Proactive Route Construction for UAV Delivery considering Distance and Safety using Wireless Multi-hop Network

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Abstract: A method of constructing a route using “Smart meter” radio devices has been studied for the automatic operation of home delivery by small Unmanned Aerial Vehicle (UAV). Each smart meter node was given information about its own densely populated or scattered residential area, the source node should construct a delivery route to the destination node to avoid the densely populated area. In this study, we adopt OLSR-based route construction because the smart meter network is stable. We propose a method using Dijkstra’s method, which uses the distance between nodes and the density of nodes as costs for selecting the optimal route. The effectiveness and characteristics of the proposed method are evaluated by computer simulation.

Keywords: Wireless multi-hop Network, UAV Delivery, OLSR

Classification: Navigation, guidance and control systems

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1 Introduction

Recently, radio devices known as “Smart Next Generation Electricity Meters” have been installed in each home in Japan. These radio devices use an energy-efficient multi-hop radio (920 MHz) network. RPL[1] is used in smart meter networks to transfer electricity usage information.

We considered that the smart meter network could be used for a route navigation service basis using wireless multi-hop network in addition to the electricity usage information transfer. As service examples, we suppose route navigation in the home delivery service by Unmanned Aerial Vehicle (UAV)[2].

RPL is the protocol that forwards information from each node to the concentrator. We need other routing protocols to build communication routes between node nodes. Conventional mobile ad hoc network routing protocols include the reactive AODV[3] and the proactive OLSR[4]. However, conventional routing protocols do not provide optimal routes for UAV home delivery which requires safer and shorter routes.

For safer navigation, it is desirable to avoid high density populated areas in order to avoid damage to people and houses due to UAV possibly crashing. As a result, a two layered network model has been adopted; a network of nodes in a scattered residential area (relay node), which is a safer navigation route (relay network), and an access network of nodes in a densely populated area. An overview of the network topology is presented in Fig.1 (B).

Smart meter network is a stable ad hoc network with no node movement and few deletions and additions of smart meters. Therefore, in this research, we establish a routing method based on the proactive OLSR.

![Network topology for shortest route between nodes](image)

![Network topology for UAV navigation](image)

Fig. 1. UAV navigation network based on multi-hop wireless networks.

2 Related works

2.1 UAV navigation in avoidance from no-fly zone

A new UAV navigation with considering the no-fly zone and efficient selection of the charging station are proposed[5]. It considered only avoidance of no-fly zones for safety, and the architecture is centrally managed by the UAV.
traffic control center, which has problems with scalability in terms of area and number of nodes scale. It is necessary to consider dangerous and safe areas within the area where UAVs can fly, and an autonomous decentralized network approach is needed.

2.2 AODV-based UAV route construction
We established the method constructing UAV route based on AODV, which is a typical example of reactive type[2]. First, all nodes are given information about the area, “scattered residential area” where UAV can move safely, or “densely populated area” where is dangerous. The source node sends a RouteRequest (RREQ) to the destination node in order to create a routing table. The destination node receives the RREQ via multiple routes and sends a RouteReply (RREP) to the route that minimizes the number of hops in the densely populated area[2].

2.3 OLSR
HELLO message serves to advertise its own existence and to exchange information about neighboring nodes, and it sends its own address to neighboring nodes. By sending and receiving multiple messages, it obtains and updates the information of neighboring nodes, which is called local link information.

Topology Control (TC) message serves to advertise topology information to the entire network. It is periodically sent based on local link information.

2.4 Dijkstra method
Dijkstra method[6] is one of the shortest paths finding algorithms, which can determine the route to minimize the cost between specific nodes based on the link cost between nodes.

3 Proposed method
In conventional OLSR, the route is selected based on the number of hops, which is not optimal for home delivery. We propose to use the Dijkstra method to construct a route that consider the distance traveled by the UAV. In addition, we introduce the weight of safety between links to the distance. We propose a route construction method that can establish a safe route with a short travel distance. The basic part of this method, the flow of sending and receiving messages and route generation, is based on the conventional OLSR.

3.1 Information sharing between nodes
We propose method that each node exchanges whether it is in a densely populated area or a scattered residential area, the distance between neighboring nodes by HELLO message. We add the information to the HELLO message header to the sender’s district information corresponding to the neighboring interface address (Fig.2 (A)).
In the TC message, the distance between nodes will be advertised, so that to share distance between nodes corresponding to the TC message sender. The area information and the neighbor main address are also added in TC message header to be advertised (Fig.2 (B)).

3.2 Weighting for link cost

We refer to the conventional method that determines the route based on the number of hops as “OLSR” and the Dijkstra method with distance as the cost (“Dijkstra method”). The proposed method (“Weighted Dijkstra method”) weights the distances based on the safety level between links in the shortest path search of the Dijkstra method. The weighting pattern is changed according to the link states of four moving area: from the densely populated area (A) to the densely populated area (A-A), from the scattered residential area (B) to the densely populated area (B-A), (A-B) and (B-B).

Each method has its own weighting pattern (Fig.2 (C)). Since the Dijkstra method does not consider safety, only the distance traveled is used as the link cost for the shortest path search. In the “Weighted Dijkstra method”, links to densely populated area (A-A, B-A) are weighted by 3.0, and links to scattered residential area (A-B, B-B) are weighted by 0.6. With this weighting, the safest route is given priority.

![Fig. 2. Message headers and weighting of proposed method.](image_url)

4 Evaluation

We compare the distance between source node and destination node (Total distance) by the conventional “OLSR”, “Dijkstra method”, and “Weighted
Dijkstra method”, and the distance over the densely populated area (Densely distance), to see if we can construct a safe and short route. The results were compared with AODV-based methods in previous studies.

4.1 Evaluation methods
In order to experiment with a model close to the real environment, a simulation was created using NS-3. The radio was simulated with wifi802.11b, which can be used with NS-3 instead of 920MHz specific power-saving radio. The communication distance is 120m. The nodes are arranged in 9 cells (3×3), and the densely populated area is placed in the center. The cells outside the center are scattered residential area (Fig. 1). In this paper, we assume a small town with a population of thousands and a cell size of 333m×333m. A cluster consists of approximately 100 houses, with one node per cluster having a relay function. The number of nodes in each cell is randomly arranged with 50 nodes in densely populated area and 20 nodes in scattered residential area, and the source and destination nodes are selected that are sufficiently far apart. Since the experiment assumes a “Smart meter” network, nodes are not moved, added, or deleted. The weighting used is the same as in Table 1. The experiment is repeated 10 times.

As Experiment 1, the source and destination are selected from the scattered residential area nodes so that it is verified whether a route that bypasses the densely populated area can be constructed. As Experiment 2, the source and destination are selected from the nodes in the densely populated area, and it is verified whether a safe route can be selected even if it is long distance.

4.2 Evaluation results
4.2.1 Experiment 1
Fig. 3 (A) show the results of the total distance and the distance over the densely populated area for the three methods. It can be confirmed that the total distance of the “Weighted Dijkstra method” is about 20.3% higher than that of the conventional “OLSR” method. The distance over the densely populated area improved by about 98.3%. As a result of constructing a route that avoided the densely populated area nodes, navigation in the danger zone was significantly reduced, although the total distance increased.

The reason why the improvement rate of the “Weighted Dijkstra method” did not reach 100% is because there were cases in which the total distance increased significantly when the densely populated areas were avoided.

The total distance was 2,070 for the AODV-based method, while the proposed method was able to shorten it to 1,326.8. The densely distance was 10 for the AODV-based method, while the proposed method performed slightly better at 7.4.

4.2.2 Experiment 2
The results of Experiment 2 are shown in Fig. 3 (B). In the “Weighted Dijkstra method”, we were able to construct a route that leaves the densely populated area once and goes through the scattered residential area. As a result, the
Total distance increased, but the distance over the densely populated area improved by about 67%.

Although it is possible to reach the nodes in the densely populated area in a short distance, it is considered dangerous to proceed through the densely populated area by weighting.

The total distance was 511 for the AODV-based method, but 950.4 for the proposed method, which is longer. The densely distance was 224.5 for the AODV-based method and 143.6 for the proposed method, showing good performance.

Fig. 3. Experiment results.

5 Conclusion

We proposed a route construction method that considers the safety and physical distance of UAV. From the experiments, it is confirmed that the safety is improved by calculating the route using Dijkstra method and safety weighting the link cost.

As future issues, we will verify the characteristics of the method by examining differences in size such as large cities and regional cities.

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