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PROTOCOL - INDEPENDENT EVALUATION OF UAV NETWORK

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Abstract. This article focuses on the FANET network consisting of UAV devices. The aim of the article was to point out the analysis of such a network by protocol-dependent and protocol-independent methods. The main research area in the paper is the evaluation of the communication model with random and group mobility model of UAV devices in FANET network using protocol independent methods. The modular quality as well as the detection of communities during missions based on UAV assignment movements were investigated.

Keywords: FANET, UAV, modularity quality, network analyse, group detection

1. INTRODUCTION

UAV devices are starting to be used in increasing numbers both in military tasks and in the civilian field. Their task is to explore the unknown surroundings, to help ensure communication in devastated areas, to deliver small parcels, but to find their application in the entertainment of the population. UAV devices have the ability to establish a direct radio connection to a ground station that monitors and controls them. A second way of communicating with UAV devices may be to exchange information when they become members of the FANET network. In most cases, UAVs have defined trajectories or mission plans to accomplish. These may be affected by external influences. Routing protocols are involved in securing the communication, whether it is a direct connection to a ground station or a mutual FANET communication. For the purpose of the research, a combination of a direct connection with the base station was used as well as a mutual radio connection between members of the FANET network. When analyzing the mission of UAV devices, evaluation is possible based on portocolor-dependent as protocol-independent methods. As a research outcome in this paper, protocol-independent analysis of the FANET network was used, sweeping the analysis of movement (group and random) as well as community detection during missions. The behavior of the network when changing the speeds of UAV devices has been corrupted [1-3,7].

2. FLY AD-HOC NETWORK

Flying ad hoc network (FANET) is, in general, a special form of Mobile / Vehicle ad hoc (MANET/VANET) network (Figure 1). This type of network consists of unmanned aerial vehicle (UAV) like different types of drones Figure 1. There is possible to observe some differences between FANET and ad hoc networks (MANET and VANET). The mobility degree of UAV devices is much higher than the velocity for devices in VANET (cars) of MANET (human). The mobility degree depends on type of mobility model. Generally, the topology is changed with much higher frequency than the MANET or VANET topology. Grouped UAV with the same target can reach high velocity compared with the other objects but the velocity to the other members of the group is very low. Comparison of FANET, VANET and MANET is possible to see in Table 1[1].

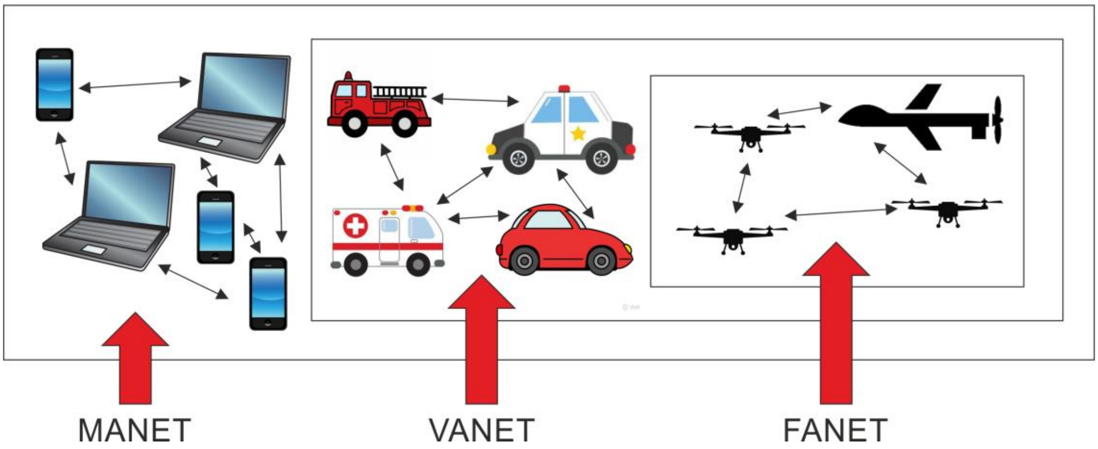


Figure 1 MANET, VANET and FANET

Table 1 Comparison of FANET, VANET and MANET

Type of network / *Parameter*	**FANET**	**VANET**	**MANET**
Node mobility	High compactness	Medium compactness	Low compactness
Mobility model	Usually predetermined	Steady	Arbitrary
Node density	Low	Medium	Low
Topology change	Rapid and speedy	Average speed	Slow and steady
Radio propagation model	High above the ground level,LoS (Line of Sight) is accessible for most of the cases	Close to ground, LoS is not accessible for all cases	Very close to ground, LoS is not accessible for all cases

2.1 UAV in FANET

UAV (Unmanned Aerial Vehicles) is a type of aircraft without a human pilot on-board. Many different types of UAV are known based on the various purposes of their usage. It is necessary to control them directly from the ground or based on programmed instructions. The data transfer can be online directly with the ground station or the transfer of information among them can be in autonomous meaning. It means, that the UAV device is a member of FANET network where information is being exchanged [2, 3].

2.2 Communication in FANET

Ensuring communication between the UAV and the ground station is very important. If the UAV is part of a FANET network, communication is very similar to MANET communication, which is provided by routing protocols. There are two types of node traffic in the FANET network. This is Air-to-Air (FIG) and Air-to-Ground (FIG) transmission.

When using the Air-to-Air transmission type, UAV devices use an ad-hoc architecture to communicate and exchange information with each other. This type of communication does not require a ground station and centralized control. The used wireless communication can support various applications as well as a multihop exchange model. This model represents the transfer of information through the connected network created from UAV devices based on radio range. Communication paths are established based on suitable routing protocols for the given environment.

When an Air-to-Ground transmission is used, a communication link is established between each UAV and the ground station [4, 5,6].

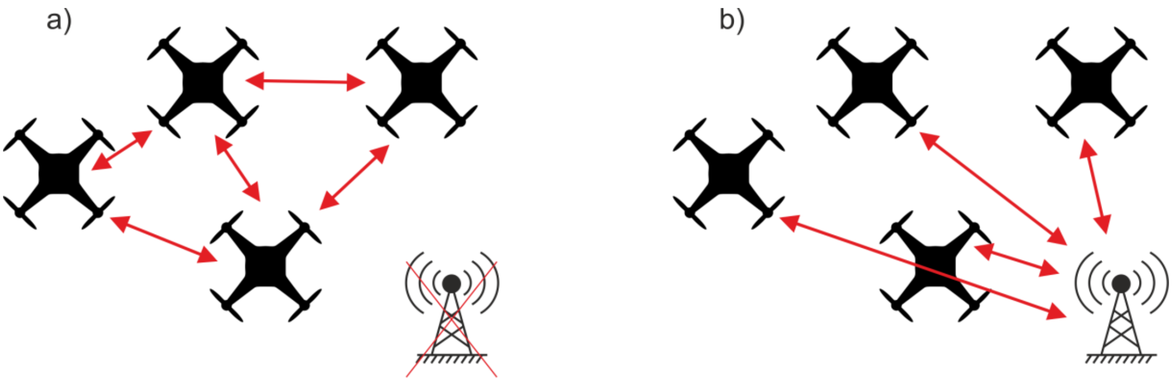


Figure 2 Types of transmissoions for FANET

2.3 Mobility in FANET

The movement of nodes in the FANET is generally defined beforehand and is influenced by external factors (other UAVs, weather, mission, space, etc.). In [4, 5] are described different mobility models for UAVs (Random way point mobility model, Random movements, Gauss–Markov, Pheromone repel, Semi-Random Circular Movement, Paparazzi mobility model). It is very important to know not only what communication model was deployed, but also what movement model was chosen for each UAV device. On the one hand there is a statement about the used communication model and on the other it is verification of the correctness of the used movement model, which can be ensured by the actual evaluation of the model.

3. EVALUATION METHODS OF FANET

The FANET network, its communication ability as well as the movement of UAV devices in it can be evaluated using protocol-dependent or protocol-independent evaluation methods.

Protocol-dependent evaulation methods utilize routing protocols used to transmit information during flight time to UAV devices. These are parameters such as Packet Delivery Fraction – PaDF (1), Packet Loss –PL (2), Average Throughput – AT (3).

$$PaDF = \frac{Delivered\ Packets}{Sended\ Packets} * 100\,[\%] \tag{1}$$

$$PL = Number\ of\ \ Send\ \ Packets - Number\ of\ \ Recieved\ \ Packets \tag{2}$$

$$TP = \frac{(Recived\ Bites) * 8}{(SimulationTime) * 1000}\,[kbps] \tag{3}$$

When using protocol-independent evaluation methods, it is already clear from the title that the evaluation of the FANET network is not subject to the used routing protocol, and even no routing communication protocol is needed to be deployed. In this case, parameters such as Degree of Spatial Dependence, Degree of Temporal Dependence, Relative Speed, Number of Neighbors, Path Availability are evaluated.

When evaluating the FANET network, it is also important to keep in mind the type of deployed movement that can detect the communities in the network. With this finding, it can be said whether the deployed movement shows signs of grouping UAV devices with a common goal, or each UAV device carries out its mission individually [8].

4. COMMUNICATION SCENARIO FOR FANET

The idea of a communication scenario of a FANET network consisting of UAV devices interconnects both types of transmissions for the FANET network (Figure 3). Part of the UAV equipment (UAV-G1) is in a certain mission area with the impossibility of communicating directly with the base station (GS). Therefore, it uses only the radio range characteristics of each other to collect and exchange information in ad-hoc mode (Figure 3, red lines). The second part of the UAV devices (UAV-G2) has a direct radio link to the ground station (Figure 3, blue lines) as well as the ability to maintain a direct radio link to the UAV-G1 members (Figure 3, red lines) and serves as retransmission devices for transmitting information between the UAV-G1 and GS.

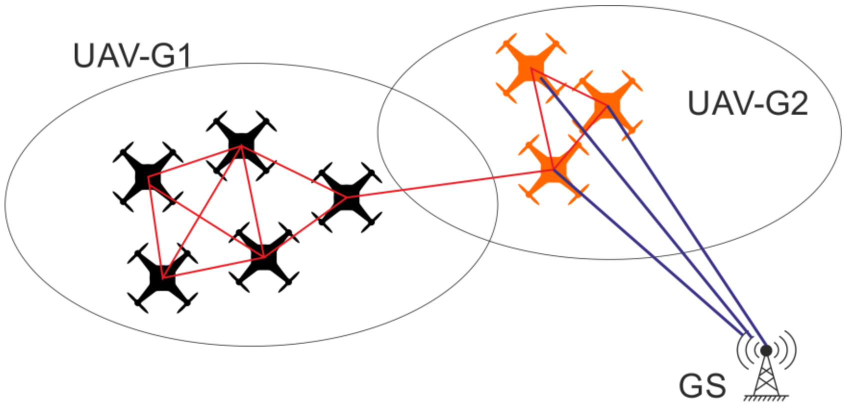


Figure 3 Communication scenario

5. SIMULATION OF FANET

The simulation was set according to the communication scenario for UAV devices occurring in the FANET network. The simulation is based on the assumption of already deployed UAV devices according to Figure 4. Each UAV device has a defined motion model. Within the FANET network analysis, it is possible to analyse the protocols in a dependent manner, since a modified DSR routing protocol [9] for the FANET network is selected, as well as protocol independent evaluation. The purpose of this article is to evaluate the behaviour of nodes during their cooperation, communication and movement in relative airspace from the point of view of their movement analysis. For this purpose, the method of detecting communities from UAV movements was called the Louvian method.

This method can retrospectively analyse the entire movement of UAVs in space and evaluate the relationship between UAVs during their mission. Each time we look at the simulation, the relative location of all UAV devices in their local memory is recorded (Figure 4a). After the simulation is completed, mutual contacts are evaluated based on the defined radio range for each time point (Figure 4b). After this analysis, a single matrix of NxN dimensions is generated, with N representing the number of devices in the network (Figure 4c).

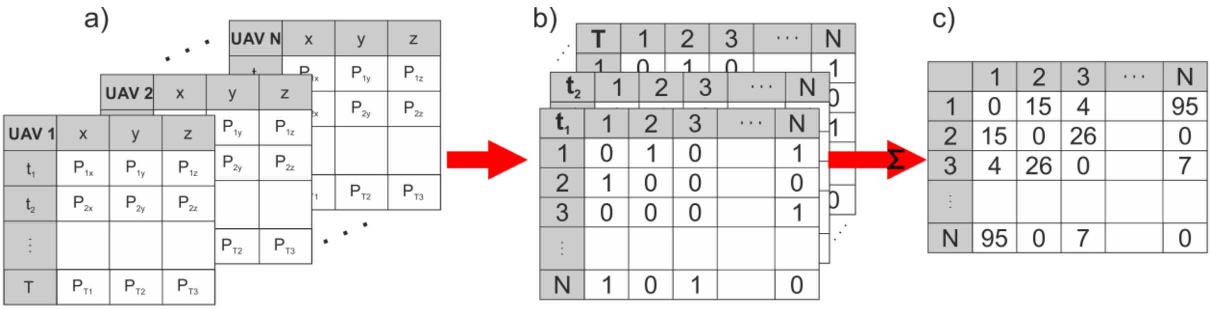


Figure 4 Relative location of UAV (a), Mutual contact matrix (b), Single matrix of_contact analising (c)

The real simulation deployment of the UAV is shown in Figure 5. From this state, the devices began to move at different speeds based on the input parameters in Table 2.

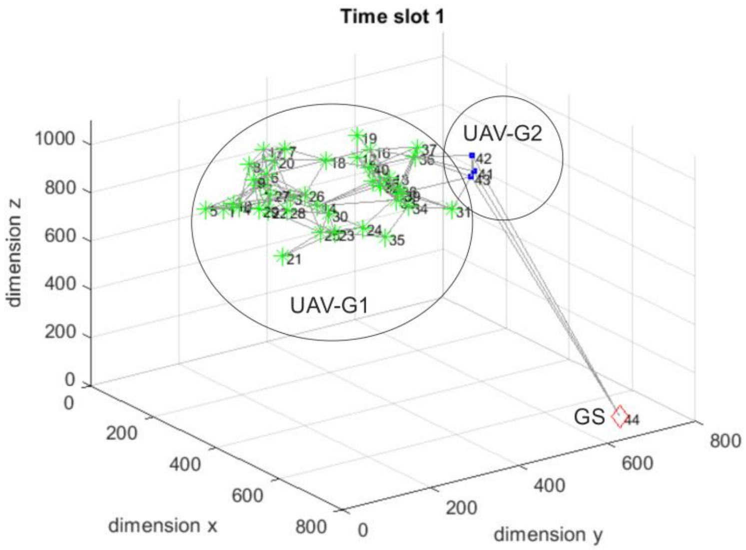


Figure 5 Real deployment of UAVs and GS at the start of the simulation

Table 2 Input parameters for simulations

Parameter	Value
Number of UAV-G1	40
Number of UAV-G2	3
Number of GS	1
Radio range	150m (UAV-to-UAV) 2000m (UAV-to-Ground)
Number of simulations	10
Number of simulation repetitions	100
Velocity	1; 3; 5; 7; 9; 11; 13; 15; 17; 19 [m/s]

6. RESULT OF FANET SIMULATION

For the purpose of evaluating the simulation of the FANET network consisting of UAV devices and GS protocol independent method, the influence of the speed of movement of UAV devices on the modular quality and number of groups that were created was investigated.

6.1 Modularity quality of UAV movement

The average quality modularity for each UAV rate of group and random movement is shown in Table 3. The Louvian method works based on information about connectivity among nodes in the network. This connectivity is perceived as meeting matrix created from Boolean matrixes in every time slot. Meeting matrix is, in fact, a weighted graph, where nodes are vertices of this graph and edges represents contact among nodes. The edges exist only in this case if a given couple of nodes met each other at least once during the observation time. Modularity quality (4) is a parameter for this method, which tells us about communities discovering. Modularity quality measures how well a given partition of a network compartmentalizes its communities. From the numerical perspective, modularity quality can reach scalar values between -1 and +1. In the cases, when some communities are detected, the value of modularity quality is in positive meaning, larger number represents a stronger community. Based on the research in [8], is the value above about 0,3 indicator of good community structure in the network. The modularity quality is calculated based on (5), where $A_{i,j}$ represents the weight of the edge between couple of nodes (i,j), k_i is the sum of the weights of the edges attached to vertex i, c_i is community to witch vertex i is assigned, $\delta(c_i,c_j)$ is 1 if $c_i=c_j$ and 0 otherwise and $m=\frac{1}{2}\sum_{i,j}A_{i,j}$ [10].

$$Q=\frac{1}{2m}\sum_{i,j}\left[A_{i,j}\frac{k_ik_j}{2m}\right]\delta(c_i,c_j) \quad (4)$$

Table 3 Modularity quality for different velocity levels of UAV movement

Modularity quality										
Velocity [m/s]	1	3	5	7	9	11	13	15	17	19
Random	0,5830	0,5780	0,5736	0,5682	0,5533	0,5524	0,5336	0,5220	0,5109	0,5007
Group	0,5824	0,5752	0,5751	0,5727	0,5619	0,5597	0,5506	0,5508	0,5329	0,5302

It can be observed (Table 3) that, when deploying group movement of UAV devices, higher modular quality was detected on average for each device speed used. With increasing speed modular quality decreased. The results in Table 3 are the average of 100 repetitions performed for each selected UAV rate.

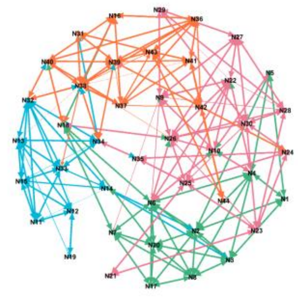
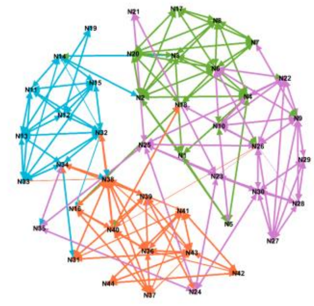
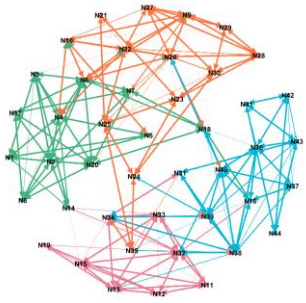
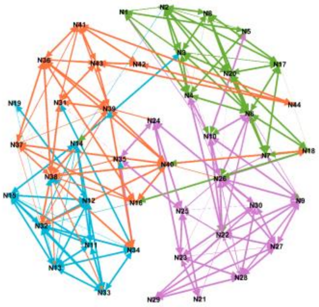
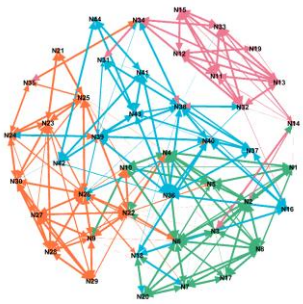
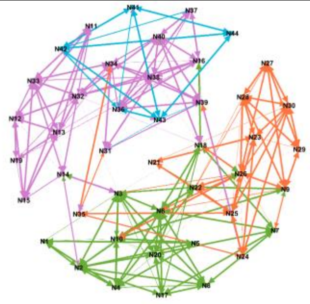
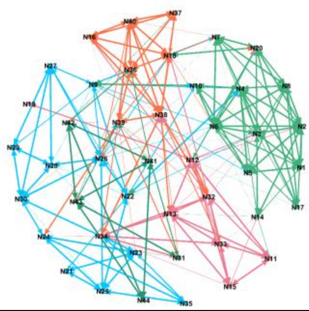
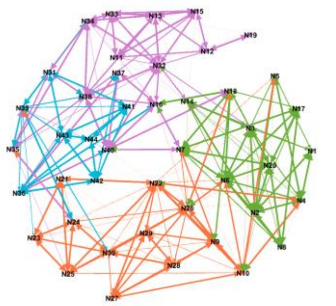
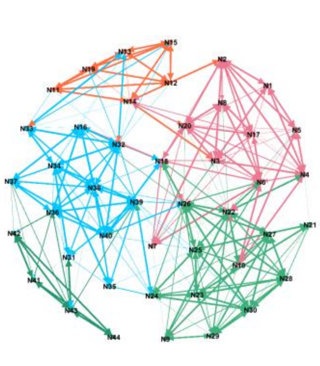
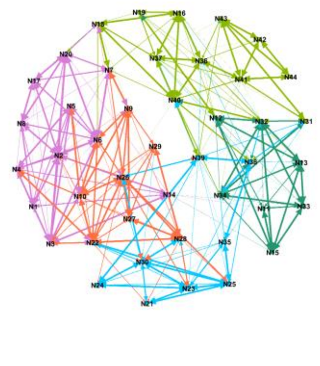
6.2 Group detection of UAV during the flight

Protocol independent method of FANET network analysis is evaluated in this section. It involves comparing the movements of UAV devices in such a network based on their mutual contacts during a mission using random and group movement. The result in Figure 6 depicts the strength of the relationship between nodes, which is expressed by line thickness as well as grouping based on modular quality. The result shows one in 100 runs performed as an example of mutual contacts during the mission.

The result in Table 4 shows the development of modular quality due to speed on the FANET network. The result is as an example of only one run, where it is possible to observe deviations from the required behavior of the network. For this reason, it is advisable to follow the average results in Table 3. The results from Table 4 are linked to a graphical representation of modular quality (Figure 6) among UAV devices in the FANET network, for the one given run selected. Results are based on modular quality and community detection tools. Gephi 0.9.2 software solution [11] was used to create visualization. The Fruchterman Reingold layout algorithm, with parameters for Area (10000), Gravity (10) and Speed (1), was chosen to create graphical deployments of the echoes based on their mutual relationships acquired during the mission.

Table 4 Modular quality of one of the 100 runs per graphical display

Modularity quality – for example										
Velocity [m/s]	1	3	5	7	9	11	13	15	17	19
Random	0,588	0,577	0,549	0,538	0,524	0,555	0,517	0,522	0,444	0,537
Group	0,597	0,575	0,605	0,575	0,567	0,551	0,567	0,561	0,388	0,547

	Group movement	Random movement
Velocity 1m/s		
Velocity 3m/s		
Velocity 5m/s		
Velocity 7m/s		
Velocity 9m/s		
	Group movement	Random movement

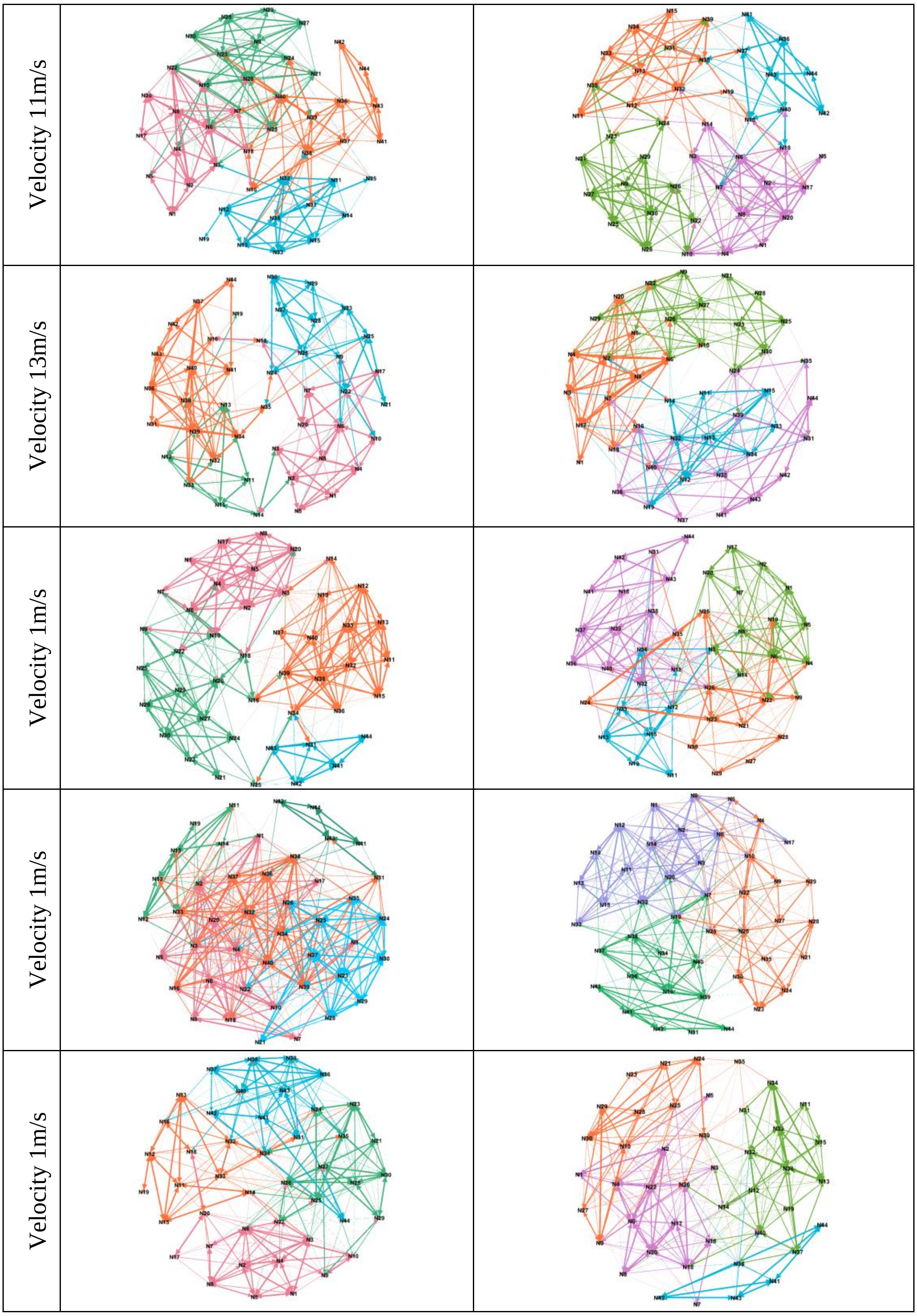


Figure 6 Comparision of group detection based on modularity quality for given run

7. CONCLUSION

The paper was focused on analysing FANET network consisting of UAV devices. The analysis focused on protocol-independent evaluation methods, namely on the analysis and comparison of used movements for UAV devices. A random and group movement model was used and based on these movements, the modular quality of the network as well as the detection of communities during the UAV mission were analysed. Based on the simulations performed in the Matlab environment and evaluation in the Gephi software it was possible to conclude that the modular quality parameter decreased for the selected movements due to increasing speed. This means that the network was less cohesive, and connections between UAVs were more and more established. From a statistical point of view, random movement showed better values of found communities and higher modular qualities than random movement. Random deviations could occur when comparing one selected movement. Averaged measurements gave us a better insight into the behaviour of the network when changing the speed of UAV devices.

For efficient and as long as possible UAV missions, it is necessary to optimize their resource management in the future. Some tasks for UAV devices may be disposable-oriented, where there is no need to consider resources to return UAVs. In this case, it is appropriate to reduce the price of UAV equipment to a minimum, to provide conventional or FANET communication for data acquisition and management [12].

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