An evolutionary computation approach for optimizing connectivity in disaster response scenarios

Item type	Other
Authors	Reina, D. G.; Toral Marin, S. L.; Bessis, Nik; Barrero, Federico; Asimakopoulou, E.
Citation	D.G. Reina et al. An evolutionary computation approach for optimizing connectivity in disaster response scenarios, Appl. Soft Comput. J. (2012), http://dx.doi.org/10.1016/j.asoc.2012.10.024
Journal	Applied Soft Computing
Downloaded	

Manuscript Number:

Title: AN EVOLUTIONARY COMPUTATION APPROACH FOR OPTIMIZING CONNECTIVITY IN DISASTER RESPONSE SCENARIOS

Article Type: Fast Track Paper

Keywords: Mobile Ad Hoc Networks (MANETs); Disaster Scenarios; Connectivity; Genetic Algorithm; NS-2

Corresponding Author: Professor Nik Bessis,

Corresponding Author's Institution: University of Derby

First Author: Daniel Gutiérrez Reina

Order of Authors: Daniel Gutiérrez Reina; Sergio Toral Marín; Nik Bessis; Federico Barrero; Eleana Asimakopoulou, PhD

Abstract: This article presents an evolutionary computation approach for increasing connectivity in disaster scenarios. Connectivity is considered to be of critical importance in disaster scenarios due to constrained and mobile conditions. Herein, we propose the deployment of a number of auxiliary static nodes which their purpose is to increase the reachability of broadcast emergency packets among the nodes which are participating in the disaster scenario. These nodes represent people and vehicles acting in rescue operations. The main goal is to find the optimum positions for the auxiliary nodes, reinforcing the communications in points where certain lack of connectivity is found. These points will depend on the movements of the rescue teams which are influenced by tactical reasons. Due to the complexity of the problem and the number of parameters to be considered, a genetic algorithm combined with the network simulator NS-2 is proposed to find the optimum positions of the auxiliary nodes. Specifically, NS-2 is used to model the communication layers and provide the fitness function guiding the genetic search. The proposed approach has been tested using the disaster mobility model included in the motion generator BonnMotion. The simulation results that have been obtained demonstrate the feasibility of the proposed approach and illustrate its applicability in other scenarios where certain lack of connectivity is evident.

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Dear Editor,

Please accept our manuscript submission as a possible publication at your journal. Please note that our Fast Track submission is an extended version from our paper published in the 3rd IEEE INoS-2011.

Prof Nik Bessis
On behalf of the manuscript authors:
Gutiérrez Reina, D., Toral Marín, S.L., Bessis, N., Barrero, F., Asimakopoulou, E.

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Highlights:

This article presents an evolutionary computation approach for increasing connectivity in disaster scenarios. Connectivity is considered to be of critical importance in disaster scenarios due to constrained and mobile conditions.

Connectivity in ad hoc networks can only be guaranteed either by increasing the number of nodes in the deployed scenario or by increasing the nodes' power transmission.

The communications in disaster scenarios are carried out during very short period of time and normally such communications are broadcasting packets shared by nodes in order to inform and alert other nodes about the situation.

This article deals with increasing connectivity guarantees in disaster scenarios. The main objective is to demonstrate whether evolutionary computation techniques can be applied to disaster management in order to improve the reachability of ad hoc networks in such constrained conditions.

The disaster area mobility model is based on a method called separation of the room. Using this method, our disaster scenario is divided into four separate areas including: incident site, casualties' treatment area, transport zone, and technical operational command zone.

This article presents an evolutionary computation approach for solving connectivity problems in disaster scenarios. We have used reachability as the connectivity metric. Improvements of up to 26.98% have been achieved by placing auxiliary beacon nodes for inter-communications. When intra-communications are considered, the improvement reaches 11%. The proposed approach relies on a GA implementation which uses the network simulator NS-2 to calculate the fitness function.

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Authors: Gutiérrez Reina, D.[1], Toral Marín, S.L.[1], Bessis, N.[2], Barrero, F.[1], Asimakopoulou, E.[2]

[1]*University of Seville (Spain)*

[2]*University of Derby (UK)*

[1] Escuela Superior de Ingenieros. Avda. Camino de los Descubrimientos, s/n

41092 Sevilla (Spain)

email: toral@esi.us.es, fbarrero@esi.us.es, dgutierrezreina@us.es

phone: +34 954 48 12 93; fax: +34 954 48

[2] School of Computing and Mathematics, Kedleston Road

Derby, DE22 1GB (UK)

email: n.bessis@derby.ac.uk, eleana.asimakopoulou@googlemail.com

phone: +44 1332 592108; fax: +44 1332 597741

Corresponding author: N. Bessis

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Keywords Mobile Ad Hoc Networks (MANETs); Disaster Scenarios; Connectivity; Genetic Algorithm; NS-2

1. Introduction

Mobile ad hoc networks (MANETs) are decentralized networks in which communication between nodes is deployed without the need of an underlying infrastructure. These nodes have power constraints, limited coverage area, and each node can act as a router in the network [27][16]. MANETs are mainly suitable for those applications where the deployment of a new fixed infrastructure is purposefully unplanned and practically difficult or impossible. Thus, MANETs are considered as the most suitable candidates for disaster scenarios due to their capability for being self-organized, self-repaired, and self-recovery networks. This is due to that communications in disaster scenarios are most likely to be destroyed, non-functioning or severely compromised following a disaster occurrence caused by natural or man-made events. In disaster response scenarios, the rescue teams should take actions quickly and operate efficiently in order to reduce further risks and fatalities. Readers in this article are pointed to [6] for further reading with regard to these contexts. In general, cooperation in such scenarios is of a significant importance in order to support disaster managers identifying and coordinating required tactical movements and response operations. Within this context, connectivity as a quality of service should be guaranteed in order to achieve the aforementioned level of cooperation.

Connectivity in ad hoc networks can only be guaranteed either by increasing the number of nodes in the deployed scenario or by increasing the nodes’ power transmission. The number of deployed nodes depends on the number of people who are participating in the emergency situation. In this article, nodes represent members of the response operation and rescue teams like fire-fighters, police officers, paramedics, nurses, and also vehicles such as ambulances and helicopters. Consequently, each node has different features in terms of mobility. Thus, the number of deployed nodes is generally limited by the number of the resource components available from the rescue teams. On the other hand, the power transmission is a design factor; it depends on the technology used. The transmission power is normally fixed and only varies due to the environment conditions. The communications in disaster scenarios are carried out during very short period of time and normally such communications are broadcasting packets shared by nodes in order to inform and alert other nodes about the situation. These messages are normally forwarded from a source node to a destination node. Routing protocols for ad hoc networks define the rules followed by the nodes in order to seek and find reliable communication path among nodes. These algorithms should deal with mobile and variant conditions. The routing protocols for ad hoc networks are normally categorized as reactive and proactive routing protocols [9]. The reactive protocols are more suitable for mobility conditions and consequently, more suitable for disaster scenarios [24][25]. Although many reactive routing protocols have been proposed for ad hoc communications [11], there is still a lack of specific reactive routing protocols for disaster scenarios. In general, reactive routing protocols use flooding as the broadcasting technique to discover communication routes. This technique can be also used to disseminate broadcasting information. The reachability of nodes depends on the efficiency of the flooding technique. Collisions and congestion are the classical problems which deteriorate the performance of the flooding technique.

To summarize, this article deals with increasing connectivity guarantees in disaster scenarios. The main objective is to demonstrate whether evolutionary computation techniques can be applied to disaster management in order to improve the reachability of ad hoc networks in such constrained conditions. The network simulator

NS-2 [14] will be useful to model the communication layers of ad hoc networks whereas the motion generator Bonnotion [4] creates the movements of nodes in a disaster scenario. This article continues with section 2 which provides a background of related work. The importance of mobility models in ad hoc networks is stated in section 3, where the mobility model for disaster scenarios is also presented. The connectivity issue in disaster scenarios is stated in section 4. While section 5 contains the proposed approach to solve the connectivity problem, section 6 describes the implementation of the genetic algorithm. Sections 7 and 8 present the simulation scenario used to validate the proposed approach and the simulation results. Finally, the conclusions are presented in section 9.

2. Related Work

The features of the mobility model for disaster scenarios have been evaluated in terms of mobility metrics [3]. This mobility model is different from classical synthetic mobility model since the movements of nodes follow tactical reasons and such movements are not distributed throughout the simulation scenario. Several real life disaster scenarios have been modelled by using this mobility model [2][3][4]. In our previous works, several routing protocols for ad hoc networks have been evaluated under the disaster area mobility model [24][25]. The Ad Hoc on Demand Distance Vector (AODV) [23] achieved the best performance for the two types of communications evaluated: inter-communications and intra-communications. It was also found that the mobility model for a disaster area can be seen as a combination of different simulation scenarios since different density and mobility of nodes can be found in each tactical area. On the other hand, connectivity is a very important issue when designing MANETs [13]. In this kind of networks, nodes are mobile; therefore they are continuously entering and getting out the coverage areas formed by other participating nodes. In turn, participant nodes as well as the number of nodes in the network are constantly changing. Evolutionary computational approaches are suitable to deal with such variable conditions. Genetic Algorithms (Gas) are widely used as optimization techniques to solve complex problems. Genetic algorithms have been applied to intelligent transportation systems [26], website structure mining [20], and Wireless Sensor Networks (WSN) [29][32] among other types of ad hoc networks.

The connectivity issue can also be seen as the topological problem. In a topological problem the objective is to find the optimal topology to optimize a certain parameter or a combination of several parameters such as end-to-delay or bandwidth. A hybrid GA was used by Tzu-Chiang et al [29], to improve the performance in local and global topology discovery of shared multicast trees. A similar idea was used by Zhou et al [32], in two-tiered WSN. The use of NS-2 to evaluate the fitness function is very interesting since it allows the designer to model the communication layers and the signal propagation models. Xu [31] included a GA in NS-2 for analyzing topology control in ad hoc wireless networks. The implemented topology control was able to calculate the suitable node’s coverage area to minimize the energy consumption. The distinction of this article as compared with previous works is that the connectivity issue is addressed and solved using an evolutionary-based approach.

3. Mobility models for ad hoc networks

Mobility models determine the movements of nodes in the deployed scenario during the simulation time. In general, the mobility model can be categorized as synthetic mobility model or trace-based mobility model [12]. In the synthetic mobility model, nodes move according to certain equations and rules. On the other hand, nodes in the trace-based mobility model obtain mobility information from real trace files. These files are obtained by tracking mobility of nodes from real scenarios. The synthetic mobility model has attracted a lot of attention in the last decades due to its simplicity. Several synthetic mobility models have been proposed to evaluate the performance of ad hoc networks under different mobility patterns [12]. So far, the Radom Waypoint mobility model is the most used in ad hoc networks. However, it does not represent any real life scenario. In addition, the nodes do not follow a uniform density since central positions are denser than the others as the simulation time goes on. The Random Walk and Random Direction mobility models solve the aforementioned density problem. The Manhattan mobility model allows nodes to move following determined paths like vehicles [7]. The simulation scenario is divided into different grids and at each intersection nodes have certain probability to turn on. This mobility model is suitable for describing vehicles in urban scenarios. Groups of nodes are taken into consideration in the Reference Point Group (RPG) mobility model. In RPG mobility model, there is a leader in each group which determines the movements of all nodes in the group. There exist other group mobility models for more specific situations such as the Column mobility model, the Nomadic mobility model, and the Pursue mobility model. Nevertheless, real scenarios are a combination of several mobility patterns. In real scenarios someone can found vehicles and people moving at different speeds or different node's density as well. In summary, there is a lack of mobility models for real life scenarios. This lack is partially solved in disaster scenarios since Disaster Area model represents the movement of rescue teams in disaster scenarios [3] [4].

3.1 Modelling Mobility in Disaster Scenarios

In the above mentioned simulation models, nodes move freely throughout the whole simulation area. However, in a disaster scenario nodes move following tactical reasons. The movements are oriented to certain points which are more important than others. For instance, the identification of the location of a patient is an important point of reference in a disaster scenario. The disaster area mobility model is based on a method called separation of the room [3][4]. Using this method, the disaster scenario is divided into different areas. These areas (see Figure 1) are: incident site, casualties' treatment area, transport zone, and technical operational command zone.

- Incident site: is the place where the disaster happened. In this place, injured people are normally found waiting to be transported to a casualties' treatment area. With regard to the rescue team, fire-fighters or police officers could belong to the incident site.
- Casualties' treatment area: consists of two places, (a) patient waiting for treatment and (b) the casualties clearing station. In (a), people wait for a first inspection and classification; after that they can be transported to a casualties' clearing station (b) in which patients will be waiting to be transported to a hospital. Paramedics belong to this area.
- Transport zone: is an area where transport units wait in stand-by areas to transport people to hospitals. The transport units can be either ambulances or rescue helicopters.
- Technical operational command: is the zone where the rescue operations are commanded and it is usually located in the casualties' treatment area.

[FIGURE 1]

It is noticeable that each area represents a different scenario where node’s density and/or node’s speed are different from one to another. Each tactical area has an entry and an exit point. In each area two types of nodes can be distinguished namely transportation and non-transportation nodes. The non-transportation or stationary nodes always remain in the same area. In contrast, transportation nodes are in charge of bringing injured people from one area to another. The transportation nodes can represent vehicles like an ambulance and people carrying injured people on a barrow. In Figure 1 the movements of the transport units are represented by the black arrows. In the incident site area each node represents a transportation unit. On the other hand, the nodes in the casualties clearing station are stationary nodes. The transportation nodes operating in the parking zone leave the scenario towards a hospital after picking up a patient. This fact is simulated by the mobility model since transportation nodes leave the scenario through an exit point and go back to the scenario through an entry point. It is assumed that there are no obstacles inside the above areas since the rescue teams cleared the zones before operating. The obstacles may be found between different areas so they only affect the transport units. Transportation nodes avoid obstacles by finding the shortest path possible between two areas. For finding the shortest path the movements of the transportation nodes are determined by methods of robot motion planning [10]. This method is based on calculating a visibility graph and using the Dijkstra’s algorithm to find the shortest path between the two areas.

Note that, this mobility model does not take into consideration mobility of patients, so it is focused on modelling the mobility of the rescue teams.

4. Formulation of the problem

Connectivity is an important issue in disaster management. A high connectivity among nodes is desired since such emergency situation requires fast response and coordination. However, features such as mobility of nodes, noisy, destructed environments and the limited power transmission, make the scenario unfeasible to have a complete connectivity deployment among nodes to support the operational tactics of the rescue teams on an on-demand fashion. Furthermore, connectivity is even more critical among nodes which are operating in different areas. For instance, the connectivity between paramedics, who are acting in the casualties clearing station and the transportation nodes, is normally low. To solve such lack of connectivity, we propose an evolutionary solution for increasing connectivity between nodes. The objective is to place auxiliary nodes, namely beacons, which increase connectivity in the deployed scenario. Thus for a given mobility of nodes, the challenge of the proposed approach is to find the optimal positions for a given number of beacons. Note that the number of beacons is a limited resource. In contrast, the number of solutions may be so many that it would be impractical to evaluate each possible combination. It is important to highlight that although this approach is evaluated in disaster scenarios, it may also be applied to other scenarios where low connectivity is evident.

In this article, connectivity is measured by reachability as a metric. Reachability is normally defined as the ratio of nodes that received the broadcast packet to the total number of nodes in the network. We have chosen broadcast packets since they are normally used to disseminate emergency data in ad hoc networks. The reachability is calculated by using the total number of nodes deployed in the disaster scenario. The rescue team and the set of beacons both are also taken into consideration to calculate reachability.

5. The proposed approach

Due to the complexities of finding an optimal solution, a simulation structure based on NS-2, BonnMotion [5] and a GA has been implemented, see Figure 2. The network simulator NS-2 is an object-oriented simulator developed as a part of the VINT project at the University of California in Berkeley [14]. It is extensively used by researchers and academia in order to simulate both wired and wireless networks [18] [21]. In the context of the proposed framework, NS-2 is used to evaluate the GA fitness function (see Figure 2). All simulation parameters are defined in a .tcl file, namely disaster.tcl, which uses Otcl as the programming language. The main features described in the .tcl file are the mobility of nodes and the traffic pattern among nodes. The mobility generator BonnMotion has been used to generate the movements of nodes in a disaster scenario. The characteristics of each simulation area of the disaster area mobility model are defined in a PERL (Practical Extraction and Report Language) script namely Disaster_Mobility.pl. This script will call BonMotion to generate a .tcl mobility file and integrate it into the Disaster.tcl. BonnMotion is a free available mobility generator that creates and analyzes mobility scenarios. It has been developed at the Institute of Computer Science IV of the University of Bonn. In addition, the traffic patterns have been defined by using a modification of the cbr generator provided with NS-2 package. Such modification has been denoted as CBRgen_Disaster. In this traffic generator two types of Constant Bit Rate (CBR) communication flows can be defined a) inter-communications and b) intra-communications. In inter-communications, the traffic flows are defined between two nodes located in the same area, for instance two nodes located in the incident site. By contrast, in intra-communication flows two nodes located in separated areas are defined as source and destination nodes, for instance the source node is located in the casualties clearing station and the destination node is located in the transportation zone. The output of CBRgen_Disaster is a .tcl file, namely traffic.tcl (see Figure 2) which is also integrated into the Disaster.tcl. A master C program is responsible for integrating traffic and mobility patters in Disaster.tcl. Once both mobility and traffic patterns have been generated, the simulation in NS-2 can be carried out. The main output of NS-2 is a trace file that logs all events occurred during the simulation time. This trace file is processed by a PERL script namely Reachability.pl (see Figure 2). This file calculates the reachability for the given scenario. This result is used by the master C program to check whether the optimal outcome has been already reached. Otherwise, a new generation will be created by using crossover and mutation operations. The master program consists of a loop whose iterations correspond to the evaluations of the population taken into account by the GA. At each iteration, the previous framework runs N_t different simulations using NS-2, where N_t is the number of chromosomes in a population.

6. Genetic Algorithm implementation

Genetic Algorithms are a family of computational models inspired by evolution [15]. These algorithms encode a potential solution to a specific problem on a simple chromosome-like data structure and apply recombination operators to these structures in order to preserve critical information [20]. The mechanism is based on the selection scheme from (evolution strategy [19]. The algorithm maintains a population of

N_t chromosomes. The fitness function evaluates the goodness of each chromosome. The best chromosomes are included directly in the next generation. The algorithm starts using an initial population Pi that is composed of N_t chromosomes. Goldberd [15] studied the optimum number of chromosomes for a population according to the chromosome's length. Goldberd's main conclusion was that the optimum population's size value gets higher as the chromosome's length increases. The initial population is generated randomly in order to preserve the diversity in the population. The GA is based on two operations, crossover and mutation. These operations are responsible of generating chromosomes of a new population. The crossover consists of using two members of a population P_j to generate two new members of the next population P_{j+1} by crossing their genetic information. The new chromosomes contain genetic information from the predecessors. The purpose of mutation is to change the genetic information of a chromosome included in P_j to generate a new chromosome of P_{j+1}. Figure 3 illustrates the implemented genetic algorithm.

[FIGURE 3]

6.1.Chromosome encoding

A chromosome C_i is a set of positions of the beacon nodes. The beacon nodes are deployed forming a collaborative system working along with the mobile nodes. We denote $K(p_1,p_2,\ldots,p_n)$ as the set of parameters coded to form the chromosome, where n is the total number of parameters. Each parameter is coded using a number of bits B_l (from). The chromosome's length is defined as follows:

.

The composition of a chromosome is shown in Figure 4.

[FIGURE 4]

Note that in our case the parameter coded will be the positions of the beacon nodes.

6.2.Evaluation function

In the proposed approach, the fitness function is evaluated running a simulation in NS-2. This simulation determines the performance of the network according to any metric. In our case the target metric is the reachability among nodes in the network. Consequently, the reachability is the evaluation function.

6.3.Stopping criteria

The population's average fitness function has been chosen as the stop criterion of the genetic algorithm. If $P_{av,j}$ denotes the population's average fitness function, the stopping criterion can be formulated as:

6.4.Procedure of transition

The procedure used to generate a new population P_{j+1} from the previous population P_j is as follows:

1) The best 20% chromosomes are copied from P_j to P_{j+1}. This ensures that the best individuals of each population will be included in the next generation. Thus, the likelihood of using a good chromosome for reproduction operations gets higher.

2) The 80% of the new chromosomes are generated by using crossover and mutation operations. This aims to favour the diversity of the chromosomes. P_c denotes the probability of a chromosome i to take part in a crossover operation. Similarly, P_m is the probability of a chromosome i to take part in a mutation operation.

6.4.1. Crossover

80% of the new population is obtained using crossover operation. The probability Pc of a Ci is calculated as follows:

The term stands for the evaluation of the fitness function for the chromosome . In this way, the best chromosomes are most likely to be selected. Note that the genetic algorithm is an elitist algorithm where the best individuals always pass to the next generation. The crossover operation is illustrated in Figure 5.

[FIGURE 5]

A two-point crossover operation has been implemented. The two points of cross are denoted by p_{k1} and p_{k2}, where , and is the size of the chromosome. The value of k_1 and k_2 are randomly chosen for each crossover operation and always . These points divide each chromosome into three parts namely RG_j, MG_j and LG_j. The two new chromosomes are then obtained swapping $LG_{j,1}$ by $LG_{j,2}$, and $RG_{j,1}$ by $RG_{j,2}$, see Figure 5.

6.4.2. Mutation

The new population is also obtained by mutation operation. The purpose of mutation is to make small changes in the chromosomes. These changes consist of modifying one chromosome’s bit. According to De Jong [17] we have calculated P_m as . The mutation operation is illustrated in Figure 6.

[FIGURE 6]

The position of the mutated bit is denoted by p_m, where . The value of p_m is randomly chosen for each mutation operation.

7. Evaluation of the proposed framework

The proposed disaster scenario is depicted in Figure 7. We have considered one incident location where injured people are picked up and brought to the patient waiting for treatment area, then, they are transported to the casualties clearing stations where a first aid can be received. Two casualties clearing stations have been considered. Finally patients are transported to a hospital. The technical operation has only been considered for completeness. However, it is not considered to evaluate the reachability of the network since the static nodes inside this area do not communicate to other outside nodes.

[FIGURE 7]

The crosses in each simulation area represent the entry and exit points. The features of each technical area are shown in Table 1.

[TABLE 1]

In order to determine the positions of the beacon nodes, a grid has been defined. We have considered a node’s coverage range of 50m so the beacon nodes have been distanced 50m from each other. The proposed evolutionary approach determines which positions of the grid are the most suitable positions for the auxiliary nodes in order to increase the connectivity of the ad hoc network.

[FIGURE 8]

Since 126 positions are possible, the number of combinations depends on the number of deployed beacons. The number of possible positions can be calculated as follows

Where N_b is the number of available beacon nodes. For instance, if , the number of combinations is . It is important to highlight that each combination is a different simulation. The time consumed by the simulation has been measured for different number of beacon nodes. For the simulation takes 2.20 min so for evaluating all possible positions 41835.99 years would be need. This result justifies the use of a GA to find an optimal solution. A future step of this work is to leverage computational power from a mobile cloud as to speed up the calculation.

In order to code the 126 positions, 7 bits are needed. The chromosome’s length depends on the number of beacon nodes. We have considered and to validate the proposed approach so we have considered chromosomes with a length of 35 and 70 respectively. The population sizes are 70 and 140 respectively (Alander, 1992). As it has been mentioned above, the 20% of the best individual pass directly to the next generation. Consequently, for 14 individuals pass to the next generation and for the number of individuals is 28. The mutation probability also depends on the chromosome’s length so the value for mutation probability will be and respectively.

As mentioned earlier, two types of communications are defined: 1) inter-communications and 2) intra-communications. The inter-communications are established between two nodes located at different tactical areas. In contrast, the intra-communications are established between two nodes located at the same tactical area.

In this article we have used the reachability as the connectivity metric. Reachability is a metric that is widely used in broadcasting techniques for ad hoc networks [22][8]. The reachability of a broadcasting procedure is normally calculated as the number of nodes receiving the broadcast packet divided by the total number of nodes in the network. We have previously obtained the reachability of the network without placing any beacon node. The reachability for inter-communication is 23.80% and the reachability for intra-communication is 72.52%. It is clear that the reachability for inter-communications is much lower than the reachability for intra-communications. This result can be expected since the inter-communications can only be established through transport nodes. The reachability for intra-communications depends mostly on the density of nodes in the tactical area.

The mobility of nodes has been obtained by using the motion generator BonnMotion 2.0. The technical movements of the rescue team are represented in Figure 9.

[FIGURE 9]

On the other hand, the routing protocol used to evaluate the proposed approach is AODV routing protocol. It uses broadcasting packets, namely request packets, to discovery new routes between a source and destination nodes. AODV is widely used in MANETs and it has been shown to have a good performance in disaster scenarios [24][25]. We have modified AODV so that only the destination node can reply to the request packets. This has been done to measure the reachability in the deployed scenario. Note that the beacon nodes help to increase the reachability by forwarding the request packets. The placement of beacon nodes favours the retransmission of packets. It is important to highlight that the discovery procedure of AODV is based on an expanding ring search [23]. It means that each request packet has a Time to Live field (TTL) so the number of times that a request packet can be retransmitted is limited by the TTL value. The TTL values used are shown in Table 2. AODV begins with using a TTL value of 5, if the discovery procedure fails; it will increase the TTL value up to 7. Finally, the TTL value would be increased up to 30 if any route towards the destination node is found. As a consequence, certain positions of beacon nodes can worsen the reachability of the network since they may increase the TTL field and may stop the expanding ring search.

8. Simulation Results

This section presents the simulation results obtained for the disaster scenario depicted in Figure 7. The global simulation parameters can be found in Table 2.

[TABLE 2]

The evolution of the generation's maximum values for inter-communications and 5 beacon nodes is shown in Figure 10.

[FIGURE 10]

The obtained results and the beacon node positions are summarized in Table 3.

[TABLE 3]

When 10 beacon nodes are used the simulation results obtained are presented in Figure 11 and Table 4.

[FIGURE 11]

[TABLE 4]

As it can be seen, the network's reachability is notably increased by the location of beacon nodes. The beacon nodes are located at the bordering positions of the tactical areas in order to favour the communication between the transportation nodes and the stationary nodes. Figures 12 and 13 show the positions of the beacon nodes in the grid.

[FIGURE 12]

[FIGURE 13]

The evolutions of the generation's maximum values for intra-communications, with 5 and 10 beacon nodes are shown in Figures 14 and 15 respectively.

[FIGURE 14]

[FIGURE 15]

The obtained results and the beacon node positions are summarized in Tables 5 and 6 respectively.

[TABLE 5]

[TABLE 6]

For intra-communications the beacon nodes are in general located in the incident side. The mobility and density of this technical area cause certain lack of connectivity which is solved by including several beacon nodes closed to the exit point. In fact, two beacon nodes are located in the position 57 when 10 beacon nodes are considered. The casualties clearing station and nodes waiting for treatment areas both have a high density of nodes so there is no need for beacon nodes. For this reason, there are not significant differences between 5 beacon nodes and 10 beacon nodes. As a result, intra-communication with 5 beacon nodes is sufficient to achieve certain improvement of connectivity. For disaster scenarios with lower level of density and lower power transmission ranges, the improvement for intra-communication would be similar to that achieved for inter-communications. Figures 16 and 17 show the positions of the beacon nodes in the grid.

[FIGURE 16]

[FIGURE 17]

To summarize the simulation results, Table 7 compares reachability achieved for the different types of communications and scenarios with 5 and 10 beacon nodes.

[TABLE 7]

The improvement is up to 26.98% for inter-communications and 10 beacon nodes. For intra-communications the improvement reaches 11%.

9. Conclusions

This article presented an evolutionary computation approach for solving connectivity problems in disaster scenarios. We have used reachability as the connectivity metric. Improvements of up to 26.98% have been achieved by placing auxiliary beacon nodes for inter-communications. When intra-communications are considered, the improvement reaches 11%. The proposed approach relies on a GA implementation which uses the network simulator NS-2 to calculate the fitness function. The simulation results demonstrate the usefulness of our proposed solution. Although it has been evaluated in a disaster scenario, it may also be applied to other ad hoc scenarios where certain lack of connectivity is evident.

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Tables

Table 1. Features of the technical areas.

Area	Size (m^2)	Nº Nodes	Nº Transport Nodes
Incident Site	200 x200	30	30
Patient Waiting For Treatment	100 x100	10	8
Casualties Clearing Stations	150 x 150	15	0
Parking	250 x 200	30	25
Technical Operation	100 x 50	2	0

Table 2. Simulation parameters.

Parameter	Value
Propagation model	Two-ray
Node’s coverage area	50 m
Simulation time	500 s
Warm up period	200 s
Scenario’s size	850 x 300 m^2
MAC Layer	802.11
Link Layer	LL
Queue Model	Droptail/PriQueue
Routing Algorithm	AODV
TTL values	5, 7, 30
Traffic	CBR
Communication flows	10
Application	UDP
Packet’s size	512 bits
Transmission rate	2048 bit/s

Table 3. Generations for the simulation scenario with inter-communication and 5 beacon nodes.

Gen.	P0	P1	P2	P3	P4	R. max (%)	R. ave (%)
0	84	23	63	43	65	34,65085639	25,2214146
1	53	62	51	118	66	35,28995757	27,1339678
2	66	7	84	42	97	39,11900066	28,0526015
3	66	7	84	42	97	39,11900066	29,5272989
4	9	86	85	64	84	40,44303797	31,1509217
5	65	80	85	44	66	40,82278481	31,9576323
6	65	80	85	44	66	40,82278481	32,8002676
7	66	86	85	64	84	45,38558786	34,2983684
8	66	86	85	64	84	45,38558786	35,3860987
9	66	86	85	64	84	45,38558786	35,7555507
10	66	86	85	64	84	45,38558786	37,0109902
11	81	86	85	64	84	45,54772582	37,636387
12	66	80	85	64	84	46,14906832	38,5499757
13	66	80	85	64	84	46,14906832	38,4341
14	66	80	85	64	84	46,14906832	40,2435332

15	66	80	85	64	84	46,14906832	40,6956917
16	66	80	85	64	84	46,14906832	41,1989618
17	66	80	85	64	84	46,14906832	42,2980268
18	66	80	85	64	84	46,14906832	42,8068796
19	66	80	85	90	84	46,33524538	43,3656804
20	66	80	85	90	84	46,33524538	44,7691484
21	66	80	85	90	84	46,33524538	45,0223619
22	66	80	85	90	84	46,33524538	45,028045
23	66	80	85	90	84	46,33524538	45,3191548
24	66	80	85	90	84	46,33524538	45,602343
25	66	80	85	90	84	46,33524538	45,7440657
26	66	80	85	90	84	46,33524538	45,8675935
27	66	80	85	44	84	46,72489083	46,1297517
28	66	80	85	44	84	46,72489083	46,077949
29	66	80	85	44	84	46,72489083	46,2208692
30	66	80	85	44	84	46,72489083	46,2499798
31	66	80	85	44	84	46,72489083	46,2781919

Table 4. Generations for the simulation scenario with inter-communication and 10 beacon nodes.

Gen.	P0	P1	P2	P3	P4	P5	P6	P7	P8	P9	R. max (%)	R. ave (%)
0	27	66	3	62	50	71	124	83	88	61	38,14569536	27,1027849
1	27	66	3	62	50	71	60	49	119	61	40,89709763	28,0014821
2	27	66	24	90	84	81	37	49	119	61	45,14145141	29,9322537
3	27	66	24	90	84	81	37	49	119	61	45,14145141	30,9607168
4	27	66	24	90	84	81	45	65	117	61	46,46464646	32,6231024
5	19	60	36	80	20	18	85	51	84	68	47,06937799	35,874131
6	19	60	36	80	20	18	85	51	84	68	47,06937799	35,874131
7	27	66	24	80	84	81	37	49	119	61	48,30142063	37,0688292
8	27	66	84	45	85	62	89	110	80	61	52,00501253	37,9405846
9	27	66	84	45	85	62	89	110	80	61	52,00501253	39,2956559
10	27	66	84	45	85	62	89	110	80	61	52,00501253	40,4013178
11	27	66	84	45	85	62	89	110	80	61	52,00501253	41,7932948
12	27	66	84	45	85	62	89	110	80	61	52,07033466	42,7257637
13	27	66	84	45	85	62	89	110	80	61	52,07033466	43,6291831
14	27	66	84	45	85	62	89	110	80	61	52,07033466	44,6362534
15	27	66	20	80	84	49	85	55	81	61	52,60663507	44,7240524
16	28	66	24	80	84	81	45	121	63	85	53,01645338	45,7074032
17	27	66	84	45	85	81	37	111	80	61	55,31914894	46,4315425
18	27	66	84	45	85	81	37	111	80	61	55,31914894	46,9112525
19	11	66	83	85	84	81	45	97	80	61	55,79470199	47,0562481
20	11	66	83	85	84	81	45	97	80	61	55,79470199	47,5322072
21	11	66	83	85	84	81	45	97	80	61	55,79470199	47,625664
22	11	66	83	85	84	81	45	97	80	61	55,79470199	48,6320643

23	11	66	83	85	84	81	45	97	80	61	55,79470199	49,2650708
24	11	66	83	85	84	81	45	97	80	61	55,79470199	48,8207363
25	11	66	83	85	84	81	45	97	80	61	55,79470199	49,4996437
26	11	66	83	85	84	81	45	97	80	61	55,79470199	50,0700228
28	27	66	23	80	84	59	45	67	81	61	56,40589569	50,6608562
29	27	66	23	80	84	59	45	67	81	61	56,40589569	50,7825108

Table 5. Generations for the simulation scenario with intra-communication and 5 beacon nodes.

Gen.	P0	P1	P2	P3	P4	R. max (%)	R. ave (%)
1	87	58	26	53	38	74,85465116	70,1455576
1	38	58	1	42	61	75,31055901	70,6880349
2	38	58	1	42	61	75,31055901	70,8997592
3	57	92	79	85	58	77,77777778	71,77177
4	57	76	74	58	36	77,91878173	72,3248966
5	57	76	74	58	36	77,91878173	72,2945555
6	57	76	74	58	36	77,91878173	72,727025
7	57	76	118	95	58	80,24096386	73,4211899
8	57	76	118	95	58	80,24096386	74,1984392
9	57	76	118	95	58	80,24096386	74,181242
10	57	76	118	95	58	80,24096386	74,9972942
11	57	76	118	95	58	80,24096386	75,0693902
12	57	76	118	95	58	80,24096386	75,5176418
13	57	28	26	89	58	80,79763663	76,7031244
14	57	28	26	89	58	80,79763663	77,6686609
15	57	28	26	89	58	80,79763663	78,1525814
16	57	28	26	89	58	80,79763663	78,2825665
17	57	28	26	89	58	80,79763663	78,9652526
18	57	28	26	89	58	80,79763663	79,4570555
19	57	28	26	89	58	80,79763663	79,7286411

Table 6. Generations for the simulation scenario with intra-communication and 10 beacon nodes.

Gen.	P0	P1	P2	P3	P4	P5	P6	P7	P8	P9	R. max (%)	R. aveg (%)
0	24	64	90	64	76	11	58	39	94	35	77,74607703	70,3936817
1	24	64	90	64	76	11	58	39	94	35	77,74607703	70,8319234
2	24	64	90	64	76	11	58	39	94	35	77,74607703	71,5903548
3	2	58	76	78	28	82	107	14	46	29	78,375	72,320177
4	2	58	76	78	28	82	107	14	46	29	78,375	72,6604994
5	2	58	76	78	28	82	107	14	46	29	78,375	72,9120431
6	2	58	76	78	28	82	107	14	46	29	78,375	73,1397577
7	9	52	58	84	61	110	57	54	95	58	78,40616967	73,3665243

8	8	58	76	78	28	114	110	72	3	1	80,3806735	73,6714508
9	8	58	76	78	28	114	110	72	3	1	80,3806735	74,3233355
10	8	58	76	78	28	114	110	72	3	1	80,3806735	74,8614683
11	8	58	76	78	28	114	110	72	3	1	80,3806735	74,8315095
12	8	58	76	78	28	114	110	72	3	1	80,3806735	75,2753102
13	31	58	107	45	64	41	57	75	29	97	80,89430894	76,0197033
14	31	58	107	45	64	41	57	75	29	97	80,89430894	75,9332973
15	31	58	107	45	64	41	57	75	29	97	80,89430894	76,138062
16	31	58	107	45	64	41	57	75	29	97	80,89430894	76,5883004
17	31	58	107	45	64	41	57	75	29	97	80,89430894	76,6289697
18	9	58	76	16	65	105	57	73	29	57	81,00490196	76,8961186
19	10	58	76	58	68	41	57	75	95	58	82,41758242	77,3746764
20	10	58	76	42	68	41	57	75	95	58	82,71446863	77,5436987
21	10	58	76	42	68	41	57	75	95	58	82,71446863	77,7357082
22	10	58	76	42	68	41	57	75	95	58	82,71446863	77,7690528
23	10	58	76	42	68	41	57	75	95	58	82,71446863	77,8624523
24	10	58	76	42	68	41	57	75	95	58	82,71446863	78,1142369
25	26	58	76	78	77	41	57	75	31	57	83,52638353	78,6859179
26	26	58	76	78	77	41	57	75	31	57	83,52638353	79,1042923
27	26	58	76	78	77	41	57	75	31	57	83,52638353	79,0436953

Table 7. Comparison of reachability for the different types of communications.

Communication type	No Beacon nodes	5 beacon nodes	10 beacon nodes
Inter-communications	23.80 %	46.72 %	50.78 %
Intra-communications	72.52 %	80.79 %	83.52 %

Figures

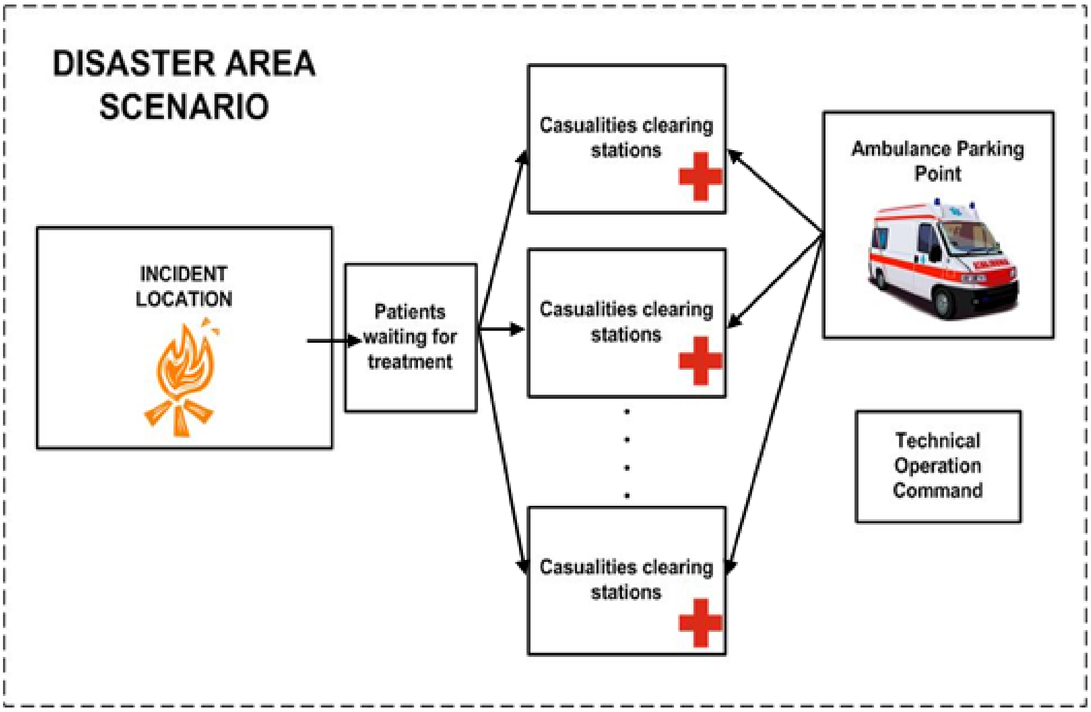


Fig. 1. Disaster scenario mobility model.

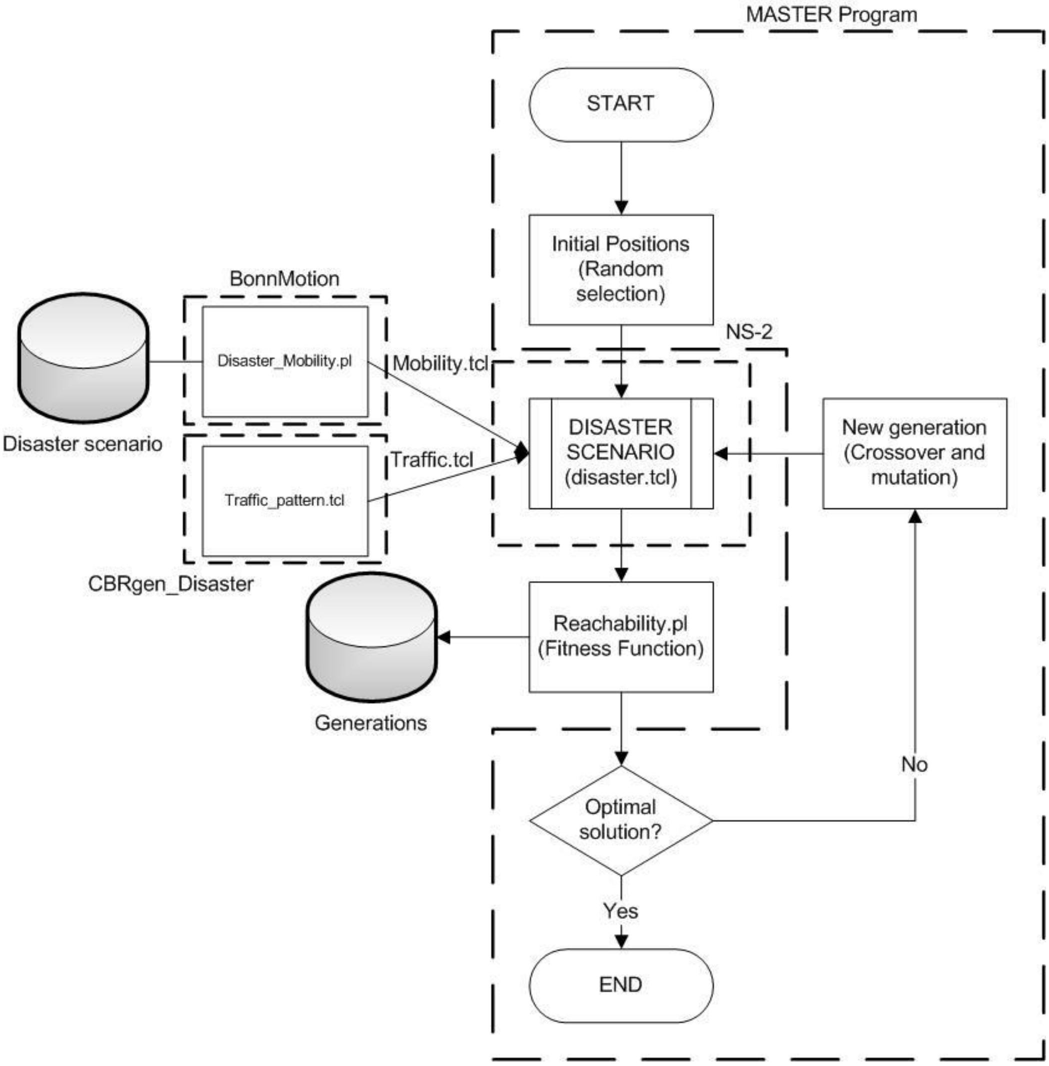
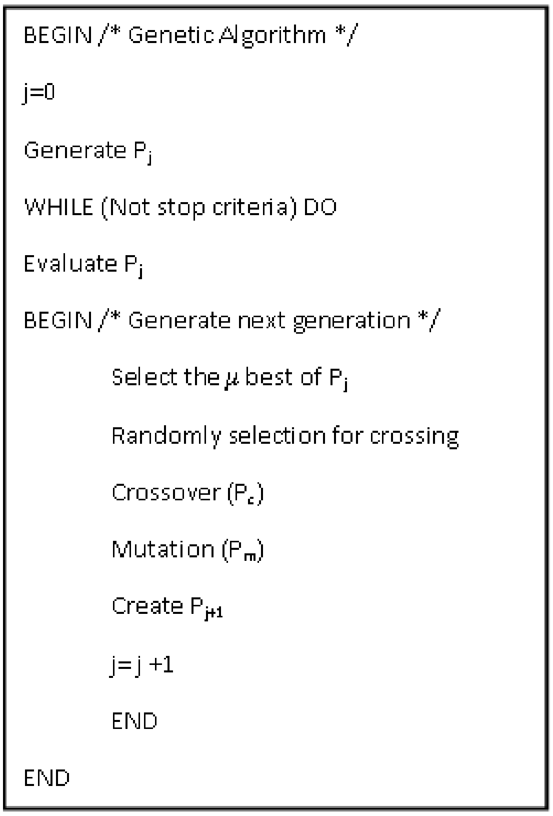


Fig. 2. Simulation architecture.



```
BEGIN /* Genetic Algorithm */
j=0
Generate $P_j$
WHILE (Not stop criteria) DO
Evaluate $P_j$
BEGIN /* Generate next generation */
          Select the $\mu$ best of $P_j$
          Randomly selection for crossing
          Crossover ($P_c$)
          Mutation ($P_m$)
          Create $P_{j+1}$
          j=j +1
          END
END
```

Fig. 3. Outline of the genetic algorithm implementation.

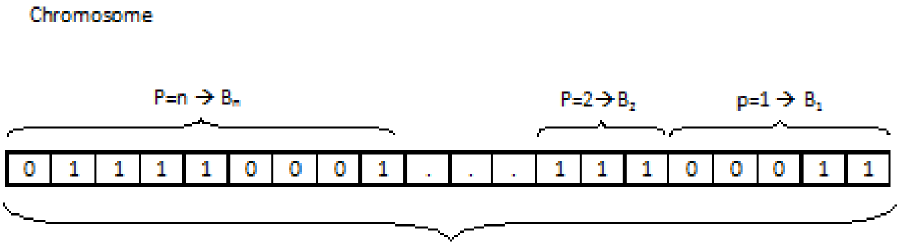


Fig. 4. Chromosome's composition.

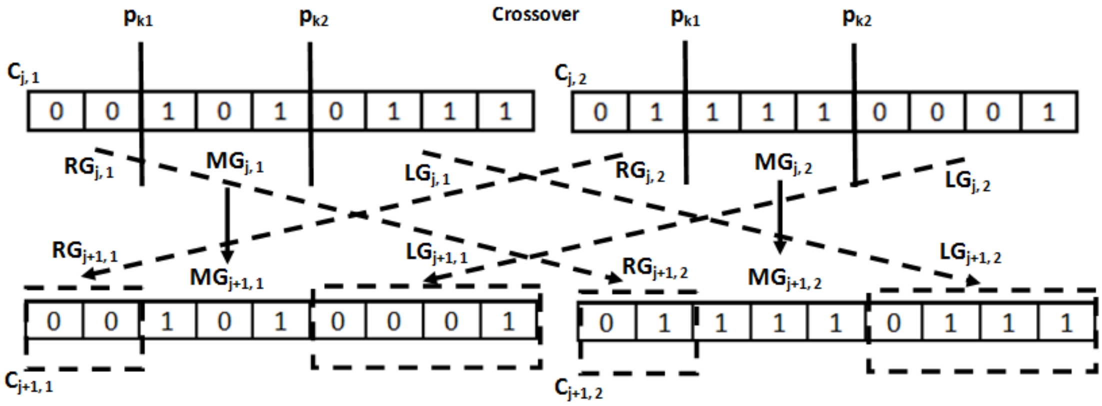


Fig. 5. Crossover operation.

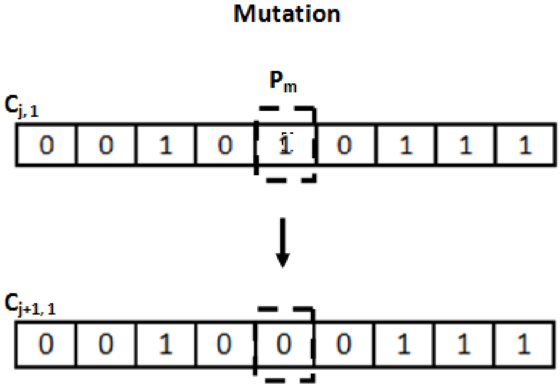


Fig. 6. Mutation operation.

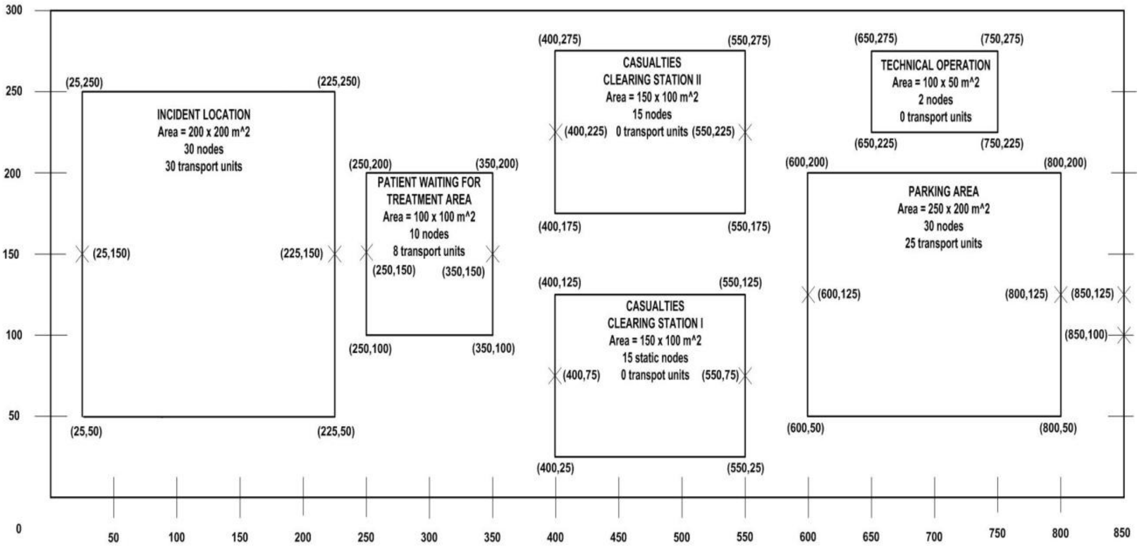


Fig. 7. The proposed disaster area scenario.

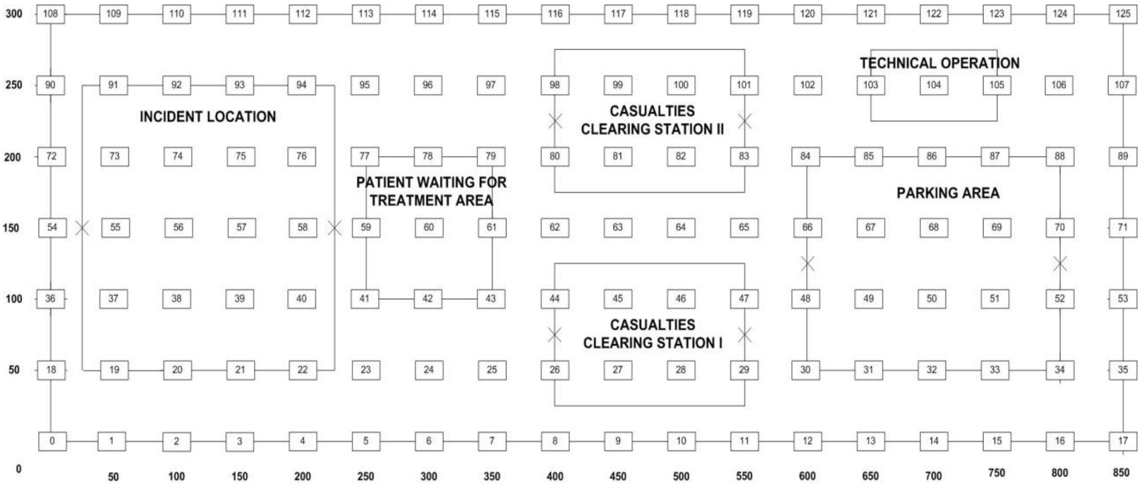


Fig. 8. The proposed grid solution.

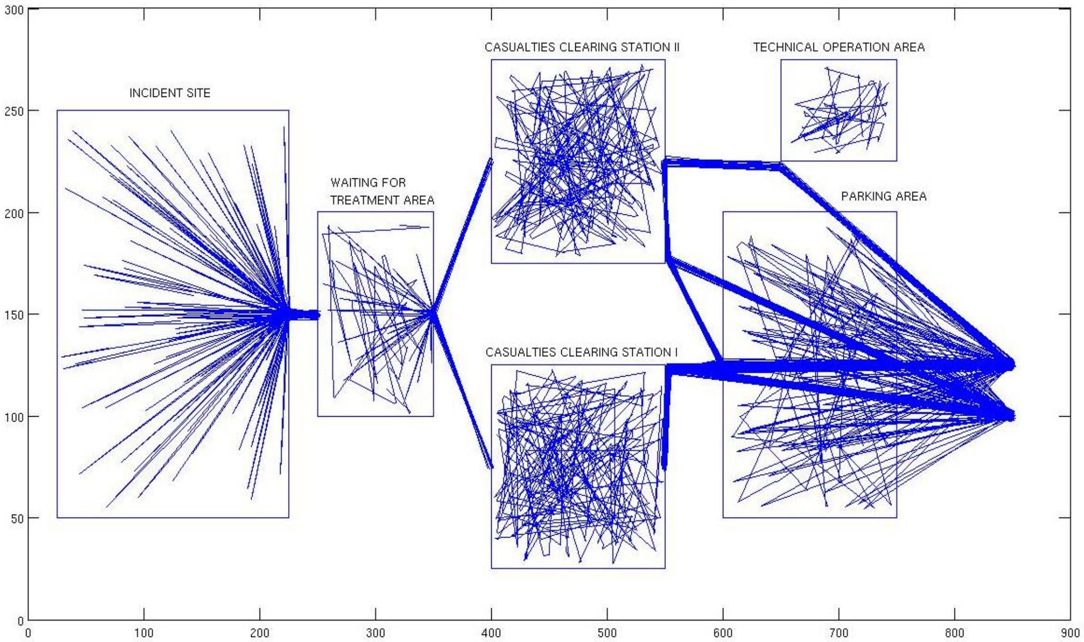


Fig. 9. Technical movements of the rescue team.

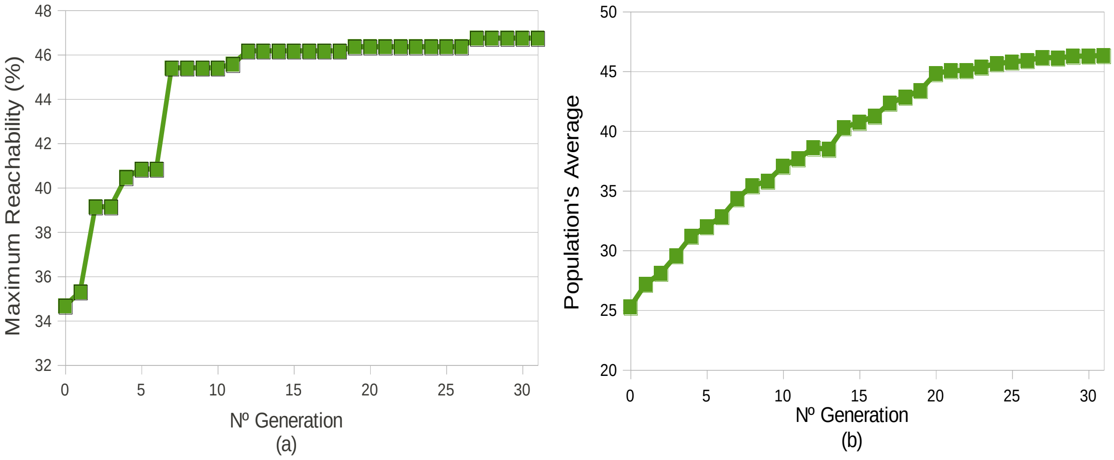


Fig. 10. Simulation results for inter-area communication with 5 beacon nodes: (a) Maximum reachability and (b) Average population’s reachability.

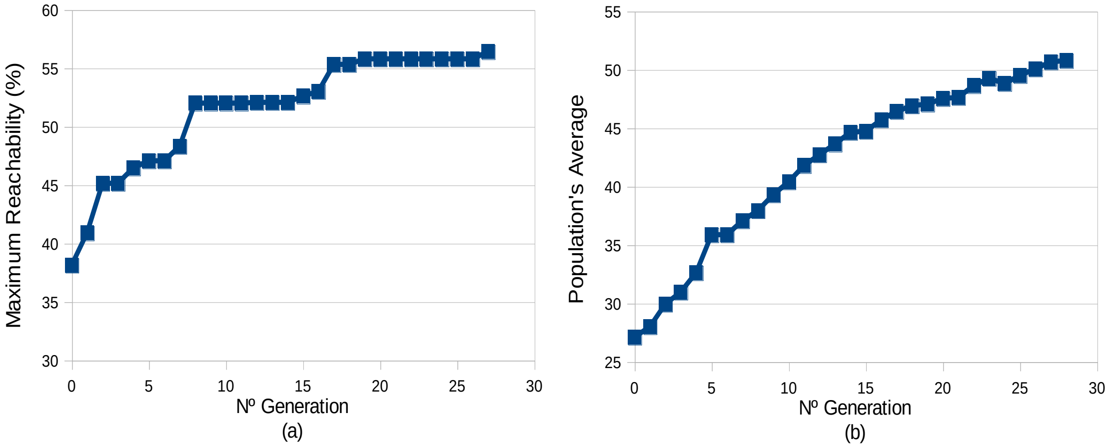


Fig. 11. Simulation results for inter-area communications with 10 beacon nodes: (a) Maximum reachability and (b) Average population's reachability.

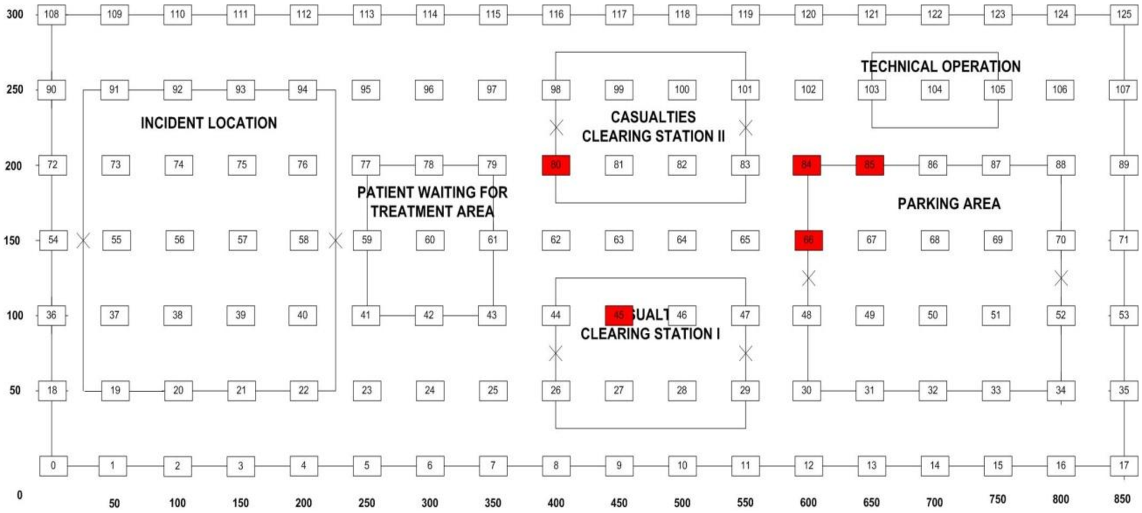


Fig. 12. Optimal locations for inter-area communication with 5 beacon nodes.

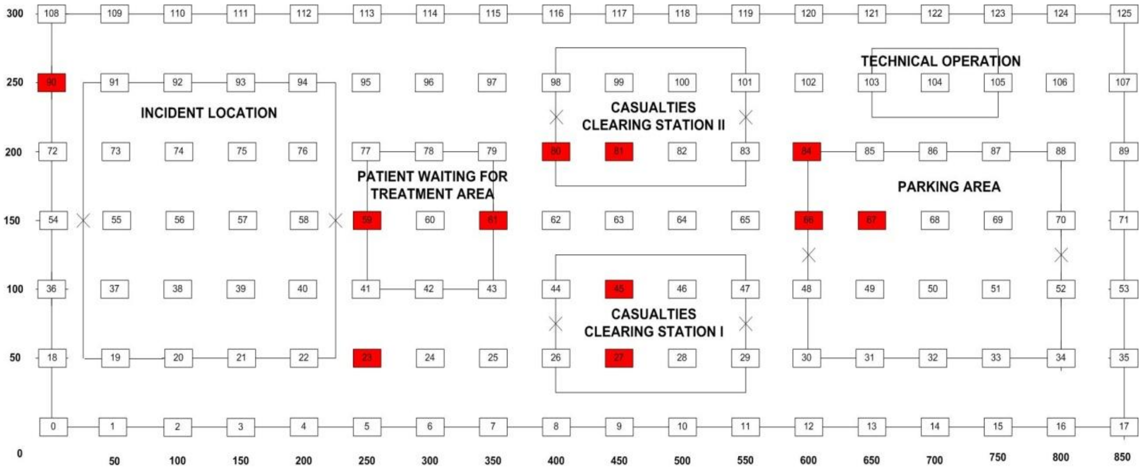
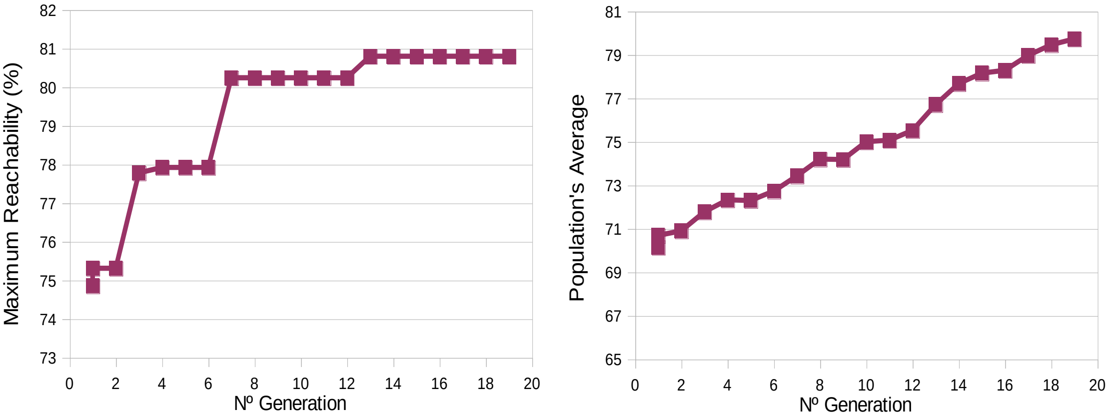


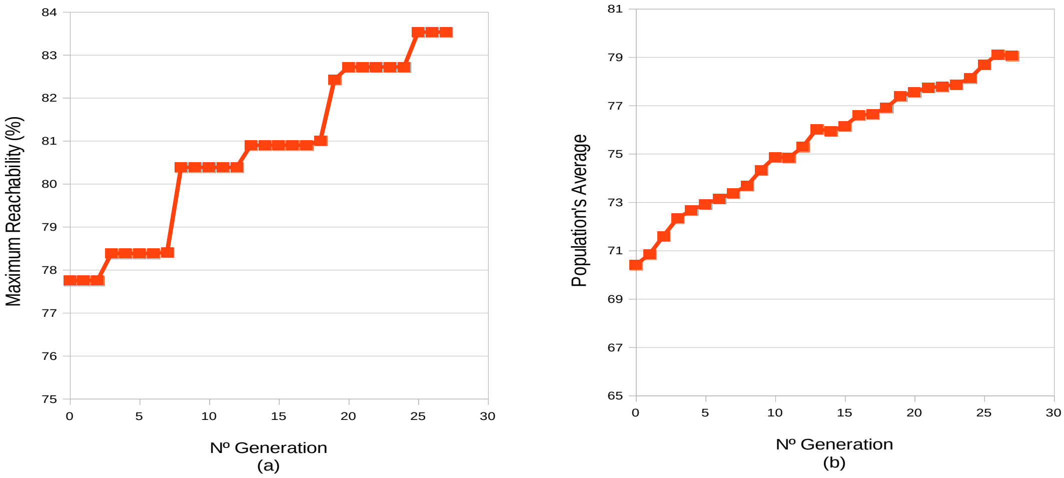
Fig. 13. Optimal locations for inter-area communication with 10 beacon nodes.



(a)

(b)

Fig. 14. Simulation results for intra-area communication with 5 beacon nodes: (a) Maximum reachability and (b) Average population's reachability.



(a)

(b)

Fig. 15. Simulation results for intra-area communications with 10 beacon nodes: (a) Maximum reachability and (b) Average population's reachability.

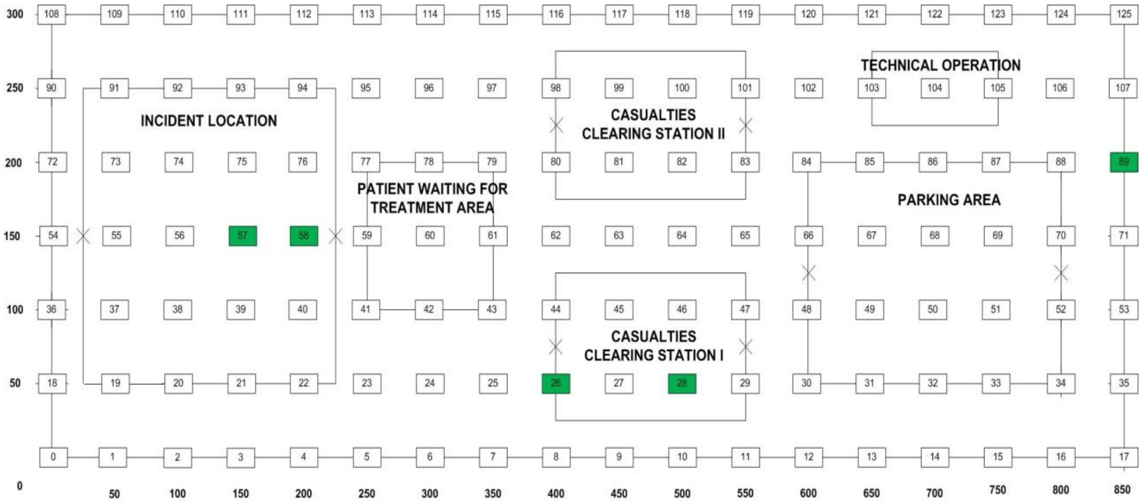


Fig. 16. Optimal locations for intra-area communication with 5 beacon nodes.

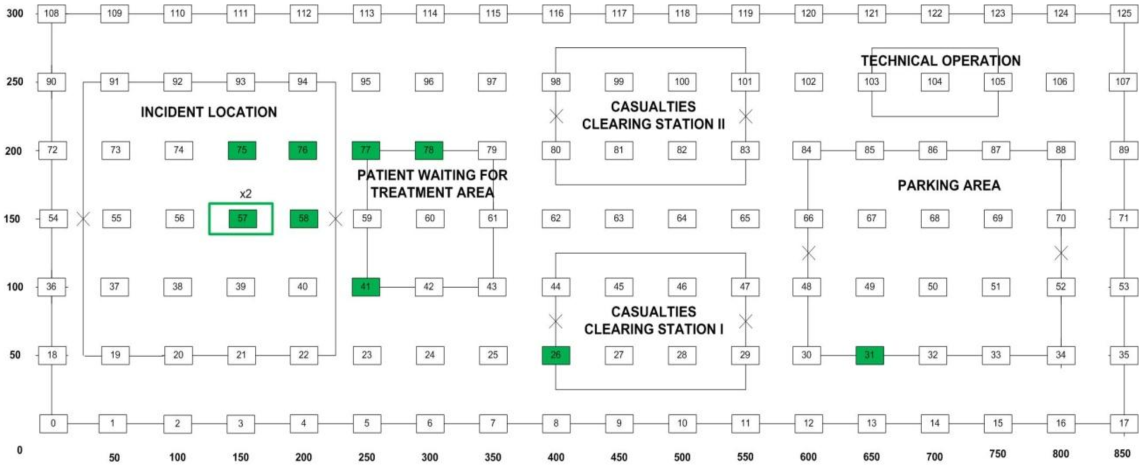


Fig. 17. Optimal locations for intra-area communication with 10 beacon nodes.