On Mass-Spring System Implementation in Cluster-Based MANETs for Natural Disaster Applications

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***Abstract*—Communication after natural disasters is paramount. Disasters such as earthquakes, hurricanes and tsunamis leave the affected area reachable only to wireless devices. In such conditions, Mobile Ad-hoc Networks (MANETs) play a critical role. The issue of MANETs communication backbone can be addressed by self-organized cluster-based algorithms. The virtual backbone will maintain an efficient communication on the MANET, adapting to the dynamic topology changes thanks to its self-organized nature. Nevertheless, they do not take into account the node's mobility. If a node moves away from its neighboring nodes, connectivity will be lost and thus, network segmentation will occur. Therefore, it is fundamental to maintain the connectivity and the communication between nodes while exploring the area. In this paper, we propose the application of a mass-spring system on the Energy-Efficient Self-Organized Algorithm (EESOA) for Disaster Area applications. Results will show that our proposal performs best when deployment of MANET's nodes is dense while maintaining a connected network.**

Keywords–MANETs; self-organization; cluster-based algorithms; Mass-Spring; Disaster Area.

I. Introduction

Almost every year natural disasters such as earthquakes, hurricanes, typhoon, flood and tsunamis strike many areas of the world. After the catastrophic events, many lives are trapped in the post-disaster area. According to the "Golden 72 hours" principle, people that are trapped have a large chance of survival if they are rescued within the initial 72 hours [1]. Emergency response teams and volunteers need to communicate in order to perform their rescue operations. Thus, the connectivity of their communication devices is paramount in such situations. Nevertheless, communication systems which provide connectivity are usually down as a result of the disaster. The advance of mobile ad hoc networks (MANETs) has enabled their usage to address disaster situations thanks to the availability and infrastructure-less nature.

A Mobile Ad-hoc Network node, consists of an wireless electronic device, such as laptops, drones, smartphones and wearable technology which communicates among each other in a decentralized manner creating a structure-less network. Research in MANETs has intensified given the usage scenarios unveiled by catastrophic disasters on which device reachability is key. The advantage of wireless MANETs nodes over wired devices have yielded a new range of applications to aid on response of catastrophic disasters. Applications range from prior alert mechanism and post disaster infrastructure [2], provide a secure payment system in disaster areas [3], Simultaneous Wireless Information and Power Transmission (SWIPT) scheme [4], hybrid communication infrastructure systems using wireless devices and the remaining cellular antennas [5]. Other applications focus on post-disaster communication like human mobility based communication system [6], an earthquake communication platforms [7] or Unmanned Aerial Vehicles (UAVs) network deployment [8].

The aforementioned applications [2]–[8] assume the network is always connected and does not take into account the dynamic topology changes of the MANET. Such topology changes can be caused by node's mobility, obstacles causing connectivity loss, node's death, malfunction and node battery drain out. Additionally, another assumption is that MANET's nodes will always be within range, and thus, connected. There must be a mobility scheme, which prevents the nodes to go far from their neighbors causing network segmentation. Such mechanism, at the same time, must prevent the nodes to be too close to each other as well.

The contribution of this paper and ongoing research [9] is the evaluation of the application of a mass-spring system on a cluster-based algorithm for disaster area applications. Implementation of mass-spring on the MANET's nodes will control the node's mobility to have a connectivity-aware network. Simulation will show that the proposed approach performs best when deployment of the MANET's nodes is dense without losing connectivity. There are several applications of the mass-spring system: An indoor positioning and tracking localization scheme [10]; smart cities applications [11]; a positioning scheme when the number of anchor nodes is insufficient [12]; a study on implementing a mass-spring based algorithm for the optimal topology on a wireless network [13]; an anchor free Wireless Sensor Network (WSN) self-localization scheme [14]; a relaxation of the model for devices' self-deployment [15] and WSN localization [16].

The rest of this paper is organized as follows: Section II shows the related work. Section III presents the application of the mass-spring system on a cluster-based algorithm. Section IV establishes the testbed simulation. Section V shows the simulation results. Finally Section VI concludes this work and presents future challenges.

II. Related Work

The research surveyed in this section [5]–[7] [17] addresses the challenge of MANET's communication in disastrous areas.

A. Decentralized Algorithm for Maximizing Coverage and Lifetime in a Mobile WSN

Etancelin et al. [17] proposed a decentralized algorithm for maximizing coverage and lifetime in mobile wireless sensor networks (DACYCLEM). Their approach is to build a connected dominating set (CDS) combined with a attraction and repulsion forces scheme to maintain connectivity. Thus, the problem addressed is to maximize the lifetime of a network while attempting to cover the maximum possible area. The solution offered by Etancelin et al. [17] is based on define coverage area as an objective and connectivity as a constraint. Their proposal is to combine the solution for each sub-problem addressed. For the backbone construction sub-problem, they used the approach proposed in [18]. For the connectivity between nodes sub-problem, in Table 1 of [18] they defined either the *attractive, repulsive* or *equilibrium* forces based on the nodes' states and their interaction. The separation of *critical backbone* and *backbone* is key for the behavior on the nodes forces interaction. Additionally, nodes' states are defined as active or standby, which will also affect the respective force defined at Table 1 of [18]. Finally DACYCLEM's algorithm 1([18]), was proposed with an initialization deployment phase. This proposal addresses the aforementioned sub-problems while maintaining connectivity as a constraint.

Although DACYCLEM shows promise, it does not consider the implications of "graceful degradation" defined in [19]. Also the battery consumption due to changing the node's state from standby to active does not seem to be taken into account. Another assumption is the nodes deployment distribution. For the purposes of their research, a random distribution of the nodes in the area is assumed. This is not realistic for disaster applications. Finally another caveat is that nodes will only start initialization once they reach a predefined meeting point.

B. MANET rescue information communication system

Verma et al. [5] presented a hybrid cellular-MANET architecture communication system. The proposal does not require modifying existing wireless infrastructure nor requires new technology but existing devices with Wireless Fidelity (Wi-Fi). The architecture consists of a sink node named *Control Station* (CS), which is connected to a vehicular *Base Station* (BS) in order to have internet and cellular service. Two *Access Point* (AP) types are defined based on the communication interface, Wi-Fi AP and Gateway AP (which uses cellular interface). Victim's devices are defined as *Mobile Devices* and *Notebooks*. The aforementioned architecture assumed the existence of a working BS, nevertheless, the architecture is robust enough to take into account broken BS causing no cellular coverage.

An energy and mobility aware, self organized routing protocol is proposed as well. APs are dropped and then register to the CS to keep their table updated. Once registered APs starts broadcasting to detect devices. Mobile devices respond to the broadcast message or use neighbor MANET nodes as relay nodes. Subscription is performed using unique physical address and a sequence number to avoid loops and old messages. The routing is defined by two processes: the *route discovery and message transmission* and the *route maintenance*. The route discovery scheme falls within the on-demand (reactive) type. The devices always will subscribe to the AP with minimum hop count. Route maintenance focuses on network topology changes. If a new node appears or an existing one moves the APs and CS will update their tables.

The limitations with this approach are, although it builds a MANET there is a sink node (CS). To have a sink node causes traffic to be higher in gateways nodes or rely nodes causing the *hotspot* problem, causing such nodes to drain their battery. The use of two technologies provides robustness but the switch between Wi-Fi and cellular schemes cases additional power consumption. This proposal assumes the network will always be connected, when mobility of rescuers, does not follow any scheme to ensure an connected network.

C. MANET-based communication platform

Jang et al. [7] outlined a MANET-based communication platform and information rescue system. It proposed to establish a temporary MANET by using WiFi-ready devices such as notebook PCs for the network construction. Thus, the architecture is not limited by the technology available post-disaster. Authors in [7] presented an "Autonomous P2P Ad-Hoc Group Communication Systems" (*P2Pnet*) as a server-less peer-to-peer communication MANET-base network. On top of the MANET, there is a peer-to-peer communication layer to support higher level communication services such as Push-to-Talk, two way radio and VoIP communications. The proposal in [7] assumed that there would be nodes with satellite communication capability such as mobile-base stations and Very Small Aperture Terminal (VSAT). The aforementioned nodes will perform gateway functions so all other nodes can access Internet through gateways.

Once the network is built, [7] introduced "Rescue Information System for Earthquake Disasters" (RISED). RISED main objective is to provide the most up-to-date rescue-related information. Such system is designed to support efficiently resource and information management for rescue mission operations in a catastrophic disaster. RISED is composed by 4 subsystems. The Disaster Assessment, fastest rescue route generation, health care & relief resources integration and wounded victim arrangement subsystems focus on specific task relying on the constructed MANET-based network. Authors in [7] assumes volunteers will be within range without any defined approach to ensure a connected network.

D. Unmanned Aerial Vehicle network deployment tool

Deruyck et al. [8] proposed a deployment tool for UAV-aided emergency network for large scaled disaster scenarios. Such UAVs will have a mounted base station which can be a femtocell base station. The deployment tool takes as input the following: human traffic and locations, disaster area 3D model environment and number of hours the communication service is required. With the 3D model path loss calculation is performed being either Line-Of-Sight (LOS) or Non-Line-of-Sight (nLOS). With the aforementioned the algorithm creates a list of all possible base stations. When all user locations are analyzed the network is then designed. The number of nodes calculated on the algorithm takes into account the number of drones in the facility. Once the UAV is on its dedicated position, the user will be able to connect to the BS. This approach generates a connected network thanks to the number of nodes calculated, still a scheme to maintain nodes within range and avoid collision among each other is not addressed.

E. Human mobility in disaster areas

Aschenbruck et al. [6], provided a realistic approach to model the mobility in a disaster area. Not only takes into account natural disasters, but human-caused disasters as well. Nevertheless, it has many assumptions such as relying on the civil protection "*separation of the room*" disaster tactics, which is unrealistic since the post-disaster terrain area could be inhospitable and unreachable. Their model does not simulate obstacles, a key factor in MANETs which causes changes on the MANET's topology. The metrics used, such as *relative mobility*, *average node degree*, *average link duration*, *minimum number of links node and its neighbors* (*mincut*) part from the assumption of a non dynamic topology network.

Relying on structured civil protection tactics assumptions provides an model which does not take into account the dynamic nature of MANETs. [6] assumptions does not take into account obstacles or MANET's nodes power making the model prone to network segmentation due to the lack of self-organization. Finally, the mobility distribution may follow the civil protection tactics, nevertheless in reality this can change drastically due to the terrain conditions. Mobility model is rigid, limited by the aforementioned civil protection tactics moreover, no approach is mentioned to avoid network segmentation when nodes are not within communication range.

III. Mass Spring Model On EESOA

From the surveyed work in section II ([5]–[7]), it can be concluded that the assumption of a connected network was made. A scheme that controls the MANET's nodes mobility to keep them within communication range, and consequently, maintain a connected network is not defined. Only [17] defines a mobility model since it defines connectivity as a constraint. Our proposal is the continuation of an ongoing research [9]. The problem of back-bone construction is already addressed by EESOA. Nevertheless, EESOA with the mass-spring model shows promise as a proposal for a connected-aware network. The novelty of this proposal is the combination of a mass-spring model with ESSOA. This provides a MANET with a virtual-backbone maintained by nodes that will have a mobility model which will maintain them connected and prevent collision. Finally leveraging from EESOA hello broadcast, nodes will share their position to neighbors within one hop. This will enable all MANETs nodes to compute all their neighbors mass spring force in a distributed manner. Interaction of mass-spring model with EESOA is described in section III-C.

The findings presented in this work are focused on the mass spring system combined with a cluster-based system in terms of number of survivors found and coverage area. Thus, EESOA [9] virtual-backbone algorithm is agnostic to removal of nodes in the network causing changes in the topology. Finally, pairing EESOA nodes with the mass-spring system, the network connectivity will be preserved in order to assist on search and rescue operations.

A. EESOA for virtual backbone & efficient communication

The Energy-Efficient Self-Organized algorithm, builds and maintains a virtual-backbone in a distributed manner. ESSOA constructs the virtual backbone through a 4-hierarchy cluster-based formation. Such roles are: Leader, Gateway, Bridge and Member. Each EESOA node will self-assign one of the 4 hierarchies role based on the information obtained from its neighbors within one-hop. The node with more neighbors and best quality criteria defined in [20] will have the Leader role. Leader will inhibit its neighbors with periodic broadcast messages. A Gateway node is an EESOA node inhibited by two or more nodes with the Leader role. A Bridge node is an inhibited node which have an inhibited neighbor from another cluster. A Member node is an EESOA node inhibited by a single leader. The hierarchy roles self-designation scheme is defined in detail in [20]. The algorithm used in the presented work is the result of an ongoing research, proposed at [9]. The proposal is an enhancement on the Bridges role-self-assignation that removes redundant links and minimizes broadcast messages and packet loss. The EESOA proposal is explained in detail in [9].

EESOA clustering [9] is shown in Figure 1. Without EESOA, communication between a node and all its neighbors will occur. Having no control on redundant links will cause unnecessary communication and problems such as broadcast storm. Therefore, the EESOA clustering will remove redundant links (non-backbone) and will construct a virtual backbone as shown in Figure 1. Thus, avoiding problems such as broadcast flooding and packet loss due to excessive redundant links.

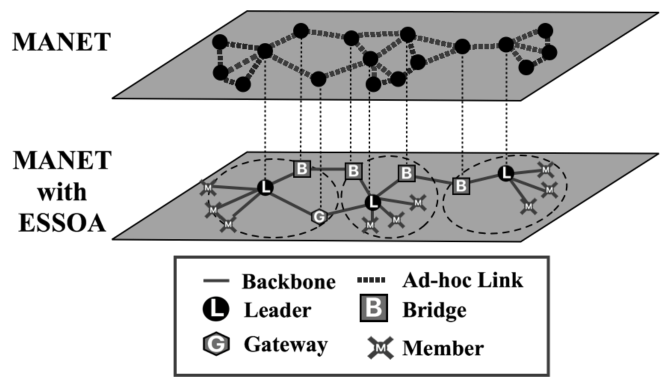

Figure 1. EESOA virtual backbone.

B. The Mass Spring Model

Node management such as maintaining a distance to avoid disconnection or preventing collision with neighboring nodes is not addressed on the surveyed work [5]–[7]. Maintaining connectivity within the network for search and rescue is paramount. The problem of construction and maintenance of a communication backbone is already addressed by EESOA. Nevertheless, EESOA provides a virtual back bone but does not avoid network segmentation. The problem of node management, such as keeping the nodes from going too far from their neighbors' range causing network segmentation and preventing nodes from being too close to each other, can be addressed by applying the mass-spring model to EESOA.

Application of mass-spring model in a MANET can give a connectivity awareness to the network and thus, address the problem of maintaining the nodes within range.

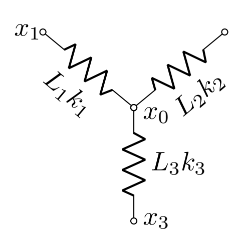

Figure 2. Mass-spring system with 3 elements

The mass-spring system maintains a minimum distance between the components of the system thanks to constant L. Also, will keep the node as close as possible to the point of equilibrium in which the sum of the forces is 0, otherwise, resultant force will move the node of position. Hence, the aim is to provide a flexible scheme which when combined with EESOA takes connectivity into account. An example of the aforementioned mass-spring system is shown in Figure 2.

Equation (1) describes the mass-spring systems with the force behavior affected by current positions (x), equilibrium distance (L) and the spring constant (k).

$$F_u = \sum_i \left[k_i(|x_i - x_u| - L_i)\frac{x_i - x_u}{|x_i - x_u|} \right], \quad i \neq u \quad (1)$$

where:
x_i Position of the i^{th} node
x_u Position of $node\ u$
L_i Equilibrium distance for i^{th} node
k_i Spring constant for i^{th} node

Each ESSOA-MANET node will generate a mass-spring model with all its neighbors within one-hop. Depending on the neighbor node role given by EESOA [9], the constant k_i and equilibrium distance L_i will be defined accordingly.

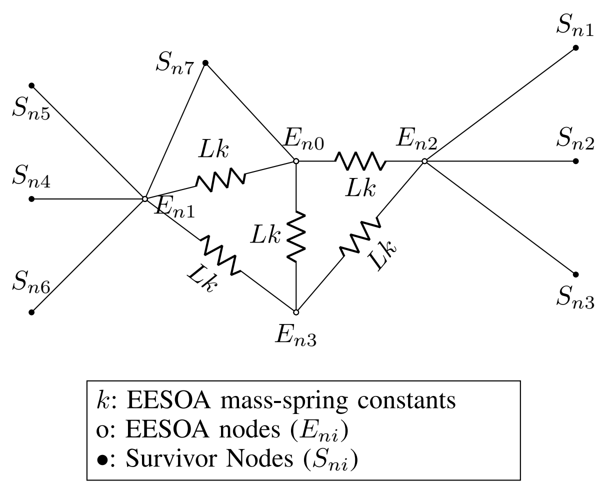

Figure 3. Mass-spring model between nodes

C. Mass-spring interaction with EESOA

The mass-spring application on EESOA consists on 2 parts. On first stage the EESOA node will generate the respective k spring constant as shown in Figure 2. Such constant will be role dependant. Further more the equilibrium distance L will be role dependant as well, making the mass spring model flexible. An example of an EESOA-based MANET with the mass-spring model is denoted in Figure 3.

On the second stage, the algorithm will iterate through all the nodes and their mass spring models. Then, it will generate a vector $\vec{v}$ which will determine the new position (x, y) of the EESOA node. Note that the algorithm will take into account the mass-spring model of its EESOA neighbor nodes to keep the equilibrium in the system as shown in Figure 3. Thus, the new position will be adjusted. Therefore, the node will not move away to cause network segmentation. Additionally, the new position will cause the neighbor nodes to adjust their vectors and new positions to maintain the equilibrium. Thus, the implementation of the mass-spring model on EESOA nodes provides a MANET, that addresses connectivity, which is key for disaster area search and rescue applications.

The aforementioned stages are represented in Algorithm 1. The First stage is denoted in Step 8, where if there is a EESOA neighbor $N(u)$ for a node *u*, it will generate the appropriate spring constant k_i according to the EESOA neighbor node. Subsequently it will compute the individual force generated between node *u* and it neighbor *v* while maintaining the minimum equilibrium range *L* defined on (1). The second stage in denoted no the loop in step 7 and the update on node *u* position in step 12. The resultant force of Neighbors of node u will denote vector $\vec{v}$ to update the node's position.

The mass spring algorithm will be performed on each *hello broadcast*, thus, being always updated with the position of Neighbors of node *u*. Additionally, it will take into account dynamic changes on the MANET topology, which will cause EESOA node role changes and thus, will update the spring constant k_i as well as the Force $F_{i,v}$. Here we can observe the interaction between the mass spring model and the EESOA algorithm. EESOA provides a back bone and the mass spring model provides connectivity awareness, both critical applications for search and rescue on disaster areas.

Algorithm 1 Mass-Spring Algorithm

1: $N(u) = Neighbors\ nodes\ within\ 1 - hop\ of\ node\ u$
2: $k_{u,v} = Spring\ constant\ between\ node\ u\ and\ v$
3: $F_{u,v} = Force\ between\ node\ u\ and\ v$
4: $F_T = Total\ Force$
5: **function** FIND_EQUILIBRIUM
6: $F_T := 0$
7: **for** All N(u) **do**
8: $Neighbor\ Spring\ k_{u,v} \leftarrow GetSpring(u, v)$
9: $Neighbor\ Force\ F_{u,v} \leftarrow GetForce(k_{u,v})$
10: $F_T := F_T + Fu, v$
11: **end for**
12: $UpdateNodePosition(u, F_T)$
13: **end function**

IV. SIMULATION

In this section, we performed simulations to observe the behavior of the mass-spring model implementation on EESOA. Performance assessment will be conducted in terms of initial and final number of survivors found and coverage area.

A. Mass-spring model on EESOA on Java Simulator

A discrete-event Java-based simulator was implemented using the Graphstream library v1.0 [21] [22]. The aforementioned was chosen since the focus of this research is to evaluate the implementation of mass-spring model in a cluster-based algorithm on a dynamic MANET [21]. Data traffic and protocols evaluation is out of the scope of this research. We will call EESOA node to the implementation of a MANET node which will be performing EESOA defined at [9] when simulating. Thereupon mass-spring model will be built-in on each EESOA node. With the aforementioned, we are linking the mass-spring behavior to the hierarchies generated by the cluster-based algorithm. In addition, the mass-spring model on each EESOA

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node will have a pre-defined set of k constants as well as equilibrium distances L for each EESOA node hierarchy. Thus, each time an EESOA node receives a `hello broadcast message`, the in-built mass-spring system will perform the Algorithm 1. Consequently, each EESOA node will generate a mass-spring model with the respective constant to all its neighbors within one-hop. Algorithm 1 implementation will take into account all the neighbor mass-spring models when computing the final movement vector $\vec{v}$. Equilibrium will be maintained by following (1). The prior defined constants L and k for each EESOA node will maintain a connectivity-aware behavior on the MANET's nodes by maintaining formation on each neighbor within one-hop. This will ensure that each node will try to stay within range L of its neighbors defined by (1).

The simulation presented in this work assumes that each node know the coordinates of its own position. Thus, the EESOA node will share its location coordinates with neighboring nodes on each periodic `hello broadcast message`. A minimum constant area range of reception of the node and non dynamic k and L constants are assumed for this simulation. With the previous defined implementation, the resulting MANET will have a virtual backbone thanks to EESOA while expanding the coverage area thanks to the mass-spring model without losing connectivity. Hence, the connectivity awareness-emergent behavior of the proposal. Note that the original vector $\vec{v}$ of movement might have been bigger but thanks to mass-spring model the node will maintain a range, hence, the connectivity emergent behavior.

B. Simulation Environment

The simulation was implemented on a java-based discrete-event simulator. For the graphic user interface and MANET simulation, the Graphstream library was used. The initial setup parameters for this simulation is defined in Table I.

TABLE I. SIMULATION SETUP

Parameter	Value
Simulation Area	50x50 mts
EESOA Nodes	20
Survivor Nodes	50
Mobility Model	Random Uniform Distribution
Java Version	Java SE 8
Graphstream Version	1.3
Node Range	10 mts
Survivor Groups	3

Figure 4 illustrates an example of a simulation setup with 10 EESOA nodes formation and a 30 survivor nodes distributed in a random uniform manner on a 50x50 mts grid.

C. Simulation Scenarios

To evaluate the performance of mass-spring implementation with EESOA we require to define scenarios, which represents realistic disaster circumstances. For the purposes of this research we will focus on the deployment configuration for both, either survivors or MANET drones. Disaster scenarios will constraint the survivors distribution on the affected area depending the catastrophe. On earthquakes, leaves groups of survivor trapped in a dense concentration, or in floods can leave survivors scattered on the area. Similarly, the deployment of drones in disaster areas depends on the terrain conditions. If

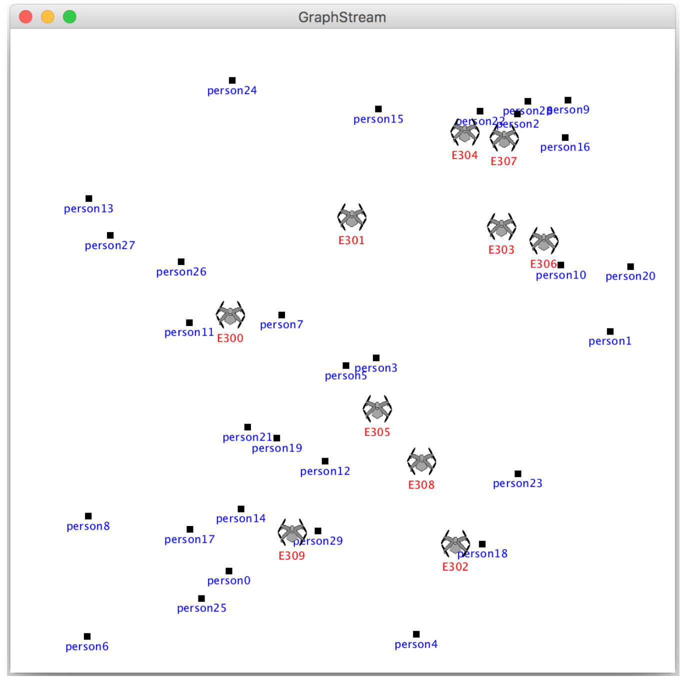

Figure 4. Simulation Example

terrain are inhospitable the deployment is required to be done by air otherwise they can be dropped in a scattered manner.

Therefore, we will define two configurations with which we will be able to generate such scenarios. Such configurations will be defined as ***SPREAD*** and ***DENSE***. For the MANETs nodes, such configuration will be translated in terms of deployment on the disaster area. Likewise, for the survivors this will be translated in terms of how the survivors are scattered or deployed across the disaster zone.

The first configuration will be named ***SPREAD***. For the survivors, this will be a random uniform distribution deployment across the simulation area. For the drones, will be translated in a connected graph placed on a random uniform distribution manner.

The second configuration will be named ***DENSE***. For the survivors, this will consist on a concentration of survivors. The groups of survivors will define the number of survivors per group. The groups of survivors will maintain a minimum distance among them. For the drones, a random position on the grid will be used as long as the condition that the generated graph is connected is fulfilled.

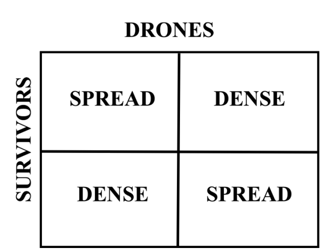

Figure 5. Deployment scenarios

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The findings presented in this work, will cover a total of four scenarios that will be simulated as shown in Figure 5.

In Figure 7 it can be observed the initial state of the scenarios combination from Figure 5 in Figure 7a, 7c, 7e and Figure 7g. Likewise the final state will be shown in Figure 7b, 7d, 7f and Figure 7h.

SPREAD survivors with ***DENSE*** MANET deployment scenario. This scenario addresses circumstances in which the survivors are scattered across the affected area and the only way to deploy the drones is in a dense concentration such as air drop from an aircraft, helicopter, etc. An example of such simulation of this scenario is shown in Figure 7a and Figure 7b.

SPREAD survivors with ***SPREAD*** MANET deployment scenario. This scenario addresses circumstances in which the survivors are scattered across the affected area and drones can be spread across area. An example a simulation of this scenario is shown in Figure 7c and Figure 7d.

DENSE survivors with ***DENSE*** MANET deployment scenario. This scenario addresses circumstances in which the survivors are clustered across the affected area in groups and drones are deployed in a dense concentration. Such scenario denotes disasters in which the survivors are trapped and drones are deployed by air due to the inhospitable terrain to deploy them by ground vehicles. An example a simulation of this scenario is shown in Figure 7e and Figure 7f.

Finally ***DENSE*** survivors with ***SPREAD*** MANET deployment scenario. This scenario addresses circumstances in which the survivors are across the affected area in groups and drones can be spread across the area. Such scenario denotes disasters in which the survivors are trapped and drones can be deployed by air or ground. An example a simulation of this scenario is shown in Figure 7g and Figure 7h.

It can be observed in Figure 7b and Figure 7h that regardless the configuration deployment either ***DENSE*** or ***SPREAD*** the virtual back bone will be formed. Also note that that the nodes maintain a range of distance among them. Observe that for purposes of disaster applications, when we have a ***DENSE*** deployment for survivors, as shown in Figure 7e, if a MANET drone reaches one survivor of such group, neighboring survivors of such survivor could provide their data to the connected survivor.

D. Simulation Metrics

With the combination of the defined scenarios, metrics to evaluate the performance of the mass-spring implementation on EESOA are required. We will define the metrics based on the initial and final deployment. This will be applied for the MANET as well as the survivors. Thus, we have defined two metrics. Coverage Area (CA) which will be defined as an approximation of the cumulative area which each node of the MANET can receive any survivor signal, see (2) below.

$$CA \approx \bigcup_{i=1}^{n} A_i \tag{2}$$

Where:
A_i The area of each i^{th} ESSOA node
n The number of EESOA nodes

The second metric will be the number of the survivors found. Both metrics are key factors to take into account when deploying a MANET for disaster applications.

We will obtain the initial and final CA as well as the number of survivors found. The final metrics will be computed once the simulation have converged for comparison purposes. Given the mass-spring model and given and equilibrium distance defined on (1). We will define a converged state of the simulation once the nodes cannot longer move since the sum of those forces have cause them to reach the equilibrium. When the simulation converges, neither the CA or survivors found metrics will change from such converged time onwards.

E. MANET node

This work considers the node as an autonomous wireless mobile device with a non-rechargeable battery. It is assumed that the node knows its coordinates (x, y). The node coverage area will be assumed to be a r square. Therefore, the CA will be square centered on the MANET node regardless its (x, y) location as denoted in Figure 6.

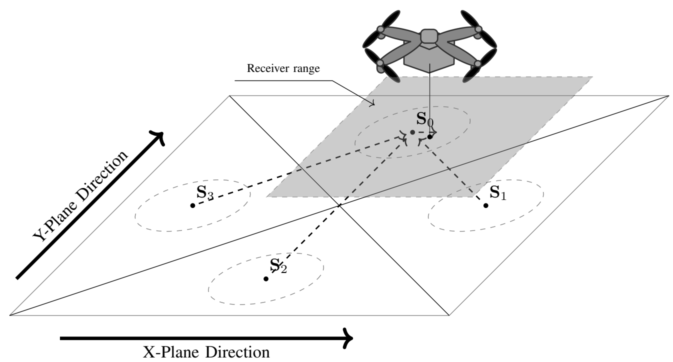


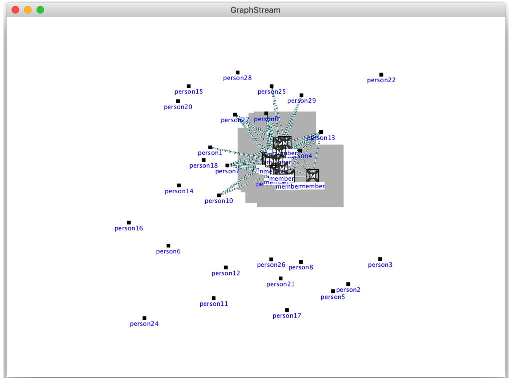
Figure 6. EESOA node coverage area

V. Simulation Results

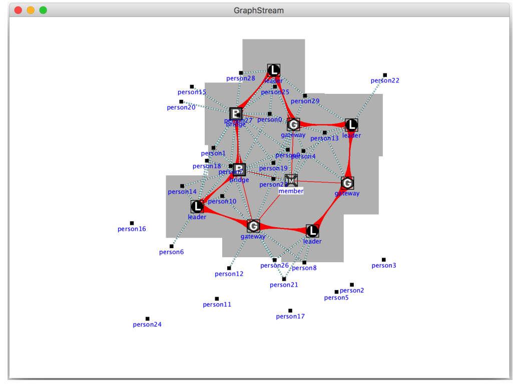
Simulation was performed in a Java discrete-event simulator paired with the Graphstream library. The setup parameters for the is described in Table I. Simulation was performed with 15 drones and 50 survivors in a 50x50 mts grid area. The aforementioned was performed for the 4 scenarios defined in Figure 5. For each scenario, 10 simulations were performed until each simulation reached a converged state as defined in Section IV-C.

A. Dense Manet Spread Survivors Scenario

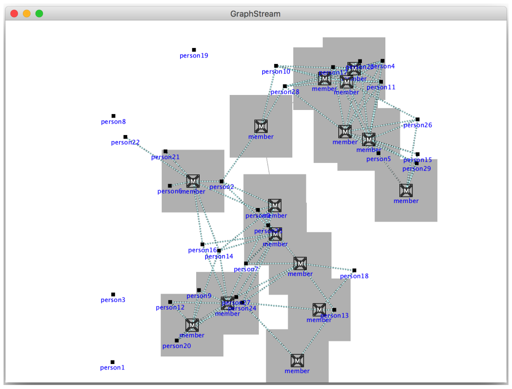
The final coverage area was significantly greater than the initial when the initial deploy configuration for nodes was ***DENSE*** as shown in Figure 8. On average, the final area showed an increase ratio of 3.7 and got to 82% from the ideal coverage area (1500 mts^2). Likewise, the final number of survivors found was greater than initial finding an average of 22 survivors (See Figure 9), showing an increase of 28% more survivors found.



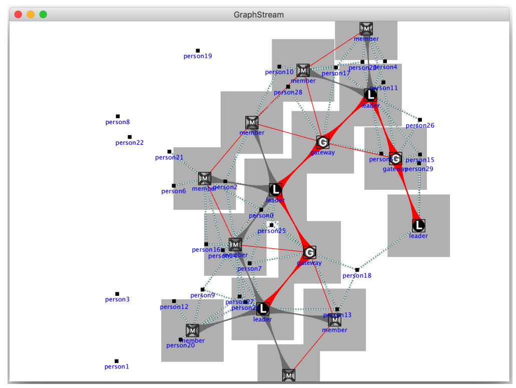
(a) Initial Dense MANET deployment with Spread survivors



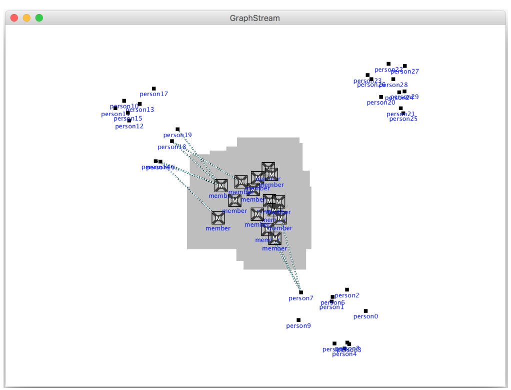
(b) Final Dense MANET deployment with Spread survivors



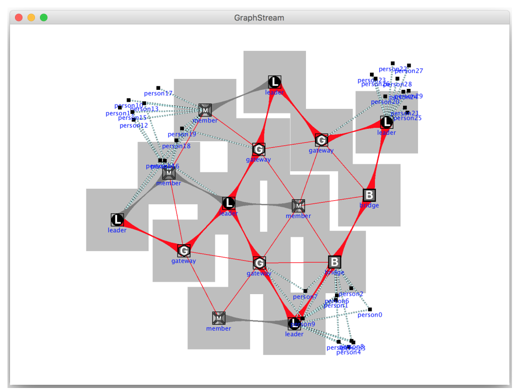
(c) Initial Spread MANET deployment with Spread survivors



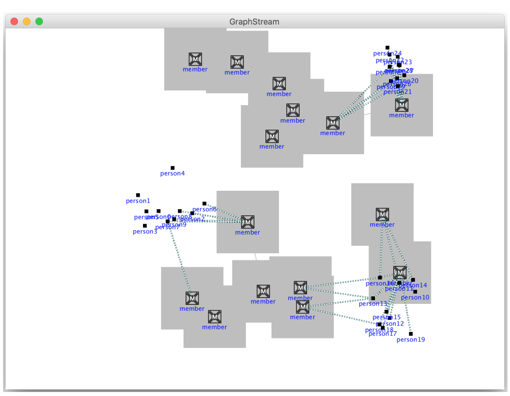
(d) Final Spread MANET deployment with Spread survivors



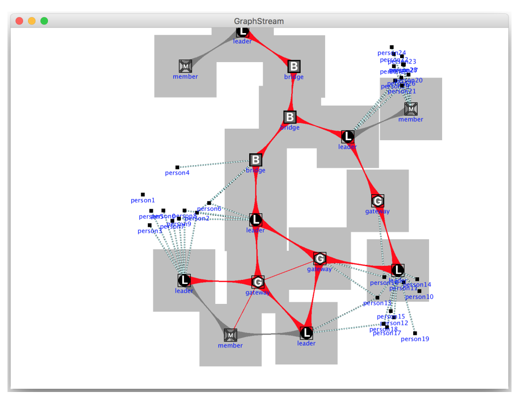
(e) Initial Dense MANET deployment with Dense survivors



(f) Final Dense MANET deployment with Dense survivors



(g) Initial Spread MANET deployment with Dense survivors



(h) Final Spread MANET deployment with Dense survivors

Figure 7. Initial and Final Simulation Scenarios Combination

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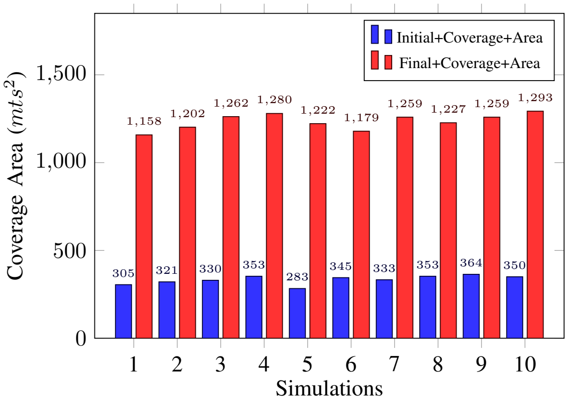

Figure 8. Dense MANET & Spread Survivors: Coverage Area

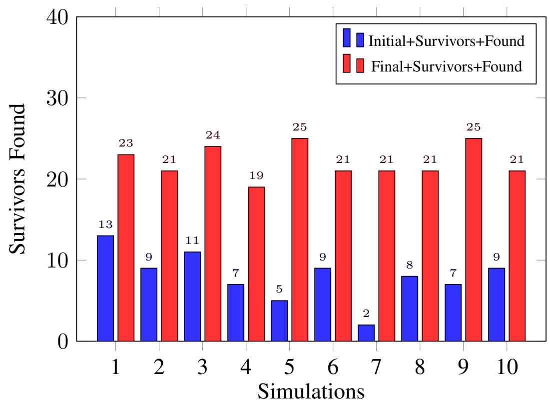

Figure 9. Dense MANET & Spread Survivors: Survivors Found

B. Spread Manet Dense Survivors Scenario

When deployment of drones was ***SPREAD*** the increase of CA against the initial state was less than when the configuration for drones was ***DENSE***. With a ratio of 1.4 as Shown in Figure 10. Also the final CA was 77% of the ideal coverage area. The number of survivors found was bigger than the ***DENSE*** MANET (See Figure 11). With ***SPREAD*** survivors with an average of 23. Thus, with an increase of 19.4% more survivors found against the model without the mass-spring.

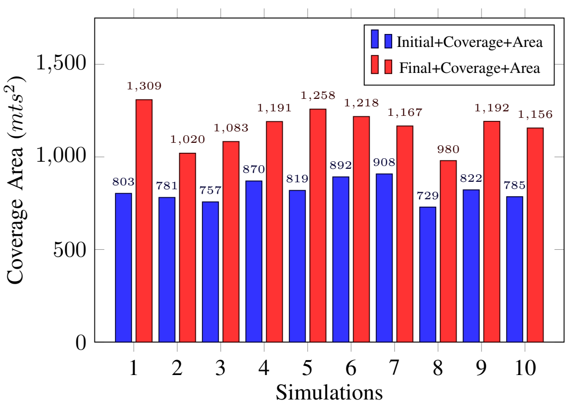

Figure 10. Spread MANET vs Dense Survivors: Coverage Area

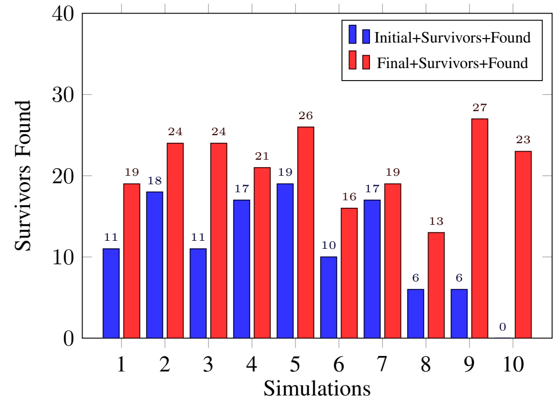

Figure 11. Spread MANET vs Dense Survivors: Survivors Found

C. Spread Manet Spread Survivors Scenario

On a ***SPREAD*** MANET configuration, increase ratio was similar against the ***SPREAD*** MANET with ***DENSE*** survivors scenario with a 1.43 increase ratio and $\sim$80% of the ideal coverage area (See Figure 12). On this configuration the percentage of survivors found not as significant against the two aforementioned scenarios with a increase of 9.2% (See Figure 13). This is consistent since CA increase was not significant, when ***SPREAD***, L limits further CA expansion.

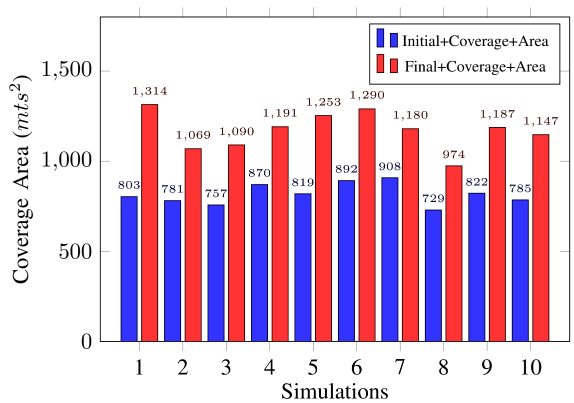

Figure 12. Spread MANET vs Spread Survivors: Coverage Area

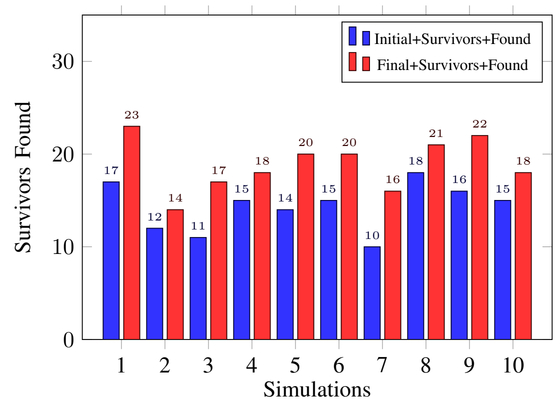

Figure 13. Spread MANET & Spread Survivors: Survivors Found

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D. Dense Manet Dense survivors

As in scenario described in section V-A, with ***DENSE*** MANET deployment the increase ratio was 3.7 with an 83% of the ideal CA. CA comparison is shown in Figure 14. Similarly, as shown in Figure 15, the survivors found percentage increase against the initial state was 30% more survivors found. We can observe that on both scenarios V-A and V-D, when the deployment of nodes is ***DENSE***, performance is better.

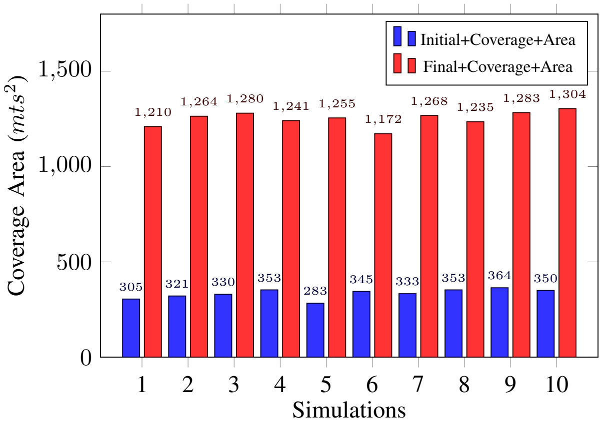

Figure 14. Dense MANET & Dense Survivors: Coverage Area

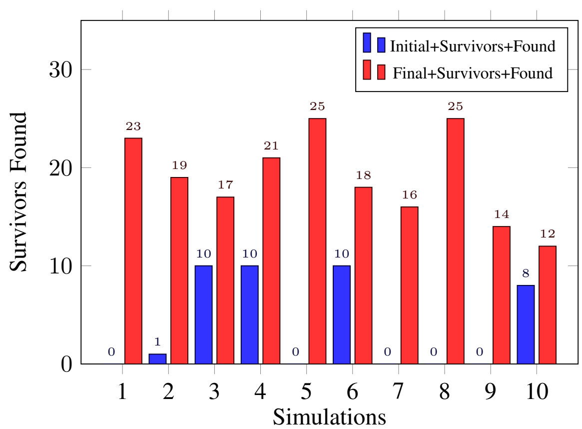

Figure 15. Dense MANET & Dense Survivors: Survivors Found

To have a global perspective and for comparison purposes in Figure 16 and Figure 17 we show the final CA and number of survivors for the 4 scenarios. Nodes deployment are denoted by the prefix "D" for ***DENSE*** deployment and "S" for ***SPREAD***. Figure 16 shows an overall better performance for CA when the deployment of MANET nodes is ***DENSE***. In Figure 17 when the MANET nodes deployment is ***DENSE*** and survivors deployment is ***SPREAD*** performance is better.

VI. Conclusion and Future Work

This paper proposed the implementation of the mass-spring model on the EESOA cluster-based algorithm for natural disaster applications. A java-based discrete event simulator using the Graphstream library was developed as shown in Section IV-A. The decentralized mass-spring interaction among nodes provided a connected-awareness emergent behavior.

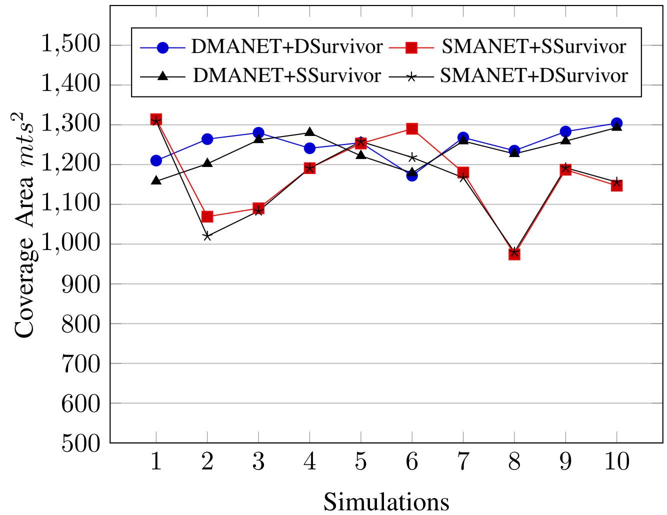

Figure 16. MANET & Survivors scenarios Area comparison

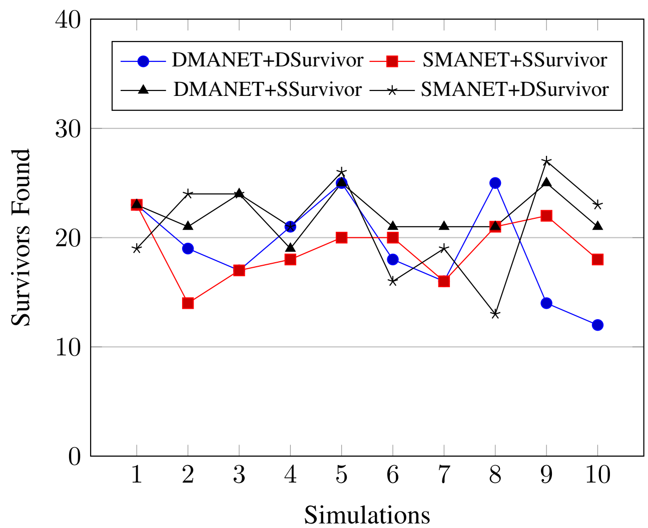

Figure 17. MANET & Survivors scenarios: Survivors comparison

Simulation results have shown that the implementation of the mass-spring on EESOA shows promise. For coverage area the scenarios in which the MANET deployment configuration is ***DENSE*** with an average of 82% of the ideal CA and an increase ratio of at least 3.7. For the number of survivors found we can see that there is no clear improvement if the layout of the survivors is Dense ***DENSE*** or ***SPREAD***. Nevertheless, when the MANET configuration was ***DENSE*** we can see in Figure 17 a slight increase in performance with at least 28% increase against the initial state. The average of survivors found against the ideal (50) is at least 38%. For the cases in which the deployment of survivor was ***DENSE***, such 38% means we found more than one third of the survivors. The aforementioned shows promise when we have a group of survivors in a ***DENSE*** deployment. For the actual search and rescue operation, if we find at least one survivor of a group of survivors, neighboring survivors could use the connected survivor as relay.

Thanks to the mass-spring model implementation on the EESOA nodes, the nodes will always generate a vector $\vec{v}$ with which will try to achieve equilibrium on the system. Thus, taking into account the range of the nodes plus their L and k constants, nodes will expand as long as possible increasing the probability of find more survivors. The aforementioned will be performed without compromising connectivity.

The implementation of the mass-spring model on the EESOA cluster based algorithm shows promise in performance on scenarios when the MANET deployment is ***DENSE*** and the survivors layout on the disaster area is ***DENSE***. Hence, providing a de-centralized cluster based algorithm which is efficient for communication as shown in [9] while maintaining the connectivity as a constraint as defined on [17] by implementing the mass-spring model. Finally proposing a connectivity aware model with an self-organized emergent behavior.

Application of MANETs with UAVs for operations in disastrous areas is an undergoing increasing research field [8]. L and k constants parameter values for EESOA optimal performance is left for future research. Moreover optimal values for specific disaster scenarios such as high density survivors concentration (evacuation points) or uniform distribution (floods, typhoon) remains as an ongoing research. In future work simulations on a large scale scenario should be performed. Battery consumption should be included in future simulations as well as delay and propagation model. The challenge of an autonomous decentralized exploration algorithm that takes full advantage of the EESOA backbone and mass-spring system remains open. Future work includes the implementation of the proposed algorithm on real UAVs.

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