ENERGY EFFICIENT ON-DEMAND ROUTING PROTOCOL BASED ON LINK COST

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Abstract*—In this paper, we propose an energy aware routing protocol for low mobility Ad-hoc networks that powered by battery. Our protocol will be built above an existing on-demand routing protocol, such as the Ad Hoc On-demand Distance Vector routing (AODV). The improvement of this protocol in energy consumption is obtained by introducing a routing metric and by adapting the transmission power. The routing metric takes into consideration the total amount of energy necessary to reach the destination node and the battery level of intermediary nodes. Many paths will be determined, but the path chosen by the source also has to be the cheapest one, electrically speaking, and at the same time it has to preserve nodes with low battery in order to extend the network lifetime.

Index Terms— **routing, energy efficient, power aware, ad hoc networks, and OMNET.**

I. INTRODUCTION

The development of telecommunication networks in South Africa has been quite unbalanced in past years. This has been due to the low population densities in rural areas that are generally categorized as non-profitable by companies and as a result, have not benefited from classical wired Internet access. Moreover, due to the cost involved in typical Internet access, a very small percentage of people at the moment benefit from Internet. On the other hand, Global System for Mobile communication (GSM) covers the whole country. The idea in this project is to use this unexploited bandwidth in the GSM network to provide Internet access points for those areas. South Africans companies try to consider alternative business models for rural communities to provide Internet access that employ low-cost Ad Hoc networks incorporating an energy efficient routing, Quality of Service and power control. The communication support chosen for this type of network is Worldwide Interoperability for Microwave Access (WiMAX) technology that can connect IEEE 802.11, the Wireless Fidelity (Wi-Fi) hotspots with each other and to other parts of the Internet and provide a wireless alternative to classical wired access without preexisting physical cable or telephone networks. There is also an interesting potential for interoperability of WiMAX with legacy cellular networks. WiMAX antennas can "share" a cell tower without causing interferences. For countries that have skipped wired infrastructure, WiMAX, with a diametrical range of 50 kilometers, can vastly improve wireless infrastructure in an inexpensive, decentralized, and easy deployable way.

Due to the lack of electrical networks in rural areas, a priority defined for ad hoc networks is to save battery life of those network infrastructures to extend the operation of such networks. Many factors influence the power consumption of wireless communication devices. In an Ad Hoc network node, the radio frequency aspects consume most of the power spent for communication.

A way to save battery power could be to turn off the radio as much as possible, but in an ad-hoc multi-hop wireless network, nodes have to cooperate in order to maintain the connectivity of the network. So turning off the radio for an extended period would certainly increase the probability of dropping packets and disconnections. So the most common way to reduce the power consumption of a node, taking into consideration our inputs, is to define an energy efficient protocol of communication. This protocol has to reduce as much a possible the percentage of energy spent for the overhead control process, try to find the least cost path in terms of energy consumption, and increase the lifetime of the network.

Ad-Hoc wireless networks are multi-hop wireless networks consisting of mobile nodes, where all the nodes cooperatively form and maintain the connectivity of temporary networks that do not rely on the presence of any fixed network. This type of network is suitable for the development of affordable locally developed Ad hoc wireless technology, to provide a cheap and easily deployed Internet access for infrastructures in rural communities that are isolated from traditional Internet and electric networks. As users join the network, they improve the coverage and increase the network throughput since every new node becomes a new router. Nodes can communicate with other nodes either directly or via intermediate nodes. Ad-hoc routing protocols can be classified as table driven routing and source initiated on-demand routing described as follows.

- *Table driven approach* uses a routing table which is maintained via periodic updates from all the other nodes in the network irrespective of the fact that the network may not be active in terms of data traffic.
- The *on-demand approach* sends out request for routes to the destination only if the source has data packets to transmit.

In General, the table driven approach is more expensive in terms of energy consumption compared to the on-demand approach due to the large routing overhead.

The choice of a route in a multi-hop network influences the overall network performance, measured in terms of energy consumption in our case. There are many algorithms proposed which emphasize energy efficient routing such as DSR **[1]**, DSDV **[2]**, AODV **[3]**, and TORA **[4]**. Some of these protocols have extremely good performance, but are not optimized for reduced energy consumption

This paper is organized as follows. Section 2 provides a presentation of the existing AODV protocol. Section 3 presents the power control algorithm. Section 4 presents the power aware routing metric used. Simulation results are then discussed in Section 5. Section 6 summarizes the main results and discusses future research directions.

II. THROUGHPUT OF AODV ROUTING

A. Overview

The Ad Hoc on-demanded Distance Vector (AODV) routing protocol is a method of routing messages between mobile computers. It allows these mobile computers, or nodes, to pass messages through their neighbors to nodes with which they cannot directly communicate. AODV does this by discovering the routes along which messages can be passed. AODV makes sure these routes do not contain loops and tries to find the shortest route possible in terms of hops. AODV is also able to handle changes in routes and can create new routes if there is an error.

B. Algorithm

The AODV protocol deals with a routing table. Every node is associated with a routing table. When a node knows a route to the destination, it sends a route reply to the source node. Its entries are as follows.

Destination Address - Destination Sequence Number - Next Hop Address - Lifetime (expiration or deletion time of the route) - Hop Count (number of hops to reach the destination).

Nodes that can be communicated with are directly considered to be neighbors. A node keeps track of its neighbors by listening for a 'HELLO' message that each new node broadcast and nodes broadcast at set intervals. When one node (the originator) needs to send a message to another node that is not its neighbor, it broadcasts a Route Request (RREQ) message. The RREQ message contains the following information: the source, the destination, the lifespan of the message and a Sequence Number, which serve as a unique ID.

When the originator node's neighbors receive the RREQ message they have two choices: if they know a route to the destination or if they are the destination they can send a Route Reply (RREP) message back to originator, otherwise they will rebroadcast the RREQ to their set of neighbors. The message keeps getting re-broadcasted until its lifespan is completed. If the originator does not receive a reply in a set amount of time, it will rebroadcast the request except that this time the RREQ message will have a longer lifespan and a new ID number. All of the nodes use the Sequence Number in the RREQ to insure that they do not re-broadcast a RREQ.

Sequence numbers allow nodes to compare how "fresh" their information on other nodes is. Every time a node sends out any type of message, it increases its own Sequence number. Each node records the Sequence number of all the other nodes it talks to. A higher Sequence numbers signifies a fresher route. In this way, it is possible for other nodes to determine which one has more accurate information.

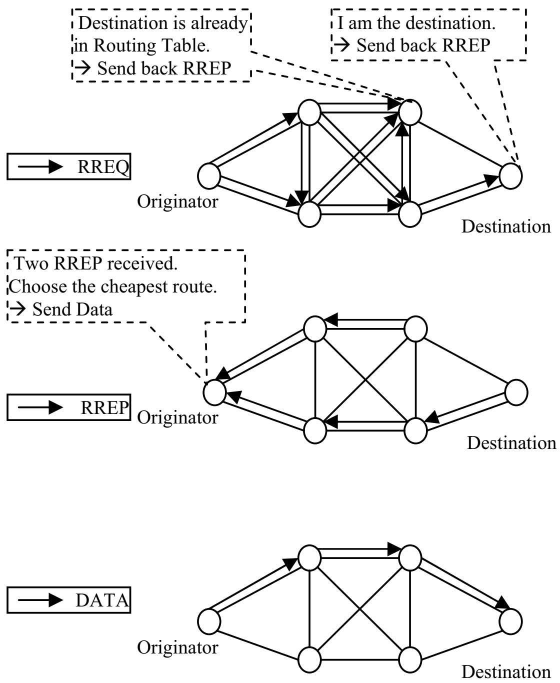

Figure 1 - *Route discovery process*

The Route Error Message (RERR) allows the AODV algorithm to adjust routes when a link between two nodes breaks. When a node receives RERR it looks at the Routing Table and removes all the routes that contain the bad nodes as a next hop or destination.

III. POWER CONTROL

By default, the packets are transmitted with maximum power, which represents a considerable loss on energy. The aim is to adapt the transmission power levels on a per-packet basis for each neighbor. The needed power level to reach a neighbor will be determined during the 'HELLO' process.

Instead of sending one 'HELLO' message, the node will broadcast four 'HELLO' messages with a power level of 100%, 75%, 50%, and 25% respectively. When a node receives a 'HELLO' message, it starts a timer to listen to the maximum messages it can. Once the timer expired, it sends back to the initiator an acknowledgement with the last power level it received. The nodes then update their routing table with the power level required to communicate.

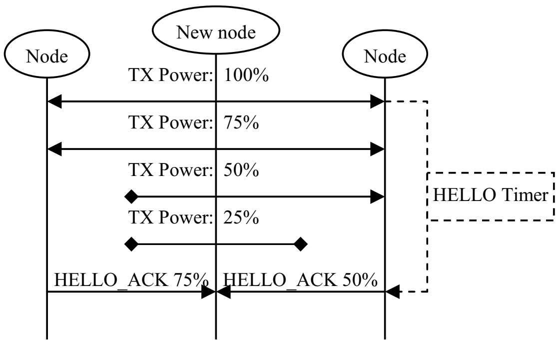

Figure 2 - *The 'HELLO' process*

When a link breakage occurs, the sending node tries to send once more the packet with a power level of 100%. If the packet is received and acknowledged by the destination, both the routing tables are updated. Otherwise, the destination node does not acknowledge the packet and the RERR process is start again.

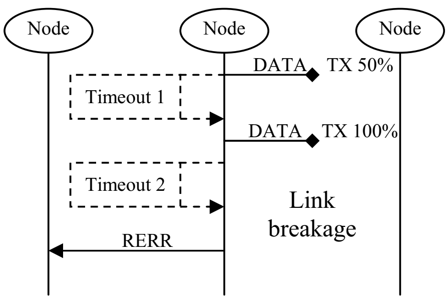

Figure 3 - *The RERR process*

IV. ENERGY AWARE ROUTING METRIC

Given the same sequence number, the traditional AODV routing protocol selects the route with the fewer number of hops to the destination, without specifically accounting for the quality of links. AODV is used for ad hoc networks to determine the shortest routes in terms of hops that are not representative of the energy spent.

To improve the energy efficiency for the AODV protocol, we will consider a metric that takes into consideration the total amount of energy necessary to reach the destination node, and the battery level of intermediary nodes.

A. Minimal Energy Consumption metric

This metric aims at minimizing the power consumed by a packet in traversing from the source node to the destination node. The energy consumed by a packet when traversing through a path is the sum of the energy required at every intermediate hop in the path determined.

First, we define as a routing metric the energy required for the correct transmission of a packet from mobile node i to node j, E^{ij} as follows**[5]**.

$$E^{ij} = \frac{MP_j}{RP_c(\gamma_{ij})} \tag{1}$$

Where M denotes the length of the packet, P_j is the transmission power, R represents the data transmission rate and $P_c(\gamma_{ij})$ is the probability of correct reception of a packet, with γ_{ij} equal to the SIR of link (i, j).

The function in (1) depends on the details of the data transmission, such as modulation, coding, radio propagation, and receiver structure. We choose the same data transmission model as the one in **[5]** given as follows.

$$P_c(\gamma_{ij}) = (1 - 2BER_{ij})M \tag{2}$$

Where BER_{ij} represents the bit error rate for link (i, j). This constraint is defined as a physical layer requirement (e.g. 10^{-2} for voice, 10^{-4} for data). For the case of data traffic transmission, the packets received in error must be re-transmitted until they are correctly received.

The energy requirement for correct transmission of a packet on a specific route (from a source node to its corresponding destination) can be determined as follows [6].

$$E_r = \sum_{link(i,j)\in r} E^{ij} \tag{3}$$

Where r represents a route. It is obvious that selecting the paths with a minimum energy requirement improves the energy efficiency of the network. Based on this observation, the energy per packet on a route can be used as the routing metric to improve the energy efficiency of the network.

However this metric does not balance the load so that uniform consumption of power is maintained throughout the network. A disadvantage of this metric is that some paths become privileged, and consequently some nodes suffer the inability to prevent the fast discharging of the node's battery.

B. *Node's Battery metric*

In Ad-Hoc Networks, the battery energy is limited and it was shown previously that the energy consumption metric does not balance the load uniformly. A way to reduce the probability of data packets being dropped due to reduced energy in the node is to avoid 'low battery' nodes. To extend the network's life, this metric is made as a function of the state of the node's battery.

This metric is defined by the use of thresholds. A node that has more than 50% of battery level is defined as a Battery metric of 1, 25%-50% as a metric of 2, and less than 25% as a metric of 4.

We then multiply the Minimal Consumption metric by the node's battery metric to obtain the final Energy Aware Routing metric for a node.

V. SIMULATION RESULTS

To simulate the performance of our routing algorithm, we build a simulation of the OADV protocol using OMNET++ (a discrete event simulation environment). The primary application area OMNET++ is in the simulation of communication networks.

The implementation of the routing techniques is done to determine whether the consideration of the energy consumption factor that is built onto the AODV protocol has achieved improvements. To evaluate the performance of the routing techniques in our new protocol, some performance metrics had to be defined. The performance metrics that we consider are the *average energy consumption per path*, the *overhead energy consumption rate* (the percentage of energy spent for the overhead control process), and the *lifetime of the network* in terms of battery level. These three metrics will enable us to determine the influence and the utility of chosen parameters, which define the routing metric used. Four different scenarios are simulated.

(i) Traditional AODV with minimum hop routing.
(ii) Traditional AODV with Power Aware routing.
(iii) Traditional AODV with Node's Battery routing.
(iv) Proposed AODV with Energy Aware as routing metric.

For the numerical results, we have selected N=49 nodes, uniformly distributed over a square area with random links. The source-destination pairs of nodes are randomly chosen. The message packet length is 64 bytes. The simulation is not yet completed. We will then compare our energy efficient algorithm in real conditions in a small area with the classical OADV protocol, after simulating in OMNET. The next step will be to run our protocol on a massive mesh indoor test bed, which consists of a grid of 49 computers equipped with Wi-Fi cards at the CSIR, and on a computer simulator for OMNET.

VI. CONCLUSION

In this work, we have proposed an energy aware on-demand routing protocol for ad hoc networks. The traditional AODV protocol was improved by introducing a procedure to adapt the transmission power levels on a per-packet basis for each neighbor as well as by changing the hop-count metric for an energy aware metric. At the network layer, routes are determined in such a way as to minimize energy consumption, and to avoid the nodes with low battery. Furthermore, we can reuse the routing metrics defined on another existing on-demand routing protocol, and then compare their efficiency in terms of power consumption.

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