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Balancing the Energy Consumption in Practical Wireless Networks

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***Abstract*—Most mobile devices in wireless networks have limited energy storage capability. Similar limitations can apply to fixed devices found in sensor networks and in the longer haul relay stations in rural networks. Current research on battery technologies shows that only small improvements in the battery capacity are expected in the near future. Thus, in order to make the wireless networks (especially rapidly deployed networks) available commercially, we need to reduce the energy consumption in wireless devices. There are two main approaches to the problem. The first approach is to reduce the energy consumption of electronic circuits in wireless devices. The second approach is to design energy based routing techniques, including some modifications on medium access control (MAC) layer to reduce the energy consumption of wireless devices in networks. The second approach is focused in this paper.**

***Index Terms*— Ad-hoc network, Cordless phone network, Network routing, AODV and Energy consumption**

I. INTRODUCTION

The primary problem concerning energy in wireless network is that battery capacity is extremely limited. The focus of battery technology research has been to increase battery power capacity while restricting the weight of the battery. However, unlike other areas of computer technology such as micro-chip design, battery technology has experienced only modest energy density increase in the past 30 years. Therefore, reducing energy consumption in mobile devices of all forms including wireless terminals remain an important research area.

Mobile Ad hoc Networks (MANETs) and sensor networks have become popular in the last couple of years. Routing protocols have been proposed for MANETs and sensor networks. Surprisingly, only a few studies have been made on routing protocols that consider energy consumption. Energy consumption is a major issue when the number of connections between nodes on MANETs and sensor networks increases. Nodes on MANETs and sensor networks are often equipped with small energy sources. The developments of applications on MANETs and sensor networks need to address the energy consumption issues. [7]

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II. MAC LAYER AND ENERGY CONSUMPTION

The design and evaluation of energy-efficient routing protocols requires practical understanding of the energy consumption behavior of the network interface. In ad hoc networks and sensor networks, an interface can be in sleep, idle, transmitting or receiving states.

A common MAC layer for MANETs and sensor networks is the IEEE 802.11. The IEEE 802.11 protocol can operate in two modes: ad-hoc or infrastructure. In ad-hoc mode, mobile station (MS) can directly communicate with each other. There are two mechanisms by the medium access control (MAC) layer to access the medium, which are distributed coordination function (DCF) and point coordination function (PCF). The infrastructure mode uses PCF and the ad-hoc mode uses DCF. Medium access in both the DCF and PCF is based on a general MAC, which was approved by the working group in 1994. It is called DFWMAC and belongs to the class of carrier sense multiple access/collision avoidance (CSMNCA) protocols.

In the 802.11 MAC design, all stations are awake all the time to hear the actions of other stations to receive data and to avoid collision. As a result, the electronic circuits of these stations are active even when there is no data transmission and so energy consumption in ad hoc idle mode was very high. Details are given in [1].

Woesner *et al.* [6] at technical university Berlin, Germany summarized modifications in 802.11 for power saving (PS) using timing synchronization. In these techniques, the general idea is for all nodes in PS mode to switch off the radio part for some period. These nodes need to be synchronized to wake up at the same time when a window opens in which the sender announces buffered frames for the receiver. A station that receives such an announcement frame stays awake until the frame is delivered. This is easy to do in the PCF, where there is a central access point (AP) which is able to store the packets for stations in sleep mode and to synchronize all mobile stations. It is much more difficult for the DCF, where packet store and forward procedure as well as timing synchronization have to be done in a distributed manner.

In PCF, the access point (AP) is responsible for generating beacons which contain a valid timestamp. Stations within the base station adjust their local timers to that timestamp. If the channel is in use after the beacon interval, the *AP* has to defer its beacon transmission until the channel is free again.

In DCF, the timer of stations needs to adjust in a distributed way. Each station has a timing synchronization function (TSF) timer that is a modulus 2^64 counting increments of microseconds. At the beginning of the synchronization, every station is responsible for generating a beacon. The sending station sets the beacon timestamp of its TSF timer at the time the beacon is transmitted. Upon reception of a beacon, the receiving station looks at the timestamp. If the beacon timestamp is later than the station's TSF timer, the TSF timer is set to the value of the received time stamp. In other words, all stations synchronize their TSF timer to the quickest TSF timer. The node that wins the competition will initiate an independent basic service set (IBSS) and establishes a synchronized beacon interval. At the beginning of each beacon interval, a common fixed length, ad hoc traffic indication message (ATIM) window is defined. All nodes in the IBSS wake up from the beginning of the beacon interval to the end of the ATIM window. Each node transmits an ATIM to every other node which has pending unicast traffic. Each node, that receives an ATIM, responds with an ATIM acknowledgement. At the end of the ATIM window, nodes that have not sent or received ATIM announcements go back to sleep. All other nodes remain awake until the end of the beacon interval to send and receive traffic. [4]

III. IDLE ENERGY CONSUMPTION OF WIRELESS DEVICES

In order to make wireless network devices viable commercially, we need to reduce the idle energy consumption in wireless network interfaces (NI) because the idle energy consumption has been a main portion of the total amount of energy of wireless devices. For example, the Proxim RangeLAN2 2.4 GHz 1.6 Mbps PCMCIA card requires 1.5 W in transmit, 0.75 W in receive, and 0.01 W in standby mode. Also, power consumption for Lucent's 15 dBm 2.4 GHz 2 Mbps Wavelan PCMCIA card is 1.82 W in transmit mode, 1.80 W in receive mode, and 0.18W in standby mode. Similar figures are 3.0W, 1.48W, and 0.18 W, respectively, for a 24.5 dBm 915 MHz 2 Mbps PCMCIA card. [11]

The energy consumption of typical UHF transceivers are 4W in transmit mode, 0.2 W in receive and stand-by modes. [9]

A normal mobile phone uses the battery of DC 3.6V Li-ion 500mAh which has idle time of 150-200 hours, and charging time of 2.5 hours.[12]

IV. BATTERY MANAGEMENT

All mobiles include measure and display residual power. These circuits are part of the battery management. There are improvements in the resolution of analog to digital converters which improve the measurement of these circuits.

V. AODV PROTOCOL

AODV protocol is already implemented in many laptops using Linux Red Hat 9.0 and Fedora Core 2 as well as PDAs Hewlett Packard iPAQ 5550 series (using Linux familiar v0.7.2 with Opie 1.2. [8]

AODV is a reactive protocol. In reactive protocols, a route is created at the request of a source node when the node needs a route to a particular destination. In the AODV protocol, a source initiates a route discovery by flooding a Route Request (RREQ) packet when it needs to transmit data to a destination. Every node receiving the RREQ stores the route to the Originator of the RREQ before it forwards the RREQ to other nodes. The destination node or an intermediate node with recent information about the path replies by unicasting a Route Reply (RREP) along the reverse path to the Originator. As the RREP travels back to the Originator, any node receiving the RREP will add or update its route to the destination generating the RREP.

As there are many possible paths from an Originator to a Destination, AODV maintains the most up to date information in the routing table of nodes. Every node on the network has its own sequence number. When a node sends a RREQ, it increases its sequence number by one and includes that number in the RREQ. Before the destination issues a RREP, it updates its sequence number to the maximum of its current sequence number and the one indicated in the RREQ. Each routing element in the routing table also has a field called route lifetime. If there are many paths to the same destination, the node will keep the one with the longest lifetime. Also after the expiry of the lifetime of a route, this route will be removed from the routing table. All nodes on the network exchange 'Hello' messages frequently to check connectivity with their immediate neighbors [5].

In our paper, we will use the operations described above as a routing protocol to maintain network connectivity. However, on top of the routing protocol, we will modify and add energy information to control packets. This modification will change the routing paths on the network. The purpose is to reduce the total energy consumption of the network, balance the energy consumption across nodes and to maximize the network life time. Details are given in the section proposed protocols.

VI. MATHEMATICAL MODEL

A general wireless network can be modeled as a directed graph $G(N, A)$. N is the set of all nodes and A is the set of all directed links $i, j \in N$. S_i is the set of all nodes that can be directly reached by node *i* in its transmit range. There are two common problems in energy consumption considerations: maximizing network life time and minimizing total energy consumption.

Both problems can be formulated as linear programming (LP) problems [3]. These LP problems can be solved by any LP software package. These packages normally implement the simplex method but some newer methods are also available.

However, a simpler heuristic solution is preferred since the computation to reduce the energy consumption must itself be energy efficient.

VII. PROPOSED PROTOCOLS

In this section, we describe our proposed routing protocol that is balanced energy consumption (BEC). RREQ, RREP and HELLO messages are described in Section AODV protocol. Let RERR be the error message that tells the nodes on a network about link broken events. In the original AODV, duplicate RREQs are discarded by intermediate nodes or destinations. RREQs are duplicated if they are created by the same originator and they have the same RREQ identifier. In our proposals, we allow the destination nodes or the intermediate nodes that have a path to a destination to process duplicated RREQs. This ensures that the source nodes learn many possible paths. These sources choose the most energy efficient path.

BEC Operation

BEC operation has two phases: handling control packets and updating routes in a routing table. It considers two parameters of a routing path: the minimum residual energy of all nodes of the path (E), the number of hop counts of the path (H). The number of hop counts is a common field in routing protocols. Remaining battery charge is readily available from the battery management electronics. The RREQ and RREP formats need to be modified so that a suitably discretised version of residual energy can be inserted into the reserved field of these formats which are described in RFC 3561 [5].

The operation of BEC is described by the flowcharts below: [7]

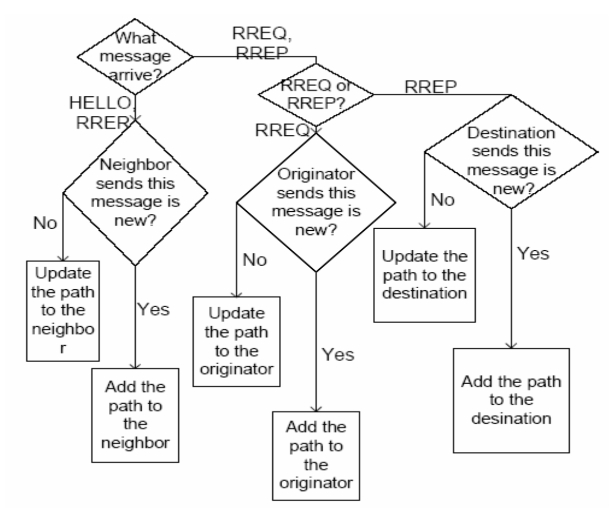

Fig. 1: Handle control messages in BEC

The BEC routing formula can be written as:

```
void updateRoutetablecost (route, residual_energy, hop_count, expiration_time)
{
        if (residual_energy_of_new_route> residual_energy_of_old_route) ||( residual_energy_of_new_route== residual_energy_of_old_route) &&hop_count<new_hop_count) )
{
        update_new_route();
}
```

The minimum hop count routing formula can be written as:

```
void updateRoutetablecost (route , hop_count)
{
        if (hop_count<new_hop_count) )
{
        update_new_route();
}
```

VIII. ASSUMPTIONS FOR WIRELESS DEVICES IN THE NETWORK SIMULATION

Typical UHF transceivers of coreless phones are used in many commercial applications and emergency services applications. Each phone can talk directly to another coreless phone in the transmission range from 1km to 5 km. In our simulation, the transmission range for each transceiver is set to 1500m. Each transceiver transmits at 4W at the current drain of 1.7A. The current drain in stand-by and receive mode is 85mA which is one of twenty of the power in the transmission mode. The battery used is BP-230 which has 25200 J. The normal operation time is Tx: Rx: standby = 5:5:90.

Let us assume the energy consumption for wireless devices. In each transceiver, we assume that the physical data rate is 2 Mbps. The packet rate from the application layer is 10 packets per second. The packet size is 1500 bytes. The burst length is 600 packets. Therefore, the throughput is approximate 120Kbps. The burst length interval follows a negative exponential distribution with an average of 5 minutes. Packets from routing layer and upper layers are queued in a M/M/1 queue in MAC layer before they are sent by the physical layer. The route lifetime in routing tables for AODV is set to 3 seconds to ensure the most up-to-date route is updated.

Let us calculate approximately the energy consumption inside a transceiver. The transmission power is 4W at the throughput of 120Kbps. As the result, the energy consumption for sending data per bit is 3.34×10^{-5} J. The idle energy is one of twenty of the energy in sending mode which is 0.2 J. The ADC used for battery management inside a transceiver is 12 bit which is 4096 bits. As a result, the residual energy of a device varies from 1 to 4096 in the increment of one. [10, 9]

IX. SIMULATION RESULTS

We use OMNeT++ to develop our simulation because it is a popular tool. Many simulation models have been developed in OMNet++ and tested by many users. The AODV model used has been published on the OMNeT++ community website and has been verified by many users [2]. We model the network interface (NI) layer as frequency division multiplexing access (FDMA) in which different nodes use different frequency slots to send packets. As the results, there is no collision in packet transmissions in networks. In GSM, a fix channel set of frequencies is assigned to a cell site on along term basis. During a call, a particular channel is assigned to a mobile on a short term basis. Most mobile GSM systems are still operating on 666 channels. Two frequencies in channel 1 are 825.03 MHz (mobile transmit) and 870.03 MHz (cell-site transmit). The two frequencies in channel 666 are 844.98MHz (mobile transmit) and 889.98 MHz (cell-site transmit) [13].

The current requirement for a normal relay coil is 38mA. With 1A current inside an adhoc or coreless phone device, we can source at least 30 relay switchings. As a result, the device can switch to at least 30 FDMA frequencies. [14]

An OMNeT ++ model consists of hierarchically nested modules. The depth of module nesting is not limited, which allows a user to reflect the logical structure of the actual system in the model structure. Modules communicate through message passing. Messages can contain arbitrarily complex data structures. It is very easy to model networking layers and messages passing between them. In our simulation, the energy level of each node is calculated from the physical layer and is passed to the routing layer to be processed. Fig. 3 shows the model of layers of a mobile node.

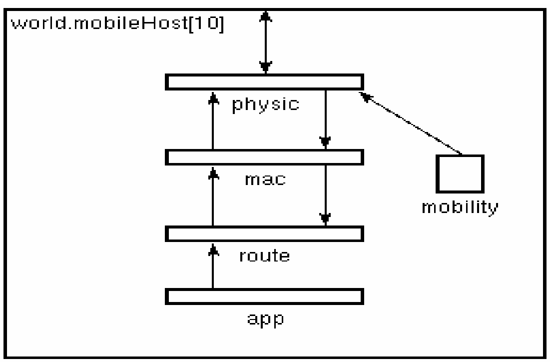

Fig. 2: Model layers of a mobile node

In the simulation, there are 30 nodes uniformly and randomly distributed on a 5500×5500m rectangular area.

All nodes are assumed to move using random walk mobility model. The node velocity is uniformly distributed between 2 m/s and 5 m/s. The distance for each move is 1000m. The pause time is 0.5 hour.

The simulation consisted of 15 runs which have different initial topologies. The average of the results of the runs was taken. The simulation time of each run is the time until any node runs out of battery. The 95% confidence interval is also calculated. The data collection guarantees consistent and confident results. For the purpose of readability, the 95% confidence interval is not included in the diagram.

Let us define the normalized variance as the standard deviation of the energy consumption of all nodes in a network divided by the average energy of these nodes, and the normalized peak energy as the peak energy consumption of all nodes divided by the average energy of these nodes.

We ran simulations on 15 different topologies with the pause time of each node is fixed at 30 minutes. Trials indicated that BE consumes only around 12% that of energy consumption of minimum hop count routing protocol for data communication. The result is shown in Fig. 3.

It is also of interest to calculate the normalized peak energy. The normalized peak energy is approximately equal for both routing protocols. The results are shown in Fig. 4.

It is also important to verify the performance of the BE algorithm in terms of the packet delay and packet delivery ratio. The packet delay is the average time that a packet arrives to a destination. The packet delivery ratio is the average probability that a packet reaches the intended destination.

The packet delay of BEC is 35 ms on average for 15 runs, whereas this is 60 ms for the minimum hop count. The results are shown in Fig. 6. The packet delivery ratio of BEC is 76 % on average for 15 runs, whereas this is 60 % for the minimum hop count. The results are shown in Fig. 5.

The network lifetime is the time until any node in the network runs out of energy. The simulation results show that in the 15 different initial topologies, the network lifetime of BEC is about 24 hours whereas this is shorter than 3 hours for the minimum hop count protocol. The results are shown in Fig. 7.

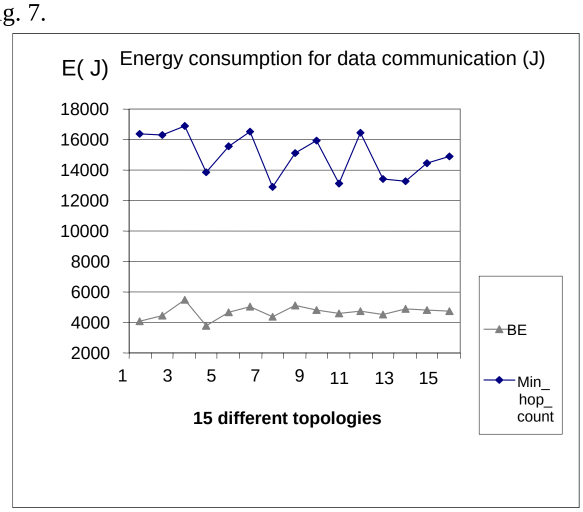

Fig. 3 Energy consumption for data communication(J)

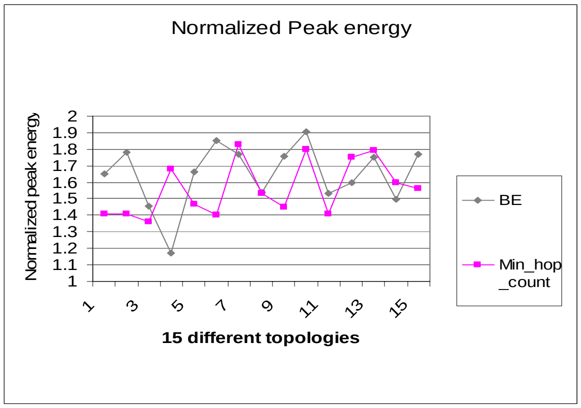

Fig.4 Normalized peak energy over 15 topologies

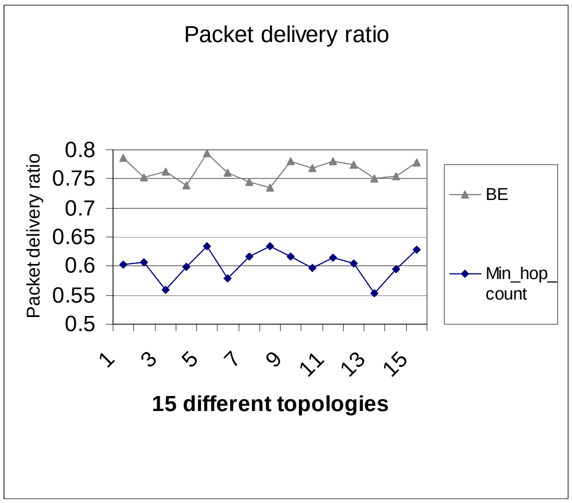

Fig. 5 Packet delivery ratio over 15 topologies

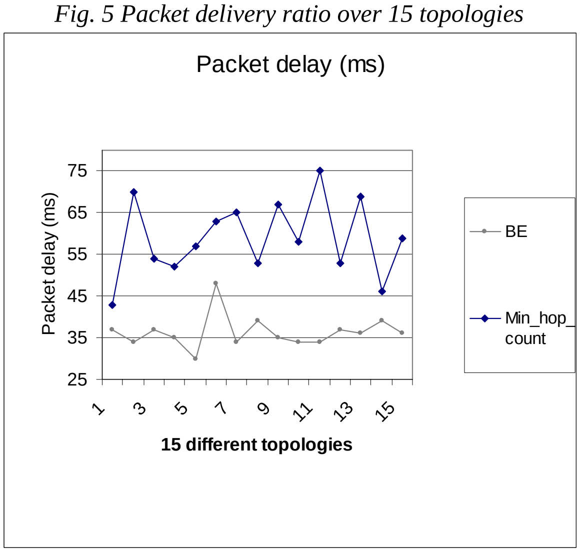

Fig. 6 Packet delay over 15 topologies

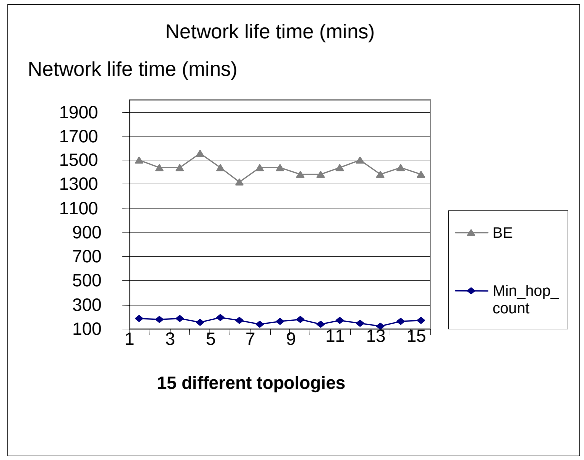

Fig.7: Network lifetime over 15 topologies

X. CONCLUSIONS

The AODV routing protocol is designed for mobile ad hoc networks with populations of tens to thousands of mobile nodes. AODV can handle low, moderate, and relatively high mobility rates, as well as a variety of data traffic levels.

Also, if the transmission range is longer and the transmission power dominates the total energy consumption, then the modified protocol can save energy significantly. In the future work, we will consider how to incorporate the proposed protocol into commercial products.

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