using RNBPC

which is determined by the transmission probability of next period. At the end of each period, the matrix **P** should be updated to keep the information of every node being real time.

According to Markov decision process, we can achieve the next state transition probability. When the variable T is big enough, the prediction is more precise. Thus we could predict the situation of each node in order to determine whether choose a backup node for the traffic node from its optimal neighbor nodes and then adjust the transmission route.

# 4 Performance Evaluation

In order to evaluate the performance of the proposed RNBPC scheme, we compare it with the ADPC scheme, mentioned before.

We consider a square field with a size of $500 \times 500\,\text{m}^2$, where 150 nodes are randomly deployed. Assume that the amount of data generated by each node per round is 1 KB. In preprocess period, we here set the time threshold T as 1 h and set the baseline of $p_0$ to judge whether a node is traffic as 35 %.

According to Ref. [6], we get the basic simulation parameters and calculation formulations. Thus, we let $E = E_{tx} + E_{rx}$ be the total energy consumption for each node, which is composed of two parts: the receiving cost $E_r x = Q(i)E_{elec}$ and the transmission power $E_{tx} = Q(i)(E_{elec} + \varepsilon d^{\lambda})$. Here, $d$ is the distance between the source and the destination; $\lambda$ represents the path loss exponent ($\lambda \geq 2$); and $Q(i)$ represents the amount of data transmitted/received by a node. According to Ref. [7], $E_{tx}$ can be computed as formulation (2):

$$\mathrm{E_{tx}} = \begin{cases} Q\,(\mathrm{i}) \times \left(\mathrm{E_{elec}} + \varepsilon_{\mathrm{Friis}}\mathrm{d}^2\right) & d \leq \mathrm{d_0} \\ Q\,(\mathrm{i}) \times \left(\mathrm{E_{elec}} + \varepsilon_{\mathrm{two-ray}}\mathrm{d}^4\right) & d \geq \mathrm{d_0} \end{cases} \quad (2)$$

Here, we let the energy consumed per bit in the transceiver electronics be $E_{elec}$ = 50nJ/bit, the coefficients $\varepsilon_{Friis} = 10pJ/(bit{\cdot}m^2)$, $\varepsilon_{two-ray} = 0.0013pJ/(bit{\cdot}m^4)$, and the threshold distance $d_0 = 75$m.

Considering that RNBPC is designing for balancing the overall energy allocation and the power consumption of the entire network, we conduct two simulation experiments to examine the average power consumption and max energy dissipation of certain single node, respectively. Figure 3 shows the average dissipated energy of all the nodes with a varying number of relay nodes. Obviously, the RNBPC curve wastes 4 % more power consumption than the ADPC does.

Figure 4 shows the max energy dissipation of single node. In RNBPC, we achieve 15 % less energy dissipation than the ADPC scheme does, which means we can get a more balanced network through RNBPC scheme. Therefore, the main concept of RNBPC scheme is to sacrifice little power consumption to achieve overall energy allocation balance and thus, to extend the lifetime of whole network.

**Fig. 3** Total energy consumption RNBPC versus ADPC

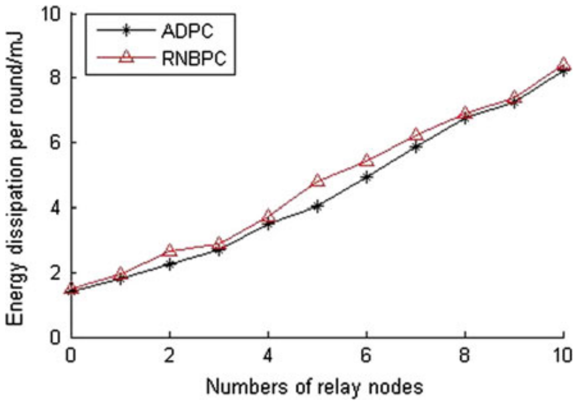
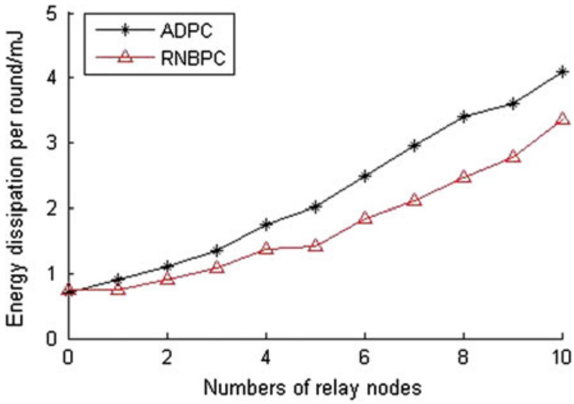



**Fig. 4** Single node's max energy consumption RNBPC versus ADPC



## 5 Conclusion

Aiming at finding optimal energy allocation scheme to extend the lifetime of the whole network and achieving optimal average energy dissipation, we study the problem of transmitting probability of every node while packets are transmitted from the source to the destination. The proposed RNBPC scheme, which is based on the DTCYC algorithm and the ADPC scheme, uses MDP to predict transmission situation in next period and get the optimal energy allocation using backup relay nodes to relieve traffic ones. The simulation results show that we achieve a balance of energy allocation by sacrificing little energy consumption than the minimal dissipation. In future, we plan to study an optimal scheme to decrease the average energy consumption while ensuring the best energy allocation balance.

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