Design and Implementation of Self-Expanding System of Unmanned Vehicles Group Based on Signal Strength

Yajie Chen, Zhen Qin, Lei Zhang, Aijing Li and Hai Wang*
College of Communications Engineering, Army Engineering University of PLA, Nanjing, Jiangsu 210007, China.
Email: chenyajie0705@gmail.com, qgzlaz912@163.com, leizhang@163.com, lishan.wh@gmail.com, haiwang@gmail.com

Abstract. Unmanned vehicles are widely used in the military field. They are equipped with a wide variety of sensors so that they can flexibly complete tasks such as enemy surveillance. Presently, unmanned vehicles generally control the movement by an obstacle avoidance system or an ultrasonic ranging system without considering the signal strength, which may cause poor communication. In this paper, we present a model based on signal strength for unmanned vehicles self-expansion to solve the problem. In the experiment, we consider and measure the relationship between signal strength, network bandwidth and packet loss rate, and select the optimal signal strength threshold. By applying this model, the vehicles group can realize the self-expansion and multi-hop communication of the vehicles in the network, which make the vehicles reach the maximum coverage areas and the optimal communication quality.

1. Introduction
In general, military unmanned vehicles are semi-autonomous and unmanned so that they can accomplish military objectives and reduce the need for human presence on the battlefield [1]. Often, channel fading and other factors are able to reduce or completely disrupt the radio communication of groups of vehicles. This is a serious problem for groups of vehicles that are coordinated or manually operated.

Nowadays, the motion control of unmanned vehicle is mostly based on obstacle avoidance systems or ultrasonic ranging systems without considering the signal strength [2]. It may cause a poor communication environment in a multi-hop network. We expect the vehicle to move forward or stop by judging the signal strength.

In this paper, considering the dangers of the battlefield, we proposed a self-expanding model of unmanned vehicle group based on signal strength, which enables the unmanned vehicles group to maximize the communication coverage area without manoeuvring [3][6]. In addition, a wireless multi-hop self-organizing communication network worked in Ad hoc mode is established in the experiment, which enables multi-hop communication. Replacing manual operation with automation of vehicles not only reduces manpower consumption, but also increases communication stability and range of unmanned vehicles.

The rest of this paper is organized as follows. In Section 2, we describe the design of the self-expanding system. In Section 3, we describe the implementation process of the model, and we present its simulation results. Finally, conclusions are given in Section 4.
2. System Design

Considering the practical application, this paper designs a new self-expanding model of unmanned vehicle group and combines with the concept of Mobile Ad Hoc Network (MANET) to measure the performance of a set of wireless networks based on multi-hop transmission. Since the signals of all vehicles are transmitted through the same channel in Ad hoc mode, we cannot directly distinguish the source of the signal so that the unmanned vehicle can self-expand. Therefore, this paper adds a UDP transmission mechanism, so that the unmanned vehicle is able to achieve the point-to-point reading signals. The basic idea of the unmanned Ad hoc network is to achieve multi-hop transmission without unconstrained distance between unmanned vehicles. It satisfies the following formula:

$$\max_{i \leq k} S_i$$

s.t. \( A_i \geq A, 1 \leq i \leq k, \)

where \( S_i \) represents the range of communications, \( k \) represents the number of the vehicle, \( A_i \) represents the signal strength of the vehicle and \( A \) represents the threshold of signal.

The experimental scheme is divided into two parts. The first part is to measure the signal value, bandwidth, packet loss rate and other data between the two vehicles as a criterion for judging whether the vehicle advances or not. The second part uses four vehicles to develop a self-organizing network. The network not only guarantees the quality of communication, but also maximizes the communication range.

2.1 The Judgment Standard of Unmanned Vehicle Motion Threshold

In the experiment, we prepare two vehicles and a display, one of which connects directly to the computer as a server and the other as a client that is shown in the figure 1.

![Figure 1. The first part of the system design](image)

First, the Ad hoc protocol and OLSR are installed on the server vehicle and the client vehicle to enable the vehicles to ping each other, and the Iperf software is installed to facilitate the capture of experimental data [7], [8].

Then, connect the server vehicle with the HDMI cable to the display screen, and continuously send several test packets to the client vehicle to test the connectivity of the two vehicles. When it is determined that the two vehicles are connected, the client vehicle is gradually moved away from the server vehicle, the distance between the two vehicles is increased, and the data is continuously captured by Iperf, and the display result is recorded.

2.2 Self-expanding Model

Prepare four unmanned vehicles and copy the written code into the Raspberry Pi from the startup script. The program starts execution when the power is turned on. First, four unmanned vehicles read their IP information. When they found that their IP is 192.168.100.1, they ran the Ad hoc protocol and did not move. Then, the rest of the vehicle moves according to the following rules:

(1) The vehicle with IP address of 192.168.100.2 (recorded as No. 2 vehicle):

First, the unmanned vehicle runs the Ad hoc protocol and the OLSR protocol, and continuously reads the signal strength of the vehicle that receives the IP address of 192.168.100.1 (recorded as the No. 1 vehicle). Then, the signal strength is compared to the threshold obtained in the first part of the experiment, and if it is greater than the threshold, the process proceeds, and vice versa.

(2) The vehicle with the IP address of 192.168.100.3 (recorded as the No. 3 vehicle):
The vehicle first proceeded with the No. 2 vehicle. When receiving the stopped UDP message sent by the No. 2 vehicle, the No. 3 vehicle starts running the Ad hoc protocol and reads the signal strength of the No. 2 vehicle. Then, it compares to the threshold. If it is greater than the threshold, it will continue to advance. Otherwise it will stop.

(3) The vehicle with IP address of 192.168.100.4 (recorded as No. 4 vehicle):
When the No. 2 and No. 3 vehicles advanced, the No. 4 vehicle also advanced. When receiving the stopped UDP information sent by the No. 3 vehicle, the No. 4 vehicle starts to run the Ad hoc protocol and reads the signal strength of the No. 3 vehicle. Then, compare with the threshold. If it is greater than the threshold, it will continue to advance. Otherwise it will stop.

The following figure is the second part of the design process that is shown in the figure 2.

![Figure 2. The second part of the system design](image)

3. Implementation and Evaluation

3.1 Implementation
The unmanned vehicles in the experiment can transmit data to each other as network nodes, and automatically connect to establish a wireless multi-hop network. Each unmanned vehicle is equipped with components such as Raspberry Pi. The more details are shown in Table 1.

| Table 1. Laboratory equipment |
|-------------------------------|
| **Equipment**                |
| Hardware                      |
| Raspberry Pi(3b+)             |
| Battery(12v)                  |
| Model of the vehicle          |
| L298N                         |
| Software                      |
| Linux                         |
| Python                        |

3.2 Evaluation
Since the selection threshold and performance test reflect the experimental data, the data test mainly faces these two directions. The experiment proves the reliability of the model by testing the networking performance of the unmanned vehicle self-expansion.

3.2.1 Signal Strength Threshold Selection
In the experiment, the signal strength is selected as the criterion for the advance or stop of the unmanned vehicle, but at the same time, the quality of the communication state is considered. We test the relationship between signal strength, bandwidth, packet loss rate and distance for unmanned vehicles. As shown in Figure 3, Figure 4 and Figure 5 [9]-[10].
Figure 3. Signal strength at different distances  
Figure 4. Bandwidth at different distances  
Figure 5. Packet loss rate at different distances

It is clear that when the signal strength is higher than -70dB, the packet loss rate and bandwidth of the vehicle are in an optimal state. However, when the value is less than this, the vehicle performance deteriorates sharply.

3.2.2 Multi-hop performance test
Considering the influence of irresistible factors such as outdoor obstructions, dust, and rainfall, the test of communication module is divided into indoor and outdoor scenario. When testing the bandwidth capacity of a multi-hop network, the topology of the indoor multi-hop network corresponds to the relative position of the outdoor unmanned vehicle. Two scenarios were set in the experiment. In scenario 1, the Hello message is the default configuration, with an interval of 2 seconds and a valid time of 20 seconds. In scenario 2, we change Hello message interval to 1 second and the effective time to 10 seconds. By reducing the Hello packet interval, we can achieve higher packet transmission rates and lower performance of packet delay network in the presence of fast-moving dominant nodes. The test uses the UDP protocol and the test is a one-way test. That is, Iperf completes the test from the client to the server. Figure 6 and Figure 7 shows the result. Hello-2 is the setting in scenario 1, and the Hello message interval is 2 seconds. Hello-1 is the setting in scenario 2, and the Hello message interval is 1 second. Experiments show that the indoor multi-hop network verifies the accuracy of the routing protocol. As the number of route hops increases, the packet loss rate increases, the network bandwidth decreases, and the performance of the network is different in two cases.
Conclusion and outlook

The indoor multi-hop environment is ideal without the influence of irresistible factors in the outdoor environment. Therefore, the performance of the multi-hop network tested is better than that of the outdoor network. As the number of hops increases, the packet loss rate will increase, but the network bandwidth will decrease. These results can be used as a reference for understanding network performance.

Combined with Figure 6 and Figure 7, we find that outdoor network performance is somewhat different from indoor test multi-hop. In fact, the outdoor multi-hop bandwidth is less than indoors, and the packet loss rate is higher than indoor multi-hop. After 2 hops, the performance of the network deteriorates and the packet loss rate increases. In addition, the network performance of scenario 1 is better than the network performance of scenario 2. This is due to the shorter Hello message interval and effective time. The more Hello messages that often occupy the communication channel, the more conflicts with traffic data and the weaker network performance. In addition, we initially determined that as delay and distance increased, network delay and packet loss increased. This will result in a drop of network bandwidth.

By designing the self-expanding model, we expect to realize the automation of the vehicle and the multi-hop transmission of wireless network. The model is expected to be used in the scenario of battlefield reconnaissance. At present, this model is only suitable for the case of fixed point. Therefore, adaptive dynamic environment will be our next research direction.
5. Acknowledgments
This work was supported in part by the National NSF of China under Grants (No. 61631020, No. 61702525, No. 61702545).

6. References
[1] Jackson, Daniel 2007 Research and Component Systems of Unmanned vehicles: A Survey.
[2] Al-Harasis 2015 Raghad. Design and Implementation of an Autonomous UGV for the Twenty Second Intelligent Ground Vehicle Competition. Int. Conf. on Software Engineering (ICSE).
[3] Noor, Md. Hasib et al. 2013 Design and development of remote-operated multi-direction Unmanned Ground Vehicle (UGV). 2013 IEEE 3rd Int. Conf. on System Engineering and Technology (ICSET): 188-192.
[4] Kandath, Harikumar et al. 2018 Autonomous Navigation and Sensorless Obstacle Avoidance for UGV with Environment Information from UAV. 2018 Second IEEE Int. Conf. on Robotic Computing (IRC): 266-269.
[5] Srinivasan, Kannan and Philip Levis 2006 RSSI is Under Appreciated.
[6] Wang, Xudong et al. 2017 Performance test and analysis of multi-hop network based on UAV Ad Hoc network experiment. 2017 9th Int. Conf. on Wireless Communications and Signal Processing (WCSP): 1-6.
[7] Clausen, Thomas H. and Philippe Jacquet 2003 Optimized Link State Routing Protocol (OLSR). RFC 3626 (2003): 1-75.
[8] Ramanathan, Rangasamy 2001 On the performance of ad hoc networks with beamforming antennas. MobiHoc ’01.
[9] Gómez-Cuba, Felipe et al. 2018 Capacity Scaling of Cellular Networks: Impact of Bandwidth, Infrastructure Density and Number of Antennas. IEEE Transactions on Wireless Communications (TWC): 652-666.
[10] Bai, Jingwen et al. 2016 Hello message scheme enhancement in CRMANET. Wireless Telecommunications Symposium (WTS): 1-6.