An Experimental Joint Modelling of RSSI and LQI to Reduce Energy Consumption in MANETs

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Abstract: ***The biggest challenge in MANETs is to find most efficient routing due to the changing topology and to reduce the energy consumption. Existing routing protocols may not perform well during difficult conditions like poor link quality and high mobility. In this paper, a new routing method based on link quality and Ant Colony Optimization (ACO) is proposed for MANETs. It has been found that Ant Colony Optimization (ACO) is a special kind of optimization technique which is highly suitable for finding the adaptive routing for such type of volatile network. To enhance the routing algorithm a new link quality metric is defined to handle the link quality between nodes to evaluate routes. The residual energy of the node is a key factor, which plays an important role in determining the lifetime of the network and hence it is taken as one of the metric in the route selection. Availability of a good estimation of link longevity between neighbouring nodes could permit the selection of a more stable route, thus enabling a better implementation of quality of service (QoS).***

Keywords: RSSI, Link Quality, MANET, Ant Colony Optimization.

1. Introduction

A mobile ad hoc network (MANET) is a decentralized group of mobile nodes which exchange information temporarily by means of wireless transmission. The network topology will modify rapidly and randomly over time as the nodes are mobile. As the topology is not a structured one, the nodes tend to enter or move away the network at their will. A node exchange information to other nodes which are within its broadcast range. Such networks suit several situations and applications as they are flexible, thereby allowing the establishment of temporary communication sans pre-installed infrastructure [1]. Because of wireless interfaces limited transmission range communication traffic is relayed over several intermediate nodes to ensure a communication link between two nodes. Hence, such networks are also known as mobile multi-hop ad-hoc networks. Nodes perform the functionality of the hosts and also act as routers, forwarding packets for other nodes. The main issue in MANETs is finding of routes between communication endpoints, due to node mobility. Literature reveals different approaches that try to handle this problem [2], but there is still no routing algorithm that suits all cases.

To handle the problem of routing in ad hoc network and overcome the shortcomings of the classical methods new methods based on swarm intelligence have been recently developed. These latter are inspired from biological swarms, like ants or honeybees to solve some complex problems such as finding food or optimizing route to food in real insect swarms [3]. These swarms often containing thousands or tens of thousands of actors routinely perform extraordinarily complex tasks of global optimization and resource allocation using only local information.

This paper proposes a new routing method based on link quality and Ant Colony Optimization (ACO) for MANETs. To enhance the routing algorithm a new link quality metric is defined to handle the link quality between nodes to evaluate routes. Availability of a good estimation of link longevity between neighbouring nodes could permit the selection of a more stable route, thus enabling a better implementation of quality of service (QoS).

2. Related Works

2.1 Ant Colony Based Routing Algorithms

Ant Colony Optimization (ACO) is a population-based meta- heuristic introduced by Marco Dorigo [4]. As the name suggests the technique was inspired by the behaviour of “real” ants [5]. Ant colonies are able to find the shortest path between their nest and a food source by depositing and reacting to the trail of pheromone to help guide future ants towards optimal paths to food. The basic principles driving this system can also be applied to many combinatorial optimization problems like routing in data networks [1], [6].

Gurpreet Singh et al [7] performed a survey on the application of various ACO algorithms to solve the routing problem in MANETs. The agents in ACO routing algorithms communicate indirectly through the stigmergy and provide positive feedback to a solution by laying pheromone on the links. Also have negative feedback through evaporation and aging mechanisms, which avoids stagnation. ACO algorithms allow the direct agent-to-agent communication which makes them more suitable for MANETs. In ABC algorithm the best path takes all call setup scheme, which means that if the best route is congested, no call can be placed until the ants can change the probability distribution. Antnet outperform a number of standard routing algorithms for constant bit rate traffic. The primary drawback of the AntNet algorithm is that it can involve long delays to propagating routing information, since routing tables are simply updated by backward ants. PERA is better in terms of less cost and also efficient in keeping up and researching new ways. ARA is similar to PERA but in ARA both forward and backward ants update pheromone value. Ant-AODV hybrid protocol is able to provide reduced end-to-end delay and high connectivity as compared to AODV. MAARA and ARAII outperform the AODV and DSR in terms of the packet delivery ratio and end to end delay. HOPNET is more scalable than AntHocNet because by nature, in starting AntHocNet is not hybrid at a moment. Substance, at start AntHocNet is a completely reactive protocol, and one time, the new route has been set up, it becomes a proactive protocol for all known routes and we know that proactive protocols are not beneficial for large nets or not scalable. However, HOPNET does not convert its state for inter-zone routing or for intra-zone routing. The routing overhead was high for small networks in PAR algorithm, but it is actually low for the large network scenario. This guarantees the scalability of the network without affecting the operation of the network.

2.2 Hardware-based LQEs

There are mainly three hardware-based LQEs: LQI, RSSI and SNR that can be directly read from the radio transceiver (e.g., the CC2420). The advantage of using these LQEs is that they do not require any additional calculation. In this paper, we are mainly concerned with RSSI and LQI.

RSSI can provide an accurate estimate of whether the quality of the link is very good or not (connected region). Srinivasan, et al. [8] proved the existence of an RSSI value (-87 dBm) above which the PRR is consistently high (99%), i.e., belong to the connected region. Below this threshold, a shift in the RSSI as small as 2 dBm can change a good link to a bad one and vice versa, which means that the link is in the transitional or disconnected region [9]. Also RSSI was shown very stable (standard deviation less than 1 dBm) over a short time span (2 s), thereby a single RSSI reading (over a packet reception) is sufficient to determine if the link is in the transitional region or not [9].

LQI can also determine whether the quality of the link is very good or not. Due to its high variance, it cannot be considered as a good indicator of intermediate link quality, unless it is averaged over a certain number of readings. Srinivasan et al. [9] argued that when the LQI is very high (near 110) the link is of perfect quality (near 100% of PRR). Further, in this situation LQI has low variance so that a single LQI reading would be sufficient to decide if the link is of perfect quality or not. For the intermediate quality links, where the variance of LQI becomes significant, a single LQI reading may not be sufficient for accurate link quality estimation. Srinivasan and Levis [10] showed that LQI should be averaged over a large packet window (about 40 up to 120 packets) to provide an accurate link quality estimation.

Bringing the above observations together, it might be logical to use a single RSSI or LQI reading to decide whether the link is of high quality or not. Such decision can be taken based on LQI and RSSI thresholds. Mainly, these thresholds depend on the environmental characteristics. For example, Lin et al. [11] found that RSSI threshold is around -90 dBm on a grass field, -91 dBm on a parking lot, and -89 dBm in a corridor. For RSSI and LQI values below, these thresholds, neither of these metrics can be used to distinguish links clearly. With the convenient averaging window, an average LQI allows a more accurate categorization of intermediate links [10].

Srinivasan and Levis [10], Tang et al. [12], and Polastre et al. [13] argued that average LQI shows stronger correlation with PRR, compared to average RSSI. Hence, LQI is a better indicator of PRR than RSSI. On the other hand, Srinivasan and Levis [10] and Tang et al. [12] claimed that RSSI has the advantage of being more stable than LQI (i.e., it shows lower variance), except for multi-path affected links.

2.3 Summary

In the literature a detailed analysis of the ACO algorithms and hardware-based LQEs have done. Energy efficient routing and increasing the lifetime are the significant issues in MANETs. Different techniques are available to optimize power consumption in MANETs and results showed that if we could combine these techniques we can save a lot of energy and improve network lifetime. In this paper, we propose a link quality based ACO routing algorithm which is aware of residual energy and link quality between the nodes and thereby results in energy efficient routing.

3. Proposed System

Here we propose RLBANT (RSSI/LQI based ant routing algorithm), a new ant colony optimization based routing algorithm which uses link quality between nodes to evaluate the route and thereby providing better quality of service. This algorithm also adjusts transmission power based on distance between nodes, which is calculated from the RSSI values. Link quality between nodes can be determined using RSSI and LQI values. Here we also consider that each node knows its energy level. A node with better battery life seems to be a good candidate for the packet routing to its neighbours. If a node with low power is selected as the next hop router, it may lead to packet losses as it might not have enough batteries to forward packets. We have made following observations about RSSI and LQI values.

1. A Weak signal in the presence of noise will give low RSSI and low LQI.
2. A weak signal in "total" absence of noise may give low RSSI and high LQI.
3. A strong signal without much noise may give high RSSI and high LQI.
4. A very strong signal in the presence of noise may give high RSSI and low LQI.
5. Strong noise may give high RSSI and low LQI.

So from the above observation, we can conclude that whenever noise is present in a signal we get a low LQI value and whenever the signal is weak we get a low RSSI value. So a link between two nodes is selected only based on LQI and RSSI thresholds. These thresholds depend on the environmental characteristics. Lin et al. [2006] found that

RSSI threshold is around -90 dBm on a grass field, -91 dBm on a parking lot, and -89 dBm in a corridor. LQI values range from 50 to 110. 50 correspond to the lowest quality frames detectable by the chip and 110 indicate a maximum quality frame. RLBANT is a reactive routing algorithm, thus routes are determined only when there is a need to send data packets from source node (S) to the destination node (D). Sending the data packets will start only after a route is established between S and D. Before that, only forward and backward ants are exchanged. The source node broadcasts route request (RREQ) to the nodes within its transmission range. On receiving RREQ each node compares the destination address with its address and if it matches it replies the source node that the respective node is the destination and the source node forwards data to it. Else the nodes replies via route reply (RREP). Route reply gives information such as LQI, RSSI and remaining energy level. Source node keeps the track of the RREP. In this algorithm, the routing table has an additional entry for neighbour node's residual energy. First distance of each node from the source node is calculated from the obtained RSSI values. The algorithm then searches for the node with maximum LQI value and the node with the highest residual energy from the routing table. If the node has high energy and maximum LQI, then that node will be taken as the next forward node. If the nodes are not satisfying any one of the requirements like high energy or high LQI, then the node with maximum energy and LQI value above the threshold will be considered as the next hop or the node with maximum LQI and with energy above the threshold will be considered as the next hop candidate. If none of these conditions are satisfied, the next optimum energy/LQI nodes are considered by searching the table again. The nodes having good energy, but a poor wireless link quality or the node having a good wireless link quality but low energy is eliminated from the forwarding list. If the node having less energy and high link quality is taken as the forwarding node, it will create a gap in the network and leads to network partitioning. Similarly, if the node having good energy, but bad link quality is considered as a forwarder, it will lead to packet loss. Hence, these nodes are not considered as forwarding nodes. Before routing data, transmission power is adjusted according to the distance (obtained from RSSI value). The Xbee transceiver used here has 5 different power modes. So appropriate power mode is set based on the distance calculated thereby reducing the transmission power.

4. System Architecture

The node consists of PIC 16F877A interfaced to a temperature sensor. Data is transmitted and received through Zigbee and the values are displayed on LCD screen. Typical architecture of the mote is shown in Figure 1.

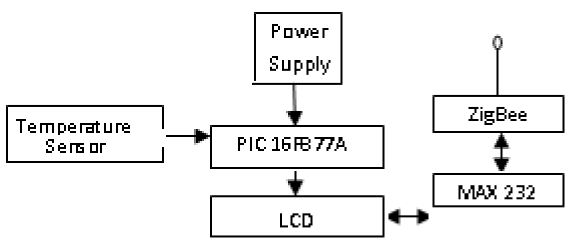

Figure 1: Architecture of node

4.1 Zigbee

Zigbee is a specification for a suite of high level communication protocols using low-power digital radios based on the IEEE 802.15.4-2003standard for WPANs (wireless personal area networks). ZigBee devices often transmit data over long distances by passing data through intermediate devices to reach more distant ones, creating a mesh network. The low cost allows the technology to be widely deployed in wireless control and monitoring applications, and the low power-usage allows longer life with smaller batteries, and the mesh networking provides the largest range and high reliability.

4.2 PIC 16F877A

Peripheral Interface Controller (PIC) is a family of microcontrollers from Microchip. PIC is the IC which was developed to control the peripheral devices, reducing the load from the main CPU. In the human being, the brain is the main CPU and the PIC is equivalent to the autonomic nervous system. PIC microcontrollers are RISC processors and use Harvard architecture. Some of the features of PIC 16F877A are;

1. Only 35 single-word instructions to learn
2. Operating speed: DC – 20 MHz clock input DC – 200 ns instruction cycle.
3. Flash Program Memory Up to 8K x 14 words, Up to 368 x 8 bytes of Data Memory (RAM), Up to 256 x 8 bytes of EEPROM Data Memory.
4. 10-bit, 8-channel Analog-to-Digital Converter (A/D).
5. Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address detection.

4.3 UART

UART consists of three main blocks;

1. CPU Interface (I/F) block
2. Serial transmit block and
3. Serial receive block.

The serial transmit block has two buffers (FIFO) into which data is written by the CPU I/F block. After the data is written into the buffers it is transmitted serially onto TXD. As long as the FIFO is not full the serial transmit block sets the signal TX_RDY high. The serial receive block has four buffers (FIFO). The block check for the parity and the validity of the data frame on the RXD input and then writes correct data into its buffers. It also sets the signal RX_RDY low if its FIFO is empty. The CPU I/F block is responsible for reading the status register, data register and writing data into interrupt enable register and data register. It also receives control signals from the CPU for performing certain tasks.

4.4 Temperature Sensor

The LM35 series are precision integrated-circuit temperature sensors. The output voltage of LM35 is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has a benefit over linear temperature sensors calibrated in ° Kelvin, as the user is not asked to deduct a large constant voltage from its production to get the convenient Centigrade scaling. LM35 does not require any external calibration or trimming to provide typical accuracies of ±¼°C at room temperature and ±¾° over a wide -55 to +150°C temperature range. Low cost is guaranteed by trimming and calibration at the wafer layer. The LM35's low output resistance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be utilized with single power supplies, or with plus and negative supplies. As it draws only 60μA from its supply, it delivers real small self-heating which is less than 0.1°C in still air. The LM35 is rated to operate over a -55° to+150°C temperature range.

5. Software Details

5.1 Embedded C

Embedded C is a set of language extensions for the C Programming language of the C Standards committee to address common problems that exist between C extensions for different embedded systems. Historically, embedded C programming needs nonstandard extensions to the C language in parliamentary procedure to support exotic features such as multiple distinct memory banks, fixed-point arithmetic, and basic I/O operations.

In 2008, the C Standards Committee expanded the C language to address these problems by providing a common standard for all implementations to adhere to. It admits a number of features not available in normal C, such as, named address spaces, fixed-point arithmetic, and basic I/O hardware addressing. Embedded C uses most of the sentence structure and semantics of standard C, e.g., main () function, variable definition, conditional statements (if, switch. case), data type declaration, loops (while, for), functions, arrays, structures and union, strings, bit operations, unions, macros etc.

5.2 MPLAB

MPLAB Integrated Development Environment (IDE) is a liberal, integrated toolset for the growth of embedded applications employing Microchip's PIC and dsPIC microcontrollers. MPLAB IDE runs like a 32-bit application on MS Windows, is easy to use and includes a horde of free software portions for quick application development and super-charged debugging. It also serves as a single, integrated graphical user interface for additional Microchip and third party software and hardware development tools. Moving between tools is a pushover, and upgrading from the free software simulator to hardware debug and programming tools is done in a flash because MPLAB IDE has the same user interface for all tools.

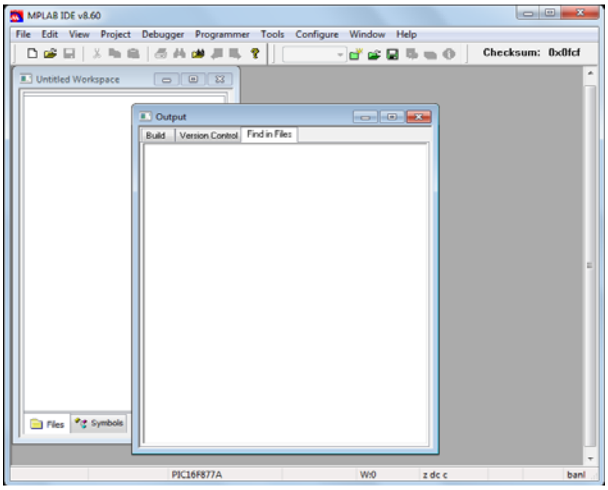

Figure 2: MPLAB user interface

5.3 X-CTU

X-CTU is the Zigbee configuration software. X-CTU is a Windows-based application provided by Digi. This program was intended to interact with the firmware files found on Digi's RF products and to provide a simple-to-use graphical user interface to them. X-CTU is designed to work with all Windows-based computers running Microsoft Windows 98 SE and above. The PC settings tab lets the user to select a COM port and configure the selected COM port settings when accessing the port. Some of these contexts include: Baud Rate: Both standard and non-standard Flow Control: Hardware, Software (Xon/Xoff), None Data bits: 4, 5, 6, 7, and 8 data bits, Parity: None, Odd, Even, Mark and Space Stop bit: 1, 1.5, and 2. To modify any of the above settings, choose the pull down menu on the left of the value and select the desired setting. To come in a non-standard baud rate, type the baud rate in the baud rate box to the left. The Test / Query button is applied to examine the selected COM port and PC settings. If the settings and COM port are accurate, you will get a response similar to the one pictured in Figure 6.4 below.

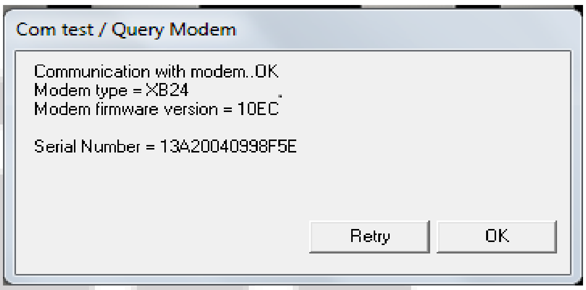

Figure 3: X-CTU connection response

6. Experimental Results

We have experimented RLBANT, using 5 nodes, which uses PIC 16F877A processor and XBee series 1 transceiver. Each mote is equipped with a temperature sensor LM 35.We evaluated the algorithm in indoor environments. With XBee radio chips, one can adjust the transmission power level in order to minimize energy consumption or increase the radio range. These chips have different transmission power levels of use, which consume different amounts of energy.

Figure 4: Hardware Test-bed

The schematic of the experiment is shown in Figure5. In this scenario, the source node A wishes to communicate with the destination node E. Nodes B, C and D are the other nodes present in the experiment. Node E is out of transmission range of node A. Hence, to communicate with node E, it should route its packets using either of the routes A-B-D-E or A-C-D-E. The proposed routing algorithm computes the cost of communicating with node E through the available routes and selects a path with adequate energy and better link quality. The optimal path selected is A-C-D-E. The minimum transmit power of 0.25mW, 0.4 mW, and 0.63 mW for link A-C, C-D, and D-E respectively. This test demonstrated faultless integration of the RLBANT routing algorithm with the hardware test-bed.

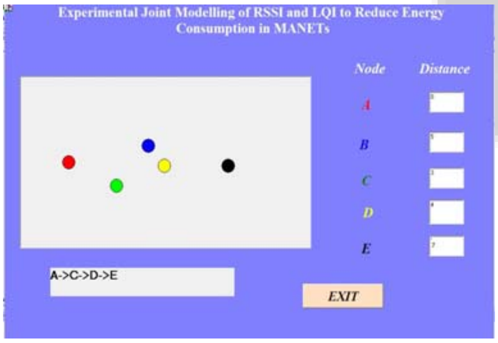

Figure 5: Optimal path chosen

Table 1: Adaptive Transmission Power Control

Distance (m)	*Tx Power (mW)*
1	0.1
3	0.25
5	0.40
7	0.63
9	1

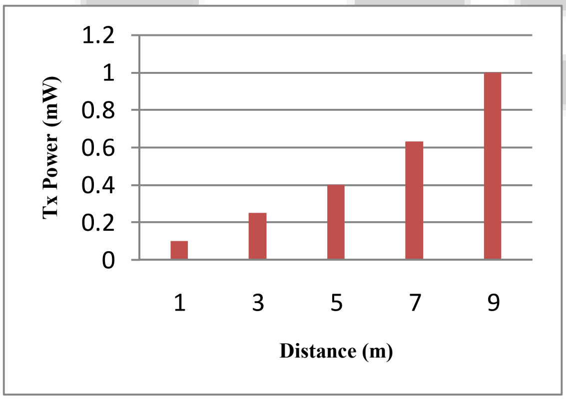

Figure 6: Tx Power vs. Distance

7. Conclusion

Energy efficient routing is an important issue in MANETs. To improve the lifetime of the network, the traffic load should be circulated among the forwarding nodes such a way that they could stay alive for a long time. In this paper, we proposed a link quality based ACO routing algorithm, which also takes into consideration the residual energy of nodes to evaluate the route. In this algorithm routes with adequate wireless link quality and more energy will be chosen for the forwarding operation without draining the nodes in the best possible path. The experimental results proved that the routing algorithm can reduce the energy consumption in indoor applications significantly.

8. Future Enhancement

In future this work will be extended to other swarm intelligence routing algorithms like Bee Colony algorithm and Ant Bee Colony Algorithms. Also the combination of hardware metrics with software metrics can improve the accuracy of the link quality estimation.

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