A Genetic-Neural Approach for Mobility Assisted Routing in a Mobile Encounter Network

Niko P. Kotilainen, Jani Kurhinen

Abstract--**Mobility assisted routing (MAR) is a concept, where the mobility of a network's nodes is used to physically carry data to its destination. Traditionally, MAR algorithms have been based on few simple rules, often limiting the performance of these algorithms. In this paper, we propose an architecture in which a trained neural network is fed information about the message and the encountered peer, and which then decides whether to forward the message to the encountered peer. This algorithm, called *NeuroRouter*, is capable of utilizing the most efficient routing strategies in different environments by adapting its behavior based on environmental variables.**

Index Terms—**Mobile encounter network, Mobile peer-to-peer, Mobility assisted routing, Neural network.**

I. INTRODUCTION

Personal digital assistants (PDA) and voice-centered mobile phones have become powerful application platforms which are used in almost all fields of modern society. In addition to supporting a wide spectrum of applications, they can be used for creating new data. For example, one can contribute to a live blog or share photographs with the world immediately after they have been captured. The created data is transmitted for the most part via cellular or wireless local area networks, but short range wireless data links are also employed. At the same time peer-to-peer communication systems such as BitTorrent and Skype have taught people to utilize this new communication paradigm in both entertainment and business. While peer-to-peer computing has clearly shown its potential on the fixed Internet, application scenarios using short range connectivity remain underdeveloped. However, the idea of harnessing millions of mobile terminals to provide all imaginable content to information consumers is intriguing.

In the past, the mobility of a network's nodes has been considered problematic with respect to data delivery in a short-range local communication system. However, as Spyropoulos et al. [8] said, "mobility can be turned into a useful ally". In fact in ad-hoc networks where connectivity is very intermittent, node mobility is often the only option to deliver messages between distant nodes of the network. In [5] we introduced the concept of a mobile encounter network (MEN), which builds on the concept cited above. In a MEN environment, data is transmitted only during node encounters. Instead of being a cause of problems, the mobility of the nodes provides a method for data delivery from one node to another. The actual mobile encounter network is the result of all the encounters and data exchange. In a communication system like MEN, a given network node is able to create short-term connections with other network nodes, i.e. the network topology can be defined as a function that is dependent on time. Due to the frequent changes in the network topology, a node may end up inside the communication range of other parties which posses desired information or desire information from the node.

In general these types of systems are called delay tolerant networks (DTNs) [1]. On the other hand, DTNs often do not rely only on direct node to node data delivery, but also benefit from multi-hop routing. Data MULEs [6], one of the first concepts to describe this kind of environment, route data using several independent mobile carriers. Our studies in [3] and [4] discuss similar network systems where data is collected from several sources to one data sink. The data is collected and transported by mobile entities already moving within the environment, and therefore the delivery does not incur additional costs. The multi-hop transmission is the most practical approach in this case; instead of giving full responsibility to one mobile entity to deliver the data packet to its target location, the data is passed to another unit that, in turn, might be able to transmit the data to the actual receiver.

In mobility assisted routing (MAR), the mobility of the nodes in the network is an important data transportation medium. Because of the continuously changing network topology, there are short term internode communication links in the network that follow certain rules based on the mobility patterns of the nodes. In this paper, we propose an architecture in which neural networks are trained to become efficient MAR algorithms.

Section II of this paper describes mobile encounter networks. Section III describes currently proposed mobility assisted routing algorithms. In section IV we present our proposal for a MAR algorithm. Section V describes the neural network training process, and section VI contains conclusions and future work plans.

II. MOBILE ENCOUNTER NETWORKS

Short-range wireless technologies, such as Bluetooth and WLAN, enable mobile devices to network with other similar devices. Information can be diffused from a member of the network to another, and the mobility of the nodes enables a sparse network to transfer information between distant nodes of

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the network. There is no known route between the nodes; the sender of the data just forwards the data to some of the devices it encounters, which in turn forward it further, and eventually the data is very likely to reach its destination. Mobile encounter networks form a new class of mobile networks that emerge when devices encounter and exchange information. One encounter is made up of the discovery of devices, the establishment of a connection between two devices and the exchange of data. The duration of the encounters is usually short, because of the mobility of the devices, but it can also be long if the mobile devices are not moving. These single information exchanges form a MEN, resulting in the diffusion of information in the network with a delay.

MENs are very dynamic, and unlike traditional ad-hoc networks, they don't provide multi-hop communication. This lack of real-time routing limits MEN usage to applications which can tolerate some delay in communication. But for suitable applications, MENs have several benefits: they are scalable, robust, do not require network infrastructure, and can work in very sparse networks. In addition, the short-range communication medium is free.

III. CURRENT MOBILITY ASSISTED ROUTING ALGORITHMS

To bring multi-hop data transmission into mobile encounter networks, the mobility of the nodes has to be used to deliver messages between nodes that do not have a direct communication route between them. The nodes forward their messages to encountered peer nodes, with the hope that they would deliver the message to the destination, or at least would forward it further to nodes going to the right direction. This is usually called mobility assisted routing (MAR). Fig. 1. shows a simple example of message delivery using MAR.

The nodes in a mobile encounter network only know their own situation and the information they get from encountered nodes; they do not have a global view of the network status or topology. Hence, making routing decisions is problematic. Mobility assisted routing algorithms can be divided into three classes: epidemic spreading, epidemic spreading with limitations or restrictions, and targeted data delivery. The third class of MAR protocols can be described as being more intelligent than the former classes. As opposed to random spreading, targeted data delivery methods focus on selecting appropriate carrier nodes among the contacted nodes.

Epidemic routing was first introduced by Vahdat and Becker [10]. As the name implies, the algorithm works like a disease: using epidemic routing, messages are passed to all possible network nodes in the hope that some node is able to deliver it to a target location. It is a very powerful method and always gives the smallest delay possible if the network system handles the data flow properly. However, its efficacy requires vast amounts of network resources. While copying the messages to other network nodes, the epidemic algorithm wastes plenty of system's resources like storage capacity, network bandwidth and battery power.

Spyropoulos et al. has proposed Spray and Wait [7] and later Spray and Focus [9] protocols, which are good examples of methods designed to limit the problems of pure epidemic diffusion. Spray and Wait exploits different types of counters to control the number of message copies in the network. Spray and Focus has evolved from Spray and Wait, and combines copying and forwarding. These schemes, however, do not qualitatively distinguish distinct nodes while passing message copies. Instead, they employ numerous randomly selected nodes as message carriers. However, the Spray and Focus protocol does try to take advantage of potential opportunities to forward the message closer to its destination during the focusing phase.

Even though they are more efficient than the pure epidemic diffusion, they still waste substantial amounts of device memory, battery power and network bandwidth while passing data to inappropriate network nodes.

There are certain limitations in all of the algorithms described above. First, these algorithms don't take into account the qualities of the receiving nodes when making the routing

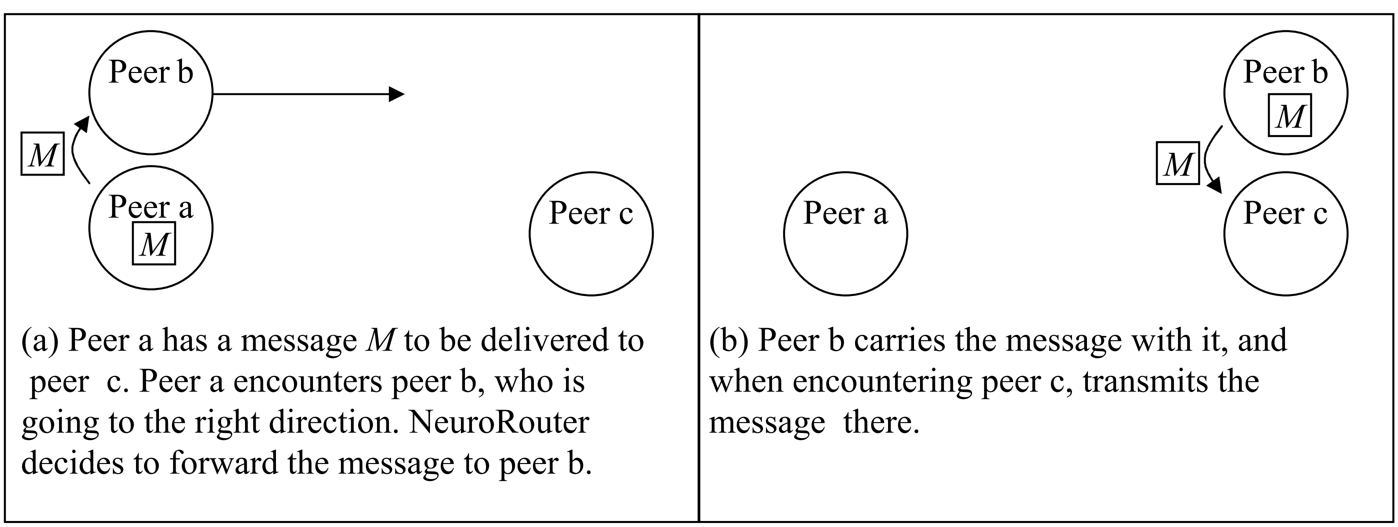

Fig. 1. Message delivery in a mobile encounter network using mobility assisted routing.

decisions. Second, each of these algorithms uses some control parameters (for example the number of "sprayed" packets or time-to-live) that can be used to tune the algorithm. In situations where a priori knowledge of the network environment is unavailable, a routing algorithm including configuration parameters is less than desirable. Finally, these algorithms don't adapt to the environment or to environmental changes because they rely only on one routing strategy. In general, only one strategy cannot be efficient in all scenarios. Therefore, an efficient algorithm should be able to utilize many strategies at the same time. To overcome these limitations, we propose a neural network based mobility assisted routing algorithm called NeuroRouter. NeuroRouter independently learns the correct behavior in given network conditions and uses many combinations of strategies to route packages. To our knowledge, it is the first MAR algorithm utilizing neural networks, or genetic algorithms in general.

IV. NEUROROUTER – A MOBILITY ASSISTED ROUTING ALGORITHM

When encountering peer nodes in the network, nodes have to decide whether to forward messages to the encountered peer node. This decision has a large impact on the efficiency of the network. As was discussed in section III, current MAR algorithms have limitations that affect their efficiency. Similar problems with resource discovery algorithms in static peer-to-peer (P2P) networks have been successfully solved using genetic algorithms [11]. In this paper we are proposing that the same idea be used in mobility assisted routing.

The proposed algorithm, NeuroRouter, decides to which of the encountered nodes to forward the messages held in its memory. Each time a pair of devices encounter one another, both devices input local information about their messages and the encountered node to a multi-layer perceptron neural network, of which output determines whether the message is forwarded to the encountered node. Fig. 2. illustrates this process. The neural network is a non-linear function approximator, which is organized into four layers: an input layer, two hidden layers and an output layer. The input layer contains the values of the neural network's inputs. The hidden layers do the actual work of decision making. The output layer simply provides a "Yes" answer if its inputs' sum is positive; otherwise the answer is "No". The layers are connected with weights, which determine the qualities of the neural network. In

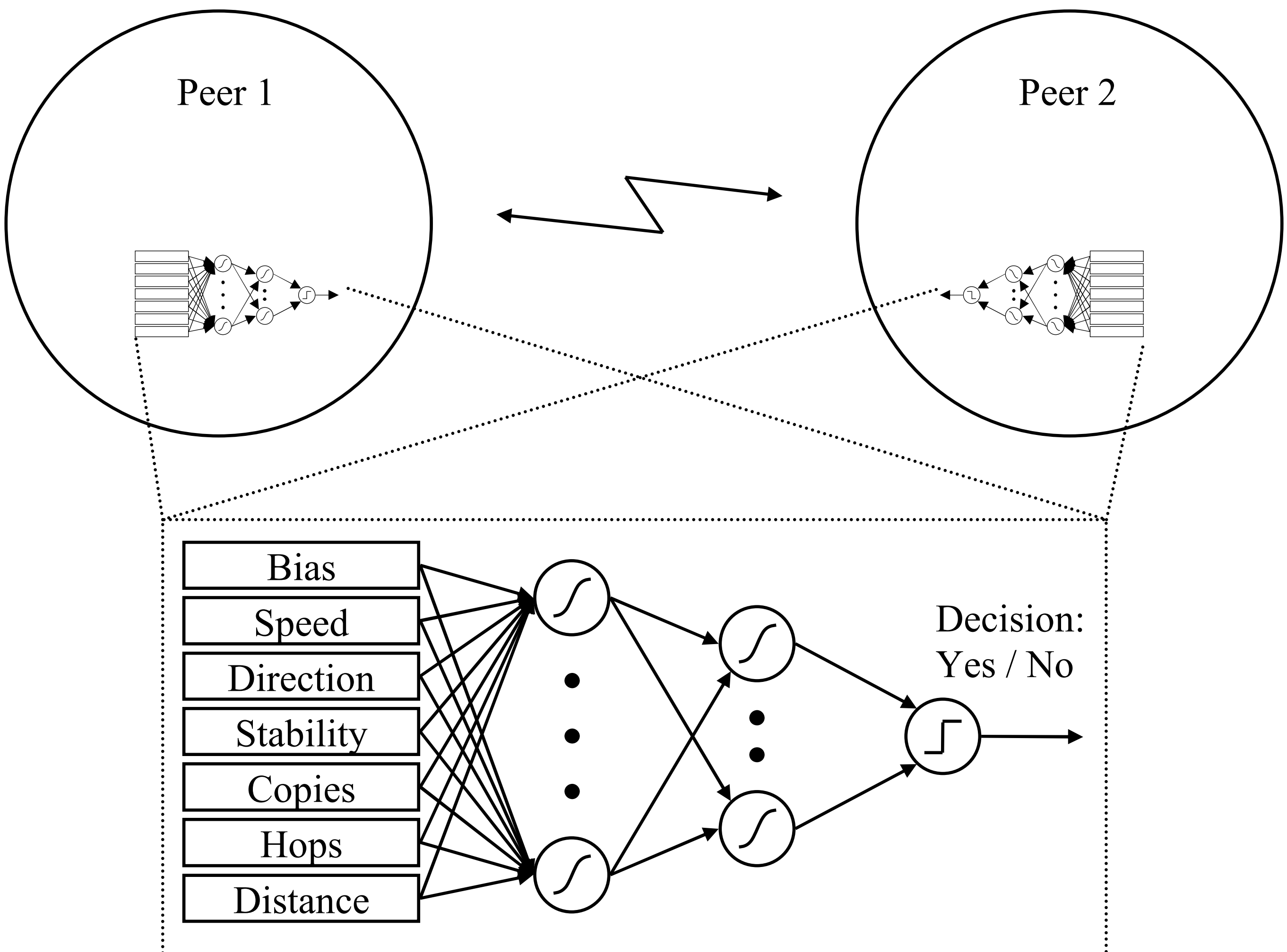

Fig. 2. When peers encounter each other, they ask a neural network whether to forward messages to the encountered peer.

Fig. 2's neural network, the arrows represent connections between layers, each connection having its own weight, and the circles represent neurons on the hidden layers and the output neuron. The first hidden layer has 16 neurons and the second one has 4 neurons. The activation function of the nodes of the hidden layer is hyperbolic tangent,

$$t(x) = \frac{2}{1+e^{-2x}} - 1,$$

where x is the sum of inputs of the neuron. The output of the neural network is calculated using neural network's weights W and inputs I with the following formula:

$$output(W,I) = \sum_{i=1}^{4} W_{3,i} t(\sum_{j=1}^{16} W_{2,j} t(\sum_{k=1}^{7} W_{1,k} I_i)).$$

The input parameters for the neural network are:

- "Bias", a constant 1.0
- "Speed", the encountered node's speed
- "Direction", the difference between the encountered node's direction and the direction to the destination
- "Stability", the stability of the encountered node's speed and direction
- "Copies", the number of copies of the message already sent.
- "Hops", the number of hops the message has taken to reach the current node from the message originator
- "Distance", the distance to the destination

V. NEURAL NETWORK TRAINING

Neural networks cannot make good decisions automatically, they have to be trained. Neural networks are trained by optimizing the weights that define the neural network's behavior until the neural network provides good results. Fig. 3. introduces the training process. Our system uses an evolutionary method to train the neural networks. In the beginning of the method, 30 neural networks are randomly generated, tested, and compared to each other. Then 15 worst performing networks are replaced with offspring of the 15 best performing networks. The offspring are created from the best performing networks by making Gaussian random changes to the parents. This test-compare-replace procedure is repeated thousands of times, and the neural networks gradually become very high-quality problem solvers. In the end the best individual from the neural networks is chosen to be the newly created MAR algorithm.

The training requires a lot of neural network evaluations. For example, training a population of 30 neural networks for 100.000 generations entails three million evaluations. As a result, the training cannot be done in a real-life network, but needs to be run in a simulator. For the training phase, we therefore need to define a mobility model of the environment. The model should reflect the parameters of the particular system, and therefore there is no one single solution that suits all. However, the random waypoint model, one of the most widely used mobility models, is a close enough approximation for training purposes.

We are currently modifying the P2PRealm [2] peer-to-peer simulator to support mobility assisted routing. After the NeuroRouter algorithm has been developed, i.e., the neural network has been trained; it can be deployed to a real-life network. After it has been deployed, the network's nodes can further improve and adapt the algorithm to their needs by using message history data as training material.

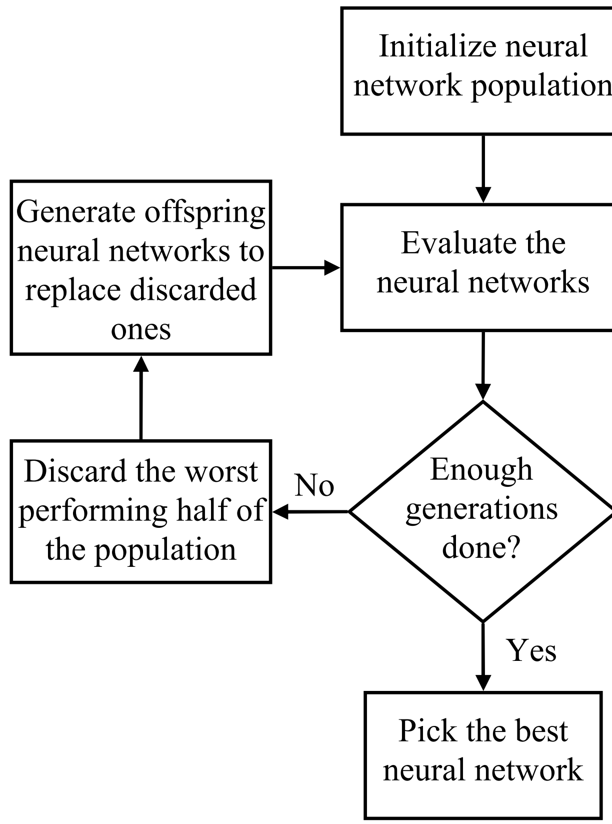

Fig. 3. Neural network training procedure

VI. CONCLUSION AND FUTURE WORK

In this paper, a new mobility assisted routing algorithm called NeuroRouter has been proposed. The algorithm employs a trained neural network to make the routing decisions when peer nodes are encountered and thus can adapt to the environment and make more efficient routing choices.

We are now in the process of implementing the described system in a simulator environment using the P2PRealm [2] network simulator, so that the proposed algorithm could be compared to currently proposed MAR algorithms. We also intend to implement a testbed to evaluate the system in a real-life scenario. Future work on the subject will include using global information about the network to find an optimal solution to this problem. This solution would be the upper bound for MAR algorithms, and current MAR algorithms could be compared to this limit.

REFERENCES

[1] K. Fall, "A delay-tolerant network architecture for challenged internets," In *ACM SIGCOMM* 2003.

[2] N. Kotilainen, M. Vapa, T. Keltanen, A. Auvinen, and J. Vuori, "P2PRealm - peer-to-peer network simulator," in *11th International Workshop on Computer-Aided Modeling, Analysis and Design of Communication Links and Networks*, 2006.

[3] J. Kurhinen, "MP2P network in collecting data from sensor networks," in *11th IEEE Symposium on Computers and Communications*, 2006.

[4] J. Kurhinen and J. Janatuinen, "Geographical routing for delay tolerant encounter networks," in *12th IEEE Symposium on Computers and Communications*, 2007.

[5] J. Kurhinen, V. Korhonen, M. Vapa, and M. Weber, "Modelling mobile encounter networks," in *17th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, 2006.

[6] R. Shah, S. Roy, S. Jain, and W. Brunette, "Data MULEs: modeling a three-tier architecture for sparse sensor networks," in *First IEEE International Workshop on Sensor Network Protocols and Applications*, 2003.

[7] T. Spyropoulos, K. Psounis, and C. S. Raghavendra, "Spray and wait: Efficient routing scheme for intermittently connected mobile networks," in *ACM SIGCOMM workshop on Delay Tolerant Networking*, 2005.

[8] T. Spyropoulos, K. Psounis, and C. S. Raghavendra, "Performance analysis of mobility-assisted routing," in *7th ACM international symposium on Mobile ad hoc networking and computing*, 2006.

[9] T. Spyropoulos, K. Psounis, and C. S. Raghavendra, "Spray and focus: efficient mobility-assisted routing for heterogeneous and correlated mobility," in *Fifth annual IEEE international conference on Pervasive computing and communications workshop*, 2007.

[10] A. Vahdat and D. Becker, "Epidemic Routing for Partially-Connected Ad Hoc Networks," *Technical Report CS-200006*. Duke University, 2000.

[11] M. Vapa, N. Kotilainen, A. Auvinen, H. Kainulainen, and J. Vuori. "Resource discovery in P2P networks using evolutionary neural networks," in *International Conference on Advances in Intelligent - Systems Theory and Applications*, 2004.

[12] O. Volovikov, T. Juonoja, M. Weber, N. Kotilainen, M. Vapa, and J. Vuori, "Mobile encounter networks and their applications," in *5th IEEE Consumer Communications and Networking Conference*, 2008.