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An evolutionary computation approach for designing mobile ad hoc networks

D. Gutiérrez-Reina [a], S.L. Toral Marín [a,*], P. Johnson [b], F. Barrero [a]

[a] University of Seville, Escuela Superior de Ingenieros, Avda. Camino de los Descubrimientos, s/n, 41092 Sevilla, Spain
[b] Liverpool John Moores University, Liverpool, UK

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ABSTRACT

This paper presents the topological design of ad hoc networks in terms of distances among static nodes and speeds of mobiles nodes. Due to the complexity of the problem and the number of parameters to be considered, a genetic algorithm combined with the simulation environment NS-2 is proposed to find the optimum solution. More specifically, NS-2 provides the fitness function guiding the genetic search. The proposed framework has been tested using a railway scenario in which several static and mobile nodes are interacting. Results show the feasibility of the proposed framework and illustrate the possibility of genetic approach for solving similar application scenarios.

1. Introduction

Mobile ad hoc networks (MANETs) are decentralized networks in which communication between nodes is deployed without the need for an underlying infrastructure. These nodes have power constraints, limited coverage area, and each node can act as a router in the network (Hanzo & Tafazolli, 2007; Royer & Toh, 1999). MANETs are suitable for those applications where the deployment of a new infrastructure is difficult or impossible. Thus, MANETs are suitable candidates for applications such as transport systems where the nodes are intrinsically mobile. In this case, they are called vehicular ad hoc networks (VANETs). Ad hoc networks can be considered as collaborative systems, where nodes communicate with each other to carry out a distributed task. They can be used wherever there is a need for establishing a networking environment for a limited duration of time. Several research topics include application of MANETs, some of them are (Sakar, Basavaraju, & Puttamadappa, 2008): search-and-rescue applications in disaster situations (Toral et al., 2010), defence (army, navy, and air force) applications, health care applications (Varshney & Sneha, 2006), academic environment applications, industrial or corporate environment applications, intelligent transport systems (Murray, Cojocari, & Huirong 2008; Sharif, Blythe, Almajnooni, & Tsimenidis, 2007; Toral, Martínez-Torres, Barrero, & Arahal, 2010), or home network (Kays, Jostschulte, & Endemann, 2004).

In all these cases, the design of MANETs faces several challenges due to the complexity of the factors that affect the performances of MANETs. Such factors can be categorized as topology, routing, mobility and implementation.

The topology of a MANET defines the distribution of the nodes in the network. Therefore, communication between nodes are affected by the deployed topology. From the point of view of MAC layer, topologies can be classified as single hop flat topology, multiple hop flat topology, clustered topology, and centralized topology (Jurdak, 2007). The routing algorithms also play an important role in the performance of MANETs due to the mobility of nodes.

The routing algorithms are responsible for finding communication paths among nodes and reacting against changes in the topology. Three steps are normally followed in this procedure: (1) discovery of new routes, (2) maintenance of existing routes, and (3) deletion of lost routes. In the first level of classification, the routing protocols are divided into multicast protocols and unicast protocols. Multicast enables a single node to communicate with a specific set of nodes. Whereas in the unicast protocols, a node can only communicate with one node at a time. This paper is focused on unicast protocols, which are normally divided into the following categories, proactive, reactive, hybrid, and position aided protocols (Beraldi & Baldoni, 2003). Proactive protocols are not suitable for frequently changing topologies due to the data-flow used to maintain the routing information. In contrast, reactive protocols maintain only the active communication paths.

With regard to mobility factors, these involve the movements followed by nodes in the network. As a consequence of these movements the communication links are broken and the routing protocols should react quickly in order to find a new communication path as soon as possible. Mobility models have been developed as a necessity for simulating movements in VANETs due to the cost of deploying this kind of networks (Kun-chan & Chien-Ming, 2008). According to implementation factors, the design of MANETs share challenges to the design of Wireless Sensor Networks. The

* Corresponding author. Tel.: +34 954 48 12 93; fax: +34 954 48.
E-mail addresses: dgutierrezreina@us.es (D. Gutiérrez-Reina), toral@esi.us.es (S.L. Toral Marín), P.Johnson@ljmu.ac.uk (P. Johnson), fbarrero@esi.us.es (F. Barrero).

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nodes must: (1) consume low power, (2) operate in high volumetric densities, (3) have a low cost, (4) be autonomous and have a long lifetime, (5) be adaptive to the environment (Akyildiz, Su, Sankarasubramaniam, & Cayirci, 2002).

This paper deals with the topology of the network when mobile nodes are considered. Several possible architectures have been discussed in the literature (Akbari, Soruri, & Jalali, 2009; Wei & Chan, 2006). However, they do not consider the optimal location of nodes for improving global features of the system. In this paper, the use of genetic algorithms (GA) is proposed to optimize the topology of the network. More specifically, the objective consists of finding the most suitable nodes' positions and nodes' speeds in order to maximize communication distances. The novelty of our approach is the use of simulation tool NS-2 to evaluate the fitness function of the GA implementation. A real-life railway scenario is used to evaluate the effectiveness of our approach.

2. Related work

Topology is a very important issue when designing MANETs. In this kind of networks, nodes are mobile; therefore they are continuously entering and getting out the coverage areas of the rest of nodes. Consequently the number of nodes in the network is changing continuously. Routing algorithms and topology configuration constitute the basis for improving the performance of MANETs. Many parameters are taken into account by the developer of MANETs to design suitable topologies for specific purposes, such as power conservation, connectivity, coverage area, routing algorithms, and the number of nodes. Different solutions have been presented in the literature to solve the problem of topology design. Two algorithms for the efficient placement of nodes were proposed by Dhillon and Chakrabarty (2003). These algorithms are based on imprecise detection and terrain properties. Akkaya, Younis, and Bangad (2005) proposed two approaches based on reallocating gateways to increase lifetime of mobile WSNs. Moreover, network metrics such as throughput, end-to-end delay, and packet delivery fraction are also dependent on the network topology. Nadeem and Parthasarathy (2006) presented an algorithm to optimize topology in ad hoc networks with the aim of maximizing the throughput capacity. This algorithm is focused on minimizing the number of interferences in the network. Nodes move to a new position where the number of nodes is lower than in the previous location. These movements take into consideration all active communications of the nodes to avoid losing connectivity.

GAs have also been used for optimizing topology design in MANETs and WSNs (Tzu-Chiang & Yueh-Ming, 2008; Zhou, Cao, Caixia, & Runcai, 2010). A hybrid GA was used by Tzu-Chiang and Yueh-Ming (2008), to improve the performance in local and global topology discovery of shared multicast trees. This approach is based on sequence and topology encoding for multicast protocol (STMP). A similar idea was used by Zhou et al. (2010), in two-tiered WSN. In many cases, the GA considers the quality of each topology (Bhondekar, Vig, Singla, Ghanshyam, & Kapur, 2009; Pradhan, Baghel, Panda, & Mulgrew, 2009; Jourdan & de Weck, 2004). In these cases, the fitness functions are composed of several terms, taking into account different characteristics of the network. Applications specific parameters, such as connectivity parameters, and energy parameters were considered by Bhondekar et al. (2009). Ferentinos and Tsiligiridis (2007) used GAs in a specific agriculture application, in order to optimize the design of WSN. This approach is based on application-specific requirements. The nodes sense environmental parameters like, temperature, humidity, solar radiation, soil moisture, and dissolved inorganic material. Xu, Haixia, Minqqiang, Mei, and Wei (2008) included a GA in NS-2 for analysing 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. In distinction to the previous works, in this paper the topology is analysed in terms of nodes' distances and speeds for collaborative transport applications.

3. Formulation of the problem

A network is usually modelled as a graph $G = \langle V,E\rangle$, where $V = \{1,\ldots,n\}$ is the set of nodes (the routers) of the graph and $E \subseteq V \times V$ is the set of edges (the links) (Tanenbaum, 1996). A wireless link among two nodes i and j is established when the physical distance Pd(i,j) is less than or equal to the transmission radius R. A change in the set E is called a topological change. A path P(S,D) from S to D is specified as a sequence of nodes $P(S,D) \equiv \langle N_0,N_1,\ldots,N_k\rangle$, where $N_0 = S$, $N_k = D$, $N_i \neq N_j$, $(N_i, N_{i+1}) \in E$ (for $i \neq j$, $0 \leq i \leq k-1$). The length of the path, $|P(S, D)|$, is the number of links a packet performs before reaching the destination node, thus $|\langle N_0, N_1, \ldots, N_k\rangle| = K$ (Beraldi & Baldoni, 2003). In collaborative systems, all the nodes forming V communicate each other to accomplish a global task. In transport applications, the nodes collaborate with each other to maximize the communication distance with a target mobile node. In the considered scenario, V is composed of mobile nodes and static nodes. All nodes forming V communicate with each other for discovering and maintaining information path from the source node to the destination node. The global task of V consists of communicating with the target node as quick as possible. This represents a common scenario in real transport systems. For example, it models a train that is arriving to a railway station, or a car that is approaching traffic lights. The objectives of the communication among the nodes consist of: (1) discovering a route from the source nodes to the destination node, (2) maintaining these routes, and (3) generating relevant information for the target node. The objectives (1) and (2) are carried out by the routing layer, while the application layer is responsible for generating the information packet for the destination. This information could be related to platform availability in the case of railway scenarios, or the state of the traffic light in the case of road transport scenarios.

The placement of nodes plays an important role in accomplishing the objectives due to the limitations in the coverage areas of the nodes. This task becomes more difficult as the number of nodes gets higher since the number of possibilities increases rapidly. In addition, selecting suitable speeds of mobile nodes help to improve the communication distance. On the other hand, the discovery process carried out by the routing layer to find communication paths is time-consuming. As a consequence, the discovery distances get shorter as the speeds of mobile nodes increase. Although this statement could indicate lower vehicle speeds for mobile nodes as a solution, the requirements of transport systems should also be taken into account in order to accurately model real-life scenarios. The time consumed by the discovery process is highly dependent on the selected routing algorithm. An overview of routing protocols in VANETs can be found in Bernsen and Manivannan (2009).

4. The proposed framework

Due to the complexities of finding an optimum solution, a simulation framework based on NS-2 and GA for optimizing the communication distance in collaborative transport systems is proposed in this paper. The simulation tool NS-2 is an object-oriented simulator developed as a part of the VINT project at the University of California in Berkeley (Fall & Varadhan, 2010). It is extensively used by researchers in order to simulate both wired and wireless networks (Layuan, Chunlin, & Peiyan, 2007; Murray et al., 2008).