Stability-aware Cognitive Packet Network Routing Protocol for MANET

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1 STAGE OF THE RESEARCH

The PhD research is currently in the simulation phase of the routing protocol using OPNET 14.5 modeler. There are three levels of simulation modelling in OPNET. First, there is the OPNET Network model, in which the research defines the MANET to perform the different simulation scenarios upon. Then there is the Node model, where the Cognitive Node is defined in detail as shown in section 3. The last level is the Process model, where the details of the routing protocol is defined as a process state diagram.

The research is in the proess model stage,in which the routing protocol states, events, conditions, and actions are defined. First the INITIAL state is identified, then more states are added as needed. The process model is then saved in the OPNET Process Editor. Finally, program code segments are added in its appropiate places in order to run the simulation of the protocol.

2 OUTLINE OF OBJECTIVES

The Cognitive Packet Network (CPN) Routing Protocol is a unique adaptive protocol with self-improvements capabilites (Gelenbe, 2011). It offers the network the ability to determine the Quality of Service (QoS) criteria according to the data being transferred (application) at the software level in a distributed way. Each node in the network runs the protocol using Computational Intelligence to find the suitable path for every packet. Network information is collected only for paths being used; there is no global network information exchange. This information is used by a Reinforcement Learning Algorithm and a Random Neural Network to take routing decisions at every node according to specific Goal Function depending on the needed QoS criteria.

This research extends the work on CPN Routing Algorithm to adapt the protocol to the Mobile Ad hoc Network (MANET) environment. MANETs are wireless networks where packet communication does not depend on any infrastructure. Thus a MANET is characterized by highly unstable topology. Node mobility is a major problem and so links between nodes are broken frequently. The research focuses on node stability within its neighbours as criteria for choosing a node as part of a routing path.

The research routing algorithm defines a Goal Function of a combination of high-stability and short-delay criteria. The nodes that satisfy this goal are chosen for routing with high probability. Thus the algorithm results in long-live, short paths while being fast adaptive to topology changes.

The research also shows that using Computational Intelligence in a challenging routing environment such as MANET gives comparable results to conventional MANET routing protocols without disrupting the overall packet delay.

3 RESEARCH PROBLEM

CPN performs routing using three types of packets: smart packets (SP), dumb packets (DP), and acknowledgments (ACK). SP is used for route discovery and route refinement and maintenance. DP carry the actual data. ACK carry feedback information about the routes discovered. All packets have the same structure: a header, a cognitive map. and the payload data. A cognitive map holds information about the nodes visited by the packet and the visiting time. To discover routes SP's are source-initiated to move through the network gathering specific network information according to the specific QoS goals determined in each SP. Until the requested path is found SP's are continuously sent by the source node. Once the first ACK reaches the source node carrying the first path discovered, the rate at which the SP's are sent is reduced in order to maintain and improve QoS delivered.

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At each node, when a SP arrives the node checks if the SP is a duplicate and thus discarded. If the SP is not a duplicate, the node checks if itself is the destination node. If the node is the destination, it creates an ACK packet for this SP. The ACK uses the reverse route of the route discovered by the SP. The ACK passes every node on the discovered route and updates the weights in RNN according to the performance.

On the other hand, if the node is not the destination, then it should use the RNN to make a decision on which outgoing link to send the SP when enough neighbour information is available. However if the neighbour information is not sufficient to make a decision, then the node broadcasts the SP to all of its neighbours on all outgoing links.

As soon as the first ACK reaches the source node, the source node copies the discovered route into all DP's ready to be sent to carry the payload from source to destination. DP's use source routing with the discovered route until a new ACK brings a new better route to the source node. Thus SP's continue to be issued from the source node at a low rate to maintain and improve QoS.

The CPN algorithm uses the Goal Function of a combination of low power consumption and short delay (QoS) to make routing decisions on wired networks. The research algorithm introduces the node stability to the goal function of CPN in order to adapt it to the MANET environment. Such that nodes with high stability are chosen for routing with high probability. In this algorithm stability is measured through the node's neighbour associativity degree over time and space (Toh, 2004).

Each node sends out low frequency beacons to signify its existence. It also keeps track of all its neighbours and the number of beacons it received from each neighbour in a table. If the number of beacons received from a certain neighbour is more than a specified threshold, the neighbour is considered stable and could be used in the routing path. The associativity threshold is a function of the beaconing interval (p), the relative velocity between the two nodes (v), and the transmission range (r) of a node as shown in equation 1 (Toh, 2000).

$$A_T = 2r/ pv \tag{1}$$

Associativity degree is reset when either the mobile node itself or the neighbour move out of transmission range. The associativity property assumes that a mobile node goes through a stage of instability with high mobility followed by a stage of stability when it is dormant (connected to the same neighbours for some time) before the mobile node moves out of proximity. The dormant stage is the best time for a node to participate in routing, which is determined by a high associativity level.

The research routing algorithm uses a goal function which optimizes the nodes stability while looking for short routes. It aims to find long-live routes without disrupting the delay constraint. Thus for some active flow k, the algorithm computes the routing goal at node i (G) using equation 2.

$$G_i = \frac{1}{A^k_{p(i)}} + D^k_{p(i)} \tag{2}$$

where $A^k_{p(i)}$ is the total node associativity level of all path nodes from node i to the destination node. And $D^k_{p(i)}$ is the total path delay for flow k measured from node i to destination node. At each node, a separate Random Neural Network (RNN) is stored for each flow k. Each neuron in RNN is associated with a specific output link for that node. When a SP is received the RNN is used to make a routing decision to send the SP on one output link.

When an ACK is received, the Reinforcement Learning algorithm is used to reward or punish the chosen path according to the delivered QoS. The research algorithm defines a reward function as shown in equation (3).

$$R = 1/ G \tag{3}$$

Successive measurements of the reward are collected and RNN weights are updated according to this historical average threshold. First T_l the threshold is computed as shown in equation (4).

$$T_l = \alpha T_{l-1} + (1-\alpha) R_l \quad \text{where} \quad 0 \le \alpha \le 1 \tag{4}$$

Then the current reward R_l is compared to the previous threshold T_{l-1} . The excitatory weights of all the neurons up to that neuron are significantly increased if the current reward is larger than the previous threshold, with slight increase in the inhibitory weights which leads to other neurons. However if the current reward is less than T_l-1 meaning that the chosen neuron was not successful of producing better reward, then all the inhibitory weights leading to the winner neuron are significantly increased. While all excitatory weights of other neurons are increased moderately. The Reinforcement Learning algorithm (Gelenbe and Seref, 2001) performs this weight update as shown in equation (5).

$$\begin{aligned}
&\bullet \text{ If } T_{l-1} \ \leq \ R_l \\
&\quad - w^+(i,j) \leftarrow w^+(i,j) + R_l, \\
&\quad - w^-(i,k) \leftarrow w^-(i,k) + \tfrac{R_l}{n-2},\ if\ k \neq j. \\
&\bullet \text{ Else} \\
&\quad - w^+(i,k) \leftarrow w^+(i,k) + \tfrac{R_l}{n-2}, k \neq j, \\
&\quad - w^-(i,j) \leftarrow w^-(i,j) + R_l.
\end{aligned} \tag{5}$$

where i, j, and k are the output links to the node's neighbours other than the link which the packet came from. And j is the output link that was most recently used to route packets. Also in equation (4) n denotes the number of neighbours to the node currently updating its RNN weights.

4 STATE OF THE ART

The Stability-Aware CPN Routing protocol for MANET is a unique research protocol which introduces node stability over space and time into the CPN Ad hoc extension routing protocol. The first subsection reviews the CPN state of art, while the second subsection reviews the stability-aware protocols state of art.

4.1 CPN Routing Protocol

CPN has been first introduced to create robust routing for the wired networks (Gelenbe, 2000). It has been tested and evaluated in later studies (Gelenbe, 2001) to be adaptive to network changes and congestions. A number of learning algorithms have been researched before using Reinforcement Learning based on Random Neural Networks (Gelenbe and Seref, 2001). Recently Genetic Algorithms (GA) have been used in CPN and tested to modify and enhance paths already discovered by SP's to give new paths (Gelenbe and Liu, 2006). However, studies show that it improves performance under light traffic only and delays decisions.

A study in (Gelenbe and Lent, 2004) investigates the number of SP's needed to give best performance. It resulted that SP's in about 10% to 20% of total data packet rate is sufficient to achieve best performance, and that a higher percentage does not enhance the performance. A slightly less percentage of SP also give good results.

The study in (Gellman, 2006) compared CPN to OSPF in IP networks. The results show that CPN performs as good as OSPF, and it gives best routes through learning in a very short time frame.

There have been many studies which evaluates the CPN performance. One research studies CPN in the presence of network worms (Skellari, 2008). It concluded in a better failure-aware CPN. It achieved that by introducing a detection mechanism which stores timestamps of the last SP and ACK that pass through the link. If no ACK was received after a SP has passed in some determined time, the link is considered under failure. However, there should be an appropriate estimate for the average delay under normal conditions for each link to be useful.

Extensions to the original CPN then followed as research in this field continues. One extension is Ad hoc CPN (Gelenbe and Lent, 2004), which uses combination of broadcast and unicast of SP's to search for routes. The authors introduced a routing metric "path availability" which models the probability to find available nodes and links on a path. Node availability was measured by the energy stored in the node (remaining battery lifetime). Thus SP's selected nodes that have the longest remaining battery with greater probability. The QoS Goal function was a combined function of two goals: maximum battery lifetime and minimum path delay. The result was good performance (short delay and energy-efficient), but there was a high number of lost packets which meant that the algorithm did not adapt to network changes quickly enough. Additionally, node availability in real systems is determined by many factors such as process load and work environment and not just battery lifetime.

The AHCPN had some later enhancements as in (Lent and Zanoozi, 2005) which proposed a solution to control both energy consumption in nodes and mutual interference of neighbouring communications. The paper suggests an adjusted transmission power level when transmitting DP's and ACK's to save energy and reduce interference. While SP's are transmitted using full power. The result is that nodes have more energy to participate in routing. Nodes with more energy are chosen in paths with higher probability.

Enhancements to AHCPN continued as research developed. A new routing metric "Path Reliability" was presented in (Lent, 2006), characterized by reliability of nodes and links. Node reliability is considered to be the probability that a node will not fail over a specific time interval which is estimated to be the average network life time. The QoS combined goal function includes maximum reliability and minimum path delay. Reliability is continuously monitored, and if it drops below a certain threshold the source node is informed to start a new Route Discovery before links break.

4.2 Stability Aware Protocols

Stability-Aware routing algorithms aim to find the longest-lived routes. However, there are many ways to study path stability. In Associative Based Routing (ABR) (Toh, 2000), associativity is defined to determine a link's connection stability and thus path stability over space and time.

Signal Stability based Adaptive (SSA) routing protocol depends on signal strength and location stability (Sridhar, 2005). However simulations show that it doesn't perform better than a simple shortest path algorithm. There are also extensions to this protocol to overcome the problems (Bakht, 2005).

There is also some significant research about link and path duration to propose that the residual lifetime of a link determines the expected path duration (Han, 2006). This kind of work studies the distribution of link lifetimes in a network. Each time a link breaks the average lifetime of the link is updated for future use in path duration estimation. However, the results of the study are closely related to the mobility model assumed. It also assumes that all nodes have the same movement pattern. It also depends on information gathered over a long time in order to reasonably estimate path duration and make routing decisions accordingly.

5 METHODOLOGY

Stability-Aware CPN Routing Algorithm for MANETs is an extension of the original Energy-Aware Ad hoc CPN routing algorithm shown in section 3. It has been enhanced to adapt to the MANET environment, where node mobility raises routing challenges. The main contribution of this algorithm is to introduce Association Stability degree to identify stable routes. Thus the algorithm provides QoS through short, long-lived routes using Computational Intelligence to make routing decisions. This contribution enhances both the Route Discovery Process and Route Maintenance Process. Thus the research protocol has a faster route discovery process. Also, it defines a route maintenance process which is faster adaptive to network topology changes. This section reviews the research routing algorithm. The main operation of the protocol are shown through these processes: Neighbour discovery and Route Discovery, Knowledge Acquisition and Storage, Routing Goal and Path Reward, and Route Maintenance.

5.1 Neighbour and Route Discovery

The research routing algorithm introduces the use of beacons to signify node existence. Nodes that are low on battery become passive and refrain from sending beacons. The number of beacons collected over time from a neighbor is the degree of Associativity for the node. Associativity degree is reset when the node itself moves out of range of its neighbors. The beacon interval determines the effect on battery lifetime.

Route discovery is triggered when a node needs to send data to unknown destination. SPs depart from source to find a route using RNN/RL algorithm to select the next hop by taking a unicast decision using collected neighbor information. Each node stores all SP identifiers which have visited it along with source address. When SP reaches Destination, an ACK is sent to the source and the new route will be stored in the route cache of source node. Transmission of data packets starts immediately.

5.2 Knowledge Acquisition and Storage

The SP's collect specific network information as they move around and store it in distributed fashion as follows. Route Caches located only at source nodes, stores complete path for all active destinations. Cognitive Maps (CM) exist in all type packets to store addresses and network metrics (Battery, Arrival time, and Associativity) of visited nodes. ACK's distribute this information to update mailboxes along the path. Packets store complete route in their CM. Mailboxes are located at every node, they keep statistics about performance of active paths such as average delay, degree of associativity. This information is used by RNN to decide on next hop. Weight Tables are located at nodes for the RNN. Weights are updated by the RL algorithm. Neighbor Tables are created and maintained at every node to keep information about neighbors and their associativity degree and forwarding delay.

5.3 Routing Goal and Path Reward

The research algorithm goal is to establish stable, short, long-lived routes using resources efficiently. To accomplish this goal, network information is gathered and stored in a distributed way as shown in the previous subsection. This information is used by the Reinforcement Learning algorithm to determine the Reward and Weight update according to the delivered Qos. The Goal function to be optimized combines Associativity degree and Delay as shown in section 3 equation 2. The Reward is defined as the inverse of the Goal as shown in section 3 equation 3.

5.4 Route Maintenance

Maintenance of previously established routes is achieved by sending a small fraction of SP's after the dump packets start communicating data. Only active routes are maintained. The use of beacons allows fast detection of link breakage. Such that when a node on a active path detects that the next hop neighbor is not up, it immediately sends a message to the source node indicating the broken path. The source node stops sending data using the broken path and searches its cache for other routes to that destination. If another path is not found, a new route discovery process is invoked.

6 EXPECTED OUTCOME

Routing in MANETs is a very challenging field. There is no one perfect solution which fits all MANETs. Different network characteristics need different routing protocols. However this research is to show that using Computational Intelligence to find suitable routes in MANETS is experimental with comparable results.

The research is to also show that stability-aware cognitive routing is resilient to link failures and fast adaptive to network topology changes. Thus the simulation statistics to be studied are packet loss ratio, route setup and reconstruction time, and total packet delay. Early detection of link breakage should avoid packet loss and decrease route reconstruction time. Using beacons for neighbour discovery allows a node to know its neighbours and any link breakage should be detected early. Route setup time should also be decreased by using beacons due to the collected knowledge about neighbours at each node. the research defines simulation scenarios to show that using a goal function based on delay alone gives unstable paths and thus more frequent broken links and more reconstruction of routes. While the combined goal function of stability and delay avoids unstable nodes without disrupting the total packet delay.

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