An Electric Power Based Incentive Mechanism for Stimulating Node Cooperation in Mobile Ad Hoc Networks

Yoshihiro Taniguchi¹ᵃ), Taku Yamazaki¹, Takumi Miyoshi¹, and Takuya Asaka²
¹Graduate School of Engineering and Science, Shibaura Institute of Technology
307 Fukasaku, Minuma-ku, Saitama-shi, Saitama 337-8570, Japan
²Faculty of Systems Design, Tokyo Metropolitan University
6-6 Asahigaoka, Hino-shi, Tokyo 191-0065, Japan
a) mg19003@shibaura-it.ac.jp

Abstract: This paper proposes an electric power based incentive mechanism that source nodes compensate the electric power required for packet transmissions in mobile ad hoc network (MANET). Although MANET forces the relay cooperation on nodes for the multi-hop communication, the relay transmission consumes their resources for other nodes, which may cause nodes to be uncooperative. We assume electric power exchange between nodes, which has been getting practical in recent years. The proposed routing method uses incentive power based on the energy consumption for relaying packets as a metric. Computer simulation confirmed that the method implemented to AODV can reduce the power consumption on the relay nodes.

Keywords: MANET, electric power based incentive mechanism, route selection, wireless power transfer technology

Classification: Network system

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1 Introduction

Mobile ad-hoc network (MANET) is realized by multi-hop communication based on the willingness of relay cooperation of every node without any installed infrastructure. In general, MANET can only be adapted to limited environments such as military, disaster, and rescue scenarios. As one of the major reasons, MANET is a resource sharing network in which nodes have to consume their resources and batteries without their own profit. In civilian applications, meanwhile, some nodes may tend to act egotistically since users are not willing to forward packets: they want to save their own resources and batteries. Therefore, it is important to persuade the users to cooperate for realizing MANET communication.

Various incentive mechanisms have been studied to promote effective information sharing. They are categorized into credit- and social-based incentive mechanisms. Buttyán and Hubaux proposed a credit-based incentive mechanism with virtual currency to motivate participants to relay packets [1]. In this mechanism, the source and/or the destination will pay the compensation to relay nodes by virtual currency when asking for a packet forwarding. However, there remain intrinsic security issues in credit-based incentive mechanisms.

Rolla and Curado proposed another credit-based incentive mechanism MooF [2]. To resolve security issues such as a fake payment, they introduce the concept of off-line central trusted authority like a virtual bank that can control virtual currency. However, the method can hardly be applied to emergency scenarios since the central authority requires a server on a fixed network to provide the service.

Uddin et al. proposed a reputation-based incentive mechanism RELICS for delay/disruption tolerant networks (DTNs) [3]. They assume that the main resource that each user cares the most is its battery life. The user is responsible for setting the shared energy rate, which enables to limit the number of packets exchanged. A third node observes and ranks its adjacent nodes based on their contribution to forward packets. The rank decides the priority of message exchange. Therefore, this mechanism can stimulate nodes to cooperate since their delivery ratio can raise by spending more its battery. However, it also has several security issues such as colluding with other nodes.

Social MANET constructs a network by nodes that belong to the same community based on social networking services [4]. This method motivates users to cooperate since only their friends are involved in the communication. However, such a social network is hardly constructed since it requires a sufficient number of nearby nodes.

In the above conventional methods, nodes whose residual batteries are lower than a certain value will be excluded from a route to prevent link failure due to battery exhaustion. Hence, they may select an ineligible route...
due to the use of detoured path.

Wireless power transfer technology, which transfers electric power by wireless medium, has been developed [5]. Assuming that each mobile terminal is equipped with antennas for power transfer in the near future, we propose an electric power based incentive mechanism that compensates the power consumption for packet forwarding by supplying electric power. Since energy cannot be replicated, this mechanism may solve some security issues such as duplication and collusion to increase the monetary value. Moreover, the nodes on the route can avoid the link failure due to the battery exhaustion by supplying electric power. By applying the amount of incentive power calculated based on the power consumption for packet forwarding as a metric, we realize a routing method reflecting user’s willingness. The route constructed by the proposed method will be more reliable since it consists of the cooperative nodes only.

2 Electric power based incentive mechanism

In this paper, we propose an incentive mechanism which compensates the energy consumption for packet forwarding by applying wireless power transfer. We also propose a route selection method to minimize the transferred energy.

(a) Incentive model

Fig. 1 shows an overview of the electric power based incentive mechanism in the proposed method. The source provides the incentive power to the intermediate nodes via the wireless power transfer. In the route discovery phase, each intermediate node calculates the required power consumption $P_T^{(i)}$ as a metric based on the information of its own antenna capability and the transmission data size as follows:

$$P_T^{(i)} = \left( P_{TX}^{(i)} + P_{RX}^{(i)} \right) D,$$

where $P_{TX}^{(i)}$ and $P_{RX}^{(i)}$ are power consumption per bit in transferring and receiving packets, respectively, and $D$ is the transmission data size. On the basis of $P_T^{(i)}$, the $i$-th node on the path from the destination to the source recursively calculates the cumulative required incentive power for the data

![Fig. 1. An overview of electric power based incentive mechanism.](image-url)
transmission from the node $i$ to the destination, $P_R^{(i)}$, as

$$P_R^{(i)} = \alpha^{(i)} \beta^{(i)} P_T^{(i)} + \frac{P_R^{(i-1)}}{R_A^{(i,i-1)}},$$

(2)

where $R_A^{(i,i-1)}$ is the attenuation factor for wireless power transfer from $i$ to $i-1$, $\alpha^{(i)}$ is user’s individual willingness ($0 \leq \alpha^{(i)} \leq 2$), and $\beta^{(i)}$ is also the residual battery based willingness ($1 \leq \beta^{(i)} \leq 2$), which is calculated by the residual battery ratio $P_B^{(i)}$ ($0 \leq P_B^{(i)} \leq 1$) plus one. In addition, the incentive power at the destination, $P_R^{(0)}$, is equal to 0 since the destination does not require the incentive power.

(b) Route selection based on incentive energy

The route selection reflecting the relay willingness of nodes is important to improve the communication reliability. Moreover, it is also very important to reduce the amount of incentive energy since the microwave attenuates corresponding to the distance between the nodes and the surrounding environment. This section proposes the method of route selection based on the amount of incentive energy as well as the path length. While the method is described in a general way, it can be implemented to existing reactive routing protocols.

When a data transmission request occurs, the source node $s$ starts the route discovery process by flooding a route request (RREQ). Multiple copies of RREQ will then arrive at the destination node $d$. For each RREQ, $d$ sends back a route reply (RREP) to $s$ along the reverse path where the corresponding RREQ travels. In receiving the RREP, each intermediate node $i$ measures the attenuation rate $R_A^{(i,i-1)}$. To make the model simple, we assume that $R_A^{(i,i-1)} = R_A^{(i-1,i)}$. $i$ then calculates and adds its incentive power $P_R^{(i)}$ to the total amount of incentive power field in RREP. $s$ stores the route candidates from the RREPs and, after the timer expiration, selects the route that satisfies both the smallest hop count and the minimum transferred energy $P_R^{(next)}/R_A^{(s,next)}$. Fig. 2 shows an example of the route construction from the candidates. Thus, the proposed method can motivate nodes to contribute with relaying data packets and avoid link failures due to battery exhaustion since the source node supplies consumed power to the relay nodes.
even if they have low residual battery.

3 Performance Evaluation

To evaluate the performance of the proposed incentive mechanism, we implemented it to the ad hoc on-demand distance vector (AODV) protocol. We performed simulation experiments with ns-3 [6] and evaluated the performance of AODV, AODV with wireless power transfer (AODV-P), and the proposed method. We implemented the AODV-P, which is a simple extension of AODV; namely, it constructs the same route as AODV but additionally transfers the incentive power to relaying nodes on the path. We also extended the packet headers of RREQ and RREP to add two fields: the data packet size and total amount of the required incentive power. In the simulation, 100 nodes were randomly placed in a 500 m × 500 m area and moved at 1.3 m/s assuming walking. Each node used IEEE 802.11b with 100 m communication range and 2 Mbps data rate. At any time, \( P_{\text{TX}}^{(i)} \) and \( P_{\text{RX}}^{(i)} \) were set to 0.684 \( \mu \)W and 0.558 \( \mu \)W, respectively. Battery capacity of each node was set to 5000 J, and its initial residual energy was randomly set from 50% to 100% of the capacity. A source node, if it has sufficient residual energy, sends a 1024 Byte packet to a destination every one second. The pair of the source and destination was randomly chosen. In this simulation, we assume that \( R_{\text{A}}^{(i,j)} \) can be calculated as \( 1 - d^{(i,j)}/d_{\text{max}} \) where \( d^{(i,j)} \) represents the distance between \( i \) and \( j \), and \( d_{\text{max}} \) is the maximum communication distance, i.e., 100 m.

Fig. 3 (a) shows that the proposed method and AODV-P can reduce the energy consumption of the intermediate nodes since they receive power as the incentive from the source node. Hence, the power transfer incentive can motivate the users to cooperate for forwarding packets.

Next, we performed the simulation to evaluate the network stabilities of three methods. In this simulation, since AODV does not have any incentive mechanism to relay packets, nodes do not cooperate for relaying if the residual energy is less than 50%. In the proposed method and AODV-P, meanwhile, nodes positively relay packets regardless of the residual energy with requesting required incentive power. From Fig. 3 (b), the proposed method and AODV-P achieve that more nodes keep still cooperative than AODV after time passage since the source compensates the energy consumption of relay nodes for packet forwarding. Moreover, the proposed method can reduce the occurrences of route construction errors compared to AODV and AODV-P. This is because it tends to select more stable routes than AODV based on the total amount of required power as well as the path length between the source and the destination.

4 Conclusions

In this paper, we proposed an electric power based incentive mechanism that compensates for the energy consumption for packet forwarding by supplying electric power. As the simulation results, we confirmed that the proposed method can calculate the amount of incentive power and control the power
transfer appropriately by extending the existing routing protocol AODV.

There still remain some issues to be solved. The calculation models are so simple and thus do not precisely reflect actual behavior, such as user’s willingness and wave attenuation. We will try to update these models and also improve the performance of the proposed method.

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