New algorithm for packet routing in mobile ad-hoc networks

Nenad S. Kojić1, Marija B. Zajeganović Ivančić1, Irini S. Reljin2 and Branimir D. Reljin2

Abstract — Mobile ad-hoc networks (MANET) are one of wireless networks implementation. MANET is very popular technology initially based on military purposes. Specific modifications of MANET created a possibility to implement several new wireless networks. One of them is a wireless mesh network (WMN). Over the last ten years, WMNs have gained more and more attention and are now considered as a convincing solution for providing better Internet access services for end users. WMN is an emerging technology that offers a cost-effective and scalable method to connect wireless devices. The main problem in WMNs is a routing protocol, especially because it has to enable the access to network for both mesh and conventional clients. Most of the existing ad hoc routing protocols use minimum hop-count as a metric for identifying the best packet route. This paper presents neural network based approach to routing protocol for WMN. Neural networks are capable to analyze very complex network environments and solve routing problems on optimal (or almost optimal) way.

Index Terms— Mobile ad-hoc networks, neural network, mobile agents, adaptive routing, wireless mesh network.

I. INTRODUCTION

New implementations of wireless networking are increasing drastically in the modern society [1]. A huge number of new mobile devices are used in everyday life. All of them give us possibility to use all benefits of global network – Internet. There are many different solutions describing techniques which realize connection between mobile users and Internet and, among others, the ad hoc topology is a very promising solution [1-3]. Ad hoc networks are introduced first in military applications and a number of authors and companies focus their attention on them thanks to the fact that ad hoc network is based on a set of nodes which dynamically communicate with each other over a wireless medium [3]. In this way, destroying one or several links communication should be continued. Starting from this, several network implementations, which are intended for civil requirements, could be solved in the same way [1-4]. Enabling Internet connection in rural area, or anywhere else where some physical obstacles exist, signal degradation, multiple fading effect, low coverage of mobile base station, poor infrastructure or similar, can be potentially solved by specific ad hoc networks implementations [4]. One of the most used one is a mobile ad-hoc network (MANET) [1, 2, 4]. MANET is a network composed of mobile nodes mainly characterized by the absence of any centralized coordination or fixed infrastructure. This makes them highly scalable and easily deployable. This topology makes every node in network as a potential router. Through this node all network traffic received by other network routes will be sent. Fluctuations in number of users have influence on a rapidly changing topology. These changes occur randomly and dynamically.

Furthermore, ad hoc networks, as opposed to cellular networks, are limited to a higher extent by the battery power of the network nodes. Also, limitations are related to the bandwidth and rate speed. MANET can be a standalone network, but at the same time it can be connected to any other public or private network. Nodes in MANET have to support traffic even in the cases when some of the communicating nodes become out of range [1-4]. All these reasons, especially frequent network topology changes, make classical routing algorithm inappropriate for these networks [1-5].

In this paper we present the algorithm for packet routing based on the Hopfield neural network and with primary goal to find optimal path through dynamic network topology. This information is used for routing packets into the WMN. For this purpose we used mobile agent technique. Mobile agent logic is realized by the Hopfield neural network, too. In this way updated messages are broadcasted all over the network via optimized flooding technique.

The paper is organized as follows: Section II consists of brief descriptions of a wireless mesh networks. Routing requirements in WMN are given in Section III. In Section IV basic principals of Hopfield neural network work are given. Proposed routing algorithm is described in Section V. Some experimental results are given in Section VI. Section VII consists of concluding remarks.

II. WIRELESS MESH NETWORKS

Wireless Mesh Network (WMN) is a specific type of MANET [1-3, 5, 6]. This network is a wireless multi-hop technology realized through a set of wireless nodes that communicate with each other. As in MANET, each node operates not only
as a host but also as a router, forwarding packets on behalf of other nodes that may not be within direct wireless transmission range of their destinations [5, 6]. In this way wireless mesh technology is used to build cost-effective outdoor wireless networks for private or public use [1-3, 5]. There are a lot of possible implementations of WMN as modern services [4-9].

This technology enables secure, high-bandwidth, scalable access to fixed and mobile applications across metropolitan areas. Also, wireless mesh networks allow mobility, connectivity, flexibility, dynamic communication and fast integration into existing network technology [5-10].

Achieving high user data rates over multi-hop wireless paths is considered the ultimate goal for WMN. Therefore, the WMN is a fast, simple and cheap solution for extending cable network or any other existing network. A lot of WMN implementations and variations point out how important these networks are in the overall networks environment [4-8].

WMN topologies are based on mesh routers. These routers are connected by wireless links. Mesh routers could be divided into two classes: intermediate mesh routers (MR) and mesh gateways (G). An example of WMN is presented in Fig. 1. Mesh gateways are nodes which provide connectivity to an infrastructure network, typically connected to the Internet. This connection is typically realized as wired network, Fig. 1.

Generally speaking, MANET infrastructure, due to node mobility and frequent link failure, requires an effective and adaptive routing protocol design [5-11].

Primary goal of every new user connected to wireless network is to make Internet connection. In WMN this problem is related to the selection of a route which leads to one of mesh gateways. After that, mesh gateway is responsible for enabling Internet connection through wired network.

Routing algorithm should find optimal route from a new user to some of the gateways. Optimal path will be found if the metric observes all necessary network parameters and uses network resources optimally.

The link choice should be based on tradeoff between the cost/complexity and the performance of the WMN. Cost can be represented either as a physical cost, or time necessary for transmission of a packet, or links lengths, or as a combination of them. A set of IEEE standards define such connections: 802.11s, 802.15.5 and 802.16a [5]. Physical connections of mobile or stationary clients to the WMN routers can be realized by common networking interfaces (Bluetooth, Ethernet, 802.11) or, in some cases, a PCI or a PCMCIA bus [1, 5]. This means that clients do not need any new investments into the equipment. Besides that, the network operator needs to have low investment in order to build or extend the existing WMN [3].

Large number of network routers and clients make a routing protocol very complex [2-11]. Many papers address solving these problems [5-11]. Main problem is to find optimal path for new clients at the moment of connecting to a network. Protocol should establish the connection of new client with the ones of the gateways, taking into account the link cost calculations, total path length, and at the same time trying to optimize network traffic as much as possible [4-11].

Because of that, we decided to use two separate procedures to solve this routing problem. The first one should address finding an optimal path based on up-to-date routing information, while the other one should provide these information to routers. These procedures are independently organized. In this way we expect a fast exchange of all network and routing information which are refreshed as soon as possible.
III. ROUTING REQUIREMENTS

3.1 General requirements

One of the most important characteristic of MANET and WMNs is the routing protocol [1, 3, 8, 9, 11]. Typical proactive routing protocol for MANETs is based on the Distributed Bellman-Ford algorithm. Main problems in protocols address to update routing information about routes. Depending on protocols type, several network parameters can be included in routing metric. Commonly it is a distance or some link parameters (in link state routing protocols). Purpose of every routing protocol is to find an optimal route, as fast as possible, minimize usage of network resources by its own routing updates information and try to guarantee any level of service quality.

Generally, quality of services in WMNs is directly related to the routing procedures. Specific organization of WMNs defines several proposed conditions which should be analyzed and embedded into the routing protocol [5]:

a) Reliability - protocol has to be able to recognize failed nodes and broken links and to reroute as fast as possible,
b) Mobile user connectivity - protocol has to be able to support fast hand-offs,
c) Efficiency - in the case of high overhead, it is not possible to scale a large number of nodes,
d) QoS - protocol should offer possibility to route different traffic classes over the “best” routes.

In order to provide all these conditions, especially QoS, we have used artificial neural network [12-20], as a primary logic, and mobile agents [21-25] as a secondary one. These two logics should improve routing protocol quality and enable implementation of four previously numbered conditions.

3.2 Routing requirements in MANETs and WMNs

Despite the availability of many routing protocols for ad hoc networks, the design of routing protocols for WMNs is still an active research area. An optimal routing protocol for WMNs must capture the following features [1, 6]:

- Multiple Performance Metrics: Many existing routing protocols use minimum hop-count as a performance metric to select the routing path.
- Scalability: Setting up or maintaining a routing path in a very large wireless network may take a long time. Thus, it is critical to have a scalable routing protocol in WMNs.
- Robustness: To avoid service disruption, WMNs must be robust to link failures or congestion. Routing protocols also need to perform load balancing.
- Efficient Routing with Mesh Infrastructure: Considering the minimal mobility and no constraints on power consumption in mesh routers, the routing protocol in mesh routers is expected to be much simpler than ad hoc network routing protocols. With the mesh infrastructure provided by mesh routers, the routing protocol for mesh clients can also be made simple.

Various routing protocols are applicable to WMNs.

1. Routing protocols with various performances metric: One of the routing protocols with various performance metrics is the link quality source routing (LQSR) which aims to select a routing path according to link quality metrics. Three performance metrics, i.e., the expected transmission count (ETX), per-hop RTT, and per-hop packet pair are implemented separately in LQSR. However, the link quality metrics are still not enough for WMNs when mobility is concerned.

2. Multi-radio routing. In WMNs, multi-radio per node may be a preferred architecture, because the capacity can be increased without modifying the MAC protocol. A new performance metric, called the weighted cumulative expected transmission time (WCETT) is proposed for the routing protocol. WCETT takes into account both link quality metric and the minimum hop-count. It can achieve good tradeoff between delay and throughput because it considers channels with good quality and channel diversity in the same routing protocol.

3. Multi-path routing for load balancing and fault tolerance. The main objective of using multi-path routing is to perform better load balancing and to provide high fault tolerance. Multiple paths are selected between source and destination. Packets flow in one of these selected paths. When link is broken on a path due to a bad channel quality or mobility, another path in the set of existing paths can be chosen. Thus, without waiting for setting up a new routing path, the end-to-end delay, throughput, and fault tolerance can be improved. However, the improvement depends on the availability of node-disjoint routes between source and destination.

4. Hierarchical routing. In hierarchical routing, a certain self-organization scheme is employed to group network nodes into clusters. Each cluster has one or more cluster heads. Nodes in a cluster can be one or more hops away from the cluster head. Since connectivity between clusters is needed, some nodes can communicate with more than one cluster and work as a gateway.

5. Geographic routing. Compared to topology-based routing schemes, geographic routing schemes forward packets by only using the position information of nodes in the vicinity and the destination node. Thus, topology change has less impact on the geographic routing than other routing protocols.

Based on these facts, routing protocol should be adaptive and try to use available resources as optimally as possible [5, 6, 8, 26, 27]. For this purpose, we suggest new routing protocol based on neural networks. We decided to use the Hopfield neural network, because this network offers good results in optimization problem and multicriteria optimization [13, 17-20]. Characteristic of neural networks is a possibility to work in environments where all parameters are not known at all. This is very important from the point of requirements.
relative to Reliability and Mobile user connection. Well selected energy function, used as routing metric, can solve problems of Scalability and QoS. This is based on the possibility to find an optimal route in the network and enable users’ information to be sent through the best link to destination.

All these reasons were indicative for us to try to use the Hopfield neural network and all its advantages in order to solve dynamic adaptive routing problem in arbitrary network topology.

IV. HOPFIELD NEURAL NETWORK

An analog computational network, inspired by the biological neural system, was introduced by Hopfield [12-15]. The model of this network is shown in Fig. 3. This model is based on the Hopfield neuron. Main goal in the Hopfield neural network implementation is the possibility of hardware realization. For this purpose, the suggested realization is shown in Fig. 4.

Hopfield and Tank proposed a neural network structure [15] capable of solving different complex problems by using the network for which an energy function has to be defined. After its minimization, optimal solution for a given and defined problem is possible. This approach was demonstrated on the well-known and computationally very hard Traveling Salesman Problem (TSP) with 30 nodes [15].

Since then, many researchers have used similar model in solving a variety of combinatorial optimization problems.

\[ E = \mu_0 \sum_{i=1}^{n} \sum_{j=1}^{n} C_{ij} V_i V_j + \mu_1 \sum_{i=1}^{n} \rho_i V_i + \mu_2 (1-V_x) \]  

(1)

In this way the neural network algorithm becomes very attractive for real time processing, since bias currents may be easily controlled via external circuitry following the changes in actual traffic through the network.

By following the Ali-Kamoun’s work [17] we derived several algorithms for routing in communication networks with neural network assistance [18-20]. For this purpose we suggest the Hopfield-like neural network with associated energy function [20]:

\[ E = \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} C_{ij} V_i V_j + \frac{1}{2} \sum_{i=1}^{n} \rho_i V_i + \frac{1}{2} (1-V_x) \]

(2)

Indexes \( s \) and \( d \) refer to node (router) positions, while \( x \) and \( d \) denote the source and destination node. Matrix \( C \) with elements \( C_{ij} \) is a distance matrix; matrix \( \rho \) with elements \( \rho_{sid} \) describes the node connectivity, while the terms \( V_{sid} \) denote node voltages (states of neurons in Hopfield network); matrix \( K \) with elements \( K_{ii} \) is a capacity matrix and matrix \( G \) with elements \( G_{sid} \) present a traffic occupancy matrix.

Energy function in (2) is used for neural network realization. This network is realized as a programmable function, and can be called by means of different input parameters. The algorithm defining the packed routing in wireless mesh network based on the Hopfield neural network is presented in the next section.

V. PROPOSED ROUTING ALGORITHM

5.1 System overview

As we mentioned before, routing is one of the most important characteristic for optimal usage of wireless networks. We organize routing process into several phases. This organization is used as logical and as programmable functions also.

From the point of end user, connectivity to wireless network could be divided into three phases:

First: Finding the shortest WMN routes (should be realized by software in mobile device),

Second: Enabling the physical connection with WMN router (which requires changing of the routing table data in the WMN router),
Third: Enabling the logical connection with one of the gateways for providing the connectivity to the distribution system over the end WMN router.

The third phase is the most critical regarding the processing time and quality of established connection. There are a lot of different solutions in literature [1, 4-11]. All of them give good results in specific environment and for selected traffic [4-6]. There are solutions which give good results but require time extension and control of internal network traffic jams [5]. In this paper, we suggest a new routing algorithm for WMNs.

In the algorithm proposed here, the procedure starts with the connection of a new user to a network. The WMN router detects the new device (earlier explained phases 1 and 2 are realized), and two procedures follow:

1) Enabling of the logical connection between mobile device and gateway through the network. The trace representing the connection should be calculated before the new device is connected, Fig. 5. The main criteria for finding this route are number of hops, but more parameters can be included in the final decision. This means that algorithm will find a physically nearest gateway in order to provide fast connectivity and network connection of a new device. In Fig. 5, we assume that the new user wants to connect to network through the closest router. After detecting the user, router should read previously calculated route from its routing table. In this case it is the path to the left gateway, marked as rectangle dash line, Fig. 5.

![Fig. 5. Example of new user associations.](image)

The most serious problem in every routing protocol is the time of exploring or triggered time of updating routing tables. Unfortunately, devices on the route could be unreachable. It is obvious that a new device will change links and routers occupancy and/or routing table should be updated. These circumstances could make changes in routing calculation. So, the assigned “best route” in this step, has to be analyzed again.

2) After enabling the logical connection, the user is able to start a session. In the meantime, the routing procedure, after updating of the routing tables, could initialize the analysis of the previous solution. If there is any other route, which is better than the established one, it should be done by rerouting in order to realize a better QoS or to balance the load in the network as much as possible. Beside that, some of the links or routers in the route could be unreachable. Particular links or routes could be included or reactivated offering new and better performances. All these changes require the routing check procedure and rerouting if a better one has been detected, Fig. 6.

![Fig. 6. Example of path rerouting after all parameters are observed.](image)

In Fig. 7, algorithm of proposed routing protocol is represented. After routers initialization, based on information in routing tables, neural network finds the route to the first (nearest) gateway in the observed network topology.

![Fig. 7. Algorithm of proposed routing protocol.](image)
criteria are number of hops, link capacity and link occupancy. These criteria should use network resources as optimally as possible. If such gateway and route is found, algorithm should perform the rerouting.

5.2 Mobile agents’ technologies

Rerouting should be based on up-to-date routing table information. Unfortunately, network exploration and detection of changes are very complicated and directly correlated with processing time. For this purpose, we use separately designed mobile agents [21-24].

Mobile agent systems provide an environment in which mobile agents can exist. This environment is called agent server. This server offers standardized services to an agent so as to enable the agent to go through the network and collect/share data [22, 24]. One of the most important service is route selection. Based on this route, mobile agents will start their journey. In [21-25], services could include access to local resources and applications, communication with other agents via message passing, migration, basic security services, creation and termination of agents. Fig. 8 shows organization of mobile agents system. Every router has additional logical function: to be Agents server. Every server can generate agents and send to network to share routing information from that router. Every mobile agent has some path and needs to go through all known routers in network and come back to its Agents server.

Any change in the network (link or routes in/excluded) can change all previously found “best” routes, and this procedure has to be repeated. Beside that, link status changes have to be detected and observed by neural network. After recalculation, traffic can be rerouted if there is a better solution. This sub procedure is shown in Fig. 10 and it starts every time when these changes are detected.

VI. SIMULATION RESULTS

Proposed packet routing in wireless mesh network is realized in Matlab. We used dynamically created network topology based on arbitrary number nodes. One of the networks topology based on 15 nodes is shown in Fig. 11a. All links are bi-directional with different parameters (explaining the links status and network topology) for different directions [13]. Network topology, connectivity and number of nodes are changeable and user can define them through appropriate Graphic User Interface (GUI). Each link is described with three parameters: distance, capacity and traffic density. All values for all parameters are randomly generated and scaled to the interval [0-1], as in [12].
12 has been chosen because this path is the shortest distance. This first phase is realized, and user is connected to Internet through wireless mesh network.

Second phase is finding of an optimal route based on multicriteria optimization, including link capacity and traffic load or density.

Let us suppose the link between router 12 and Internet is down. This event needs immediate route recalculation, with minimal changes. New route is shown in Fig. 12a. Routing algorithm found the gateway 11 as the closest one, and made extension by link 12-11. Initially, link 2-12 is occupied by another connection, and the difference between link capacity and traffic density is too small. Neural network finds route 1-4-7-8-10-11 as optimal for given input values, Fig. 12b.

In this phase, the user path is rerouted, and network is disburdened. Let us assume that all links connected to router 4 are overloaded. This means that the route must be recalculated again. User connection will be broken until mobile agent visits router 4 and gets this information. At the same time, agent goes to all other routers and changes routing table data. In this case, algorithm needs to change the route, and to make new query to neural network. New route is calculated based on the new routing table data. Now, this route is 1-2-3-5-7-8-10-11, Fig. 13a.

Any other changes in network topology or links status and parameters, need to be detected by mobile agent, and distributed through the network. Proposed algorithm is activated every time when changes occur, but it is not necessary to do rerouting whenever such situation occurs. If we suppose gateway 11 is unreachable all traffic in network should be transmitted through gateway 13. In this case, the new route is found as in Fig. 13b.

These several examples show us possibility of proposed routing algorithm to make fast connectivity, but after that, make any necessary rerouting based on multicriteria optimization in order to maximize usage of network recourses.

VII. CONCLUSION

New routing algorithm for wireless network is presented. Based on randomly generated network parameters, we found first route for new (connected to router 11) user as: 11-10-8-7-5-3, Fig. 14b. This route is established and user is connected to Internet. Let us suppose that routing algorithm found better route based on link capacity and traffic density. All links connected to router 3 are overflow. New route is calculated as 11-10-8-7-4-25-24-26, Fig 15.a. If we simulate that router 4 is out of order, algorithm need to find other route. New route should be with minimizing changes compare with previous one. Our algorithm found route shown on Fig. 15b.
neural network. The first one is responsible for routing metric and finding optimal path in network. This path should be based on multicriteria optimization in order to provide the best possible usage of resources. The second procedure is responsible for detecting and sharing all routing information which are changed during the time. For this purpose we used mobile agent technology, as one of the most used in recent period.

We realized Matlab source code for described algorithm. In order to evaluate proposed algorithm we made a lot of simulations for different types of network topology and network's parameters. We found that the proposed solution can be used for routing purposes, especially in an environment such as wireless networks.

Our future work will address the optimization of the efficiency of mobile agent usage, and the analysis of multi agent systems. From the point of metric, we will try to include more network parameters in routing metric. In this way, network resources should be used optimally and QoS can be better observed by means of more parameters.

REFERENCES