ENERGY-CONSERVING ON-DEMAND ROUTING FOR MULTI-RATE MULTI-HOP NETWORKS

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Keywords: Energy efficiency, ad-hoc routing, energy-conserving, multi-rate.

Abstract: We present a novel scheme for conserving energy in multi-rate multi-hop wireless networks such as 802.11. In our approach, energy conservation is achieved by controlling the rebroadcast times of Route Request (RREQ) packets during path discovery in on-demand wireless routing protocols. The scheme is cross-layer in nature. At the network layer, the RREQ rebroadcast delay is controlled by the energy consumption information, and at the Physical layer, an energy consumption model is used to select both the rate and transmission range. The paper describes the energy-conserving algorithm at the network layer (ECAN), along with simulation results that compare the energy consumption of Ad-hoc On-Demand Distance Vector routing (AODV) with and without ECAN.

1 INTRODUCTION

Many Mobile terminals such as PDAs, smart mobile phones and laptops are usually powered by batteries, which necessarily provide limited amounts of energy. Therefore, techniques to reduce energy consumption in wireless ad-hoc networks are attracting a lot of attention. The most well known technique to conserve energy is to employ power saving mechanisms which allow a mobile node to go to sleep mode whenever the wireless network interface is idle (J. Gomez et al., 2001). However such mechanisms may not be always a good idea, as they can partition the wireless network. A node must turn its radio on not only to receive packets, but also to participate in transmitting any higher-level routing and control protocols. An alternative approach is to reduce the route control and signalling load by using the network layer information related to the routing protocol to extend route lifetimes (Bosheng Zhou et al., 2004).

Due to the physical properties of communication channels, there is a direct relationship between the rate of communication and the energy consumption of mobile devices. Since distance is one of the factors that determines wireless channel quality (e.g. BER and SNR), long-range communication should occur at low rates, and high-rate communication should take place over short range. These multi-rate and multi-range capacities provide a number of different trade-off points (Gavin Holland et al., 2001). For example, with a high communication rate and short communication range, there is a trade-off between the number of relay nodes in routing path and the energy consumption of entire wireless network. In this work, we focus on how to balance these objectives. We propose a framework for conserving energy in multi-rate multi-hop wireless networks (IEEE 802.11 Work Group, 1999). The framework is cross-layer in nature and operates in the Physical and Network layers. Dynamic adjustment of transmission rate can produce efficient data communication for multi-hop wireless networks in the Physical layer, while a cross-layer routing algorithm in Network layer is used to provide a balance between the minimum transmission energy consumed and a fair distribution of energy consumed across the nodes involved in a route. This goal is achieved by controlling the rebroadcast delay of Route Request (RREQ) packets. Within the framework, we have designed a mechanism to estimate the end-to-end energy consumption in the routes through a multi-rate multi-hop network. This is used to adaptively control the RREQ rebroadcast delay in the wireless routing protocol.

The rest of the paper is organized as follows. Section 2, we present our proposed energy-conserving algorithm in detail. Section 3 describes

Lee T., Marshall A. and Zhou B. (2005).
ENERGY-CONSERVING ON-DEMAND ROUTING FOR MULTI-RATE MULTI-HOP NETWORKS.
In *Proceedings of the Second International Conference on e-Business and Telecommunication Networks*, pages 158-161
DOI: 10.5220/0001414501580161

the simulation results and performance comparison. Finally, we conclude the paper in Section 4.

2 SYSTEM MODEL OF NETWORK LAYER

The routing protocol for multi-hop and ad-hoc wireless networks proposed in this paper is called ECAN (Adaptive Energy-Conserving routing Algorithm in Network layer). ECAN attempts to reduce routing control overhead and processing requirement so as to minimize power utilization.

2.1 Energy-Conserving Algorithm in 802.11 Network-layer (ECAN)

Generally in on-demand routing protocols (C. E. Perkins and E.M. Royer, 1999)(S. Ni et al., 1999), a source floods a RREQ packet to search for a path from source to destination. The destination node receives the RREQ packet and unicasts RREP (Route-reply) packets back to the source to set up the path. ECAN uses a “rebroadcast time” control mechanism, coupled with information on the battery levels of nodes, to select desirable routes and reduce the routing overhead. ECAN does not implement any supplementary control packets to obtain energy information for power aware routing. The RREQ rebroadcast time is defined using the total energy cost of a path. The rebroadcast control mechanism is then executed to determine whether or not to rebroadcast the RREQ.

E_{ECAN} is the combined multi-hop energy consumption by nodes on the path and K_{cout} is the hop count number that the RREQ packet has registered. When an intermediate node has determined the rebroadcast delay of a RREQ, it then enters a competing procedure to rebroadcast the RREQ. The main parameters of our energy model are:

- P_{TX} [mJ/sec]: the power required to transmit data.
- P_{RX} [mJ/sec]: the power required to receive data.
- P_{RS} [mJ/sec]: the power required to sense radio.
- P_{R0} [mJ/sec]: the power required in idle mode.

There are three energy dissipation scenarios that can be considered, as shown in figure 1: (i) Direct Transmission Model (Single-hop). (ii) Direct transmission (Single-hop) with a neighbour node Model. (iii) Multi-hop Simple Relay Model (k-hop).

We denote the complete multi-hop energy consumed by nodes on the path, E_{ECAN}, as

$$\mathrm{E}_{\mathrm{ECAN}}^{\mathrm{k}} = \sum\nolimits_{0}^{\mathrm{k}} \left(\mathrm{P}_{\mathrm{TXcirc}} + \mathrm{P}_{\mathrm{TX}} + \mathrm{P}_{\mathrm{RXcirc}}\right) \times t$$
(1)

Where t is the total transmitting time. P_{TXcirc} is the energy expended by the circuitry in transmit mode and P_{RXcirc} is the energy expended in receive mode. $\mathrm{E}_{\mathrm{ECAN}}^{\mathrm{k}}$ is the total energy consumption at k-hop scenario.

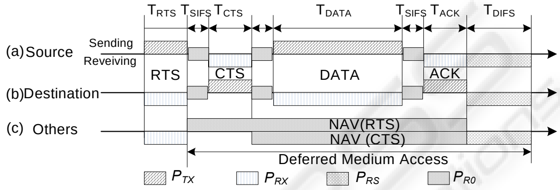

Figure 1: an illustration of RTS/CTS of Energy Consumption in DCF

i) In the direct transmission model (Fig.1a).

Figure 1 provides a model for P_{TX} and P_{RX} for IEEE 802.11 RTS/CTS/DATA/ACK handshake.

$$E_{ECAN}^{1AB}(\gamma) = (P_{TX}^{AB} + 2P_{RX} + \Delta P)\times$$
$$(T_{RTS} + T_{CTS} + \frac{H_{PHY}}{basic\_rate} + \frac{H_{MAC}}{\gamma} + T_{DATA} + T_{ACK})$$
$$+ 6P_{R0} \times T_{SIFS} + 2P_{RS} \times T_{DIFS}$$
(2)

The H_{PHY} and H_{MAC} are the frame headers of the PHY and MAC layers respectively. The basic_rate is the basic data transmission rate, which is defined in the 802.11 standard. γ is the current data transmission rate. ΔP is the energy different between the P_{TXcirc} and the P_{RXcirc}. Thus,

$$P_{TXcirc}^{A} = P_{TXcirc}^{B} = P_{RX} + \Delta P$$

ii) Direct transmission (Single-hop) with a neighbour node Model.

In this scenario (Figure. 1b), A transmits data to B and C as a neighbour node in RTS/CTS cover range of node A.

$$P_{ECAN}^{1ABC} = 3P_{RX} + P_{TX}^{AB} + \Delta P$$
$$E_{ECAN}^{1C} = P_{RX} \times T_{RTS} + P_{R0} \times T_{NAV} + P_{RS} \times T_{DIFS}$$
$$T_{NAV} = T_{CTS} + T_{DATA} + T_{ACK} + 3T_{SIFS}$$
(3)

iii) Multi-hop Simple Relay k-hop Model

E_{ECAN}^{k} is the multi-hop simple relay *k-hop* model (Figure 1c). We assume that a node i has n neighbour nodes within transmission range, we obtain the weighting factor of the multi-hop energy consumption $E_{ECAN}^{k}(\gamma)$ in node *i*.

$$
\begin{aligned}
&E_{ECAN}^{k}(\gamma)\\
&= k\times(2P_{RX}+\Delta P)\\
&\times(T_{RTS}+T_{CTS}+\frac{H_{PHY}}{basic\_rate}+\frac{H_{MAC}}{\gamma}+T_{DATA}+T_{ACK}) \qquad (4)\\
&+k\times P_{TX}(1)\times(T_{RTS}+T_{CTS})\\
&+k\times P_{TX}(\gamma)\times(T_{DATA}+T_{ACK})\\
&+2kP_{RS}\times T_{DIFS}+6kP_{R0}\times T_{SIFS}\\
&+n\times(P_{RX}\cdot T_{RTS}+P_{RS}\cdot T_{DIFS}+P_{R0}\cdot T_{NAV})\\
&T_{DATA}={}^{L}\!/_{\gamma}\ and\\
&T_{NAV}=T_{CTS}+T_{DATA}+\frac{H_{PHY}}{basic\_rate}+\frac{H_{MAC}}{\gamma}+T_{ACK}+3T_{SIFS}
\end{aligned}
$$

Where *L* is the data frame size and *γ* is the data transmission rate.

2.2 Rebroadcast time control mechanism

The goal of ECAN is to control the rebroadcast time and to reduce routing overhead whenever a node is low on battery power. This strategy will prolong the wireless network lifetime. R_{xRREQ} is the signal strength of RREQ packet.

A node determines its rebroadcast time T_{RREQ} as follows.

```
Output:
RREQ packet $Mi(E_{ECAN}(\gamma), K_{cout})$.
Begin
    Receive a RREQ packet
    if the RREQ packet come from  a new neighbour node than
        $n = n + 1$, n is the number of neighbour.
    if ($R_{xRREQ}$ > ReceiveSensitivity (11Mbps)) than
        $\gamma$ = 11Mbps
    else if (ReceiveSensitivity (5.5Mbps) < $R_{xRREQ}$ < ReceiveSensitivity (11Mbps)) than
        $\gamma$ = 5.5Mbps
    else if (ReceiveSensitivity (2Mbps) < $R_{xRREQ}$ < ReceiveSensitivity (5.5Mbps)) than
        $\gamma$ = 2Mbps
    else
        $\gamma$ = 1Mbps
        $T_{RREQ} = T_{\max}\times\sigma$
        $\sigma = \tanh(\beta)$
        $\beta = \frac{M_i(E_{ECAN}(\gamma), K_{cout})}{E_{ECAN}(11Mbps)\times(K_{cout}+1)}$
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T_{max} is the maximum delay of RREQ packet. E_{ECAN}(11Mbps) is the energy consumption at 11Mbps data rate, α is a constant variable for RREQ delay. *Tanh(β)* is a hyperbolic tangent function. *σ* □ [0,0.99] when *β* □ [0,4]. T_{RREQ} increases rapidly when *β* approaches 4 so as to differentiate rebroadcast delay between high priority nodes. In this paper, we set these parameters as T_{max} = 20 ms, T_w = 5 ms.

3 SIMULATION RESULTS

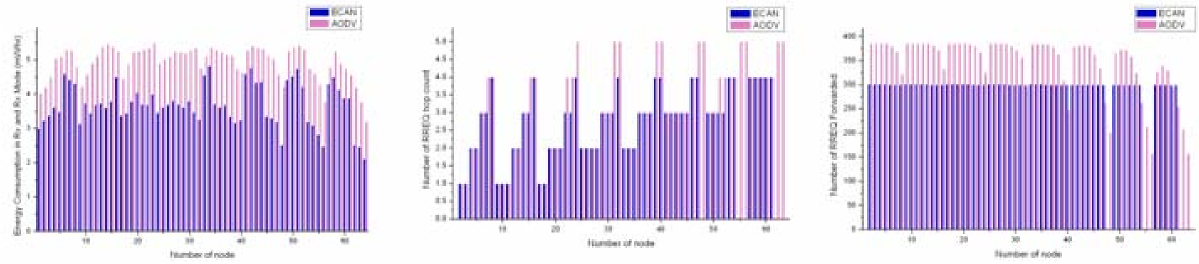
To evaluate its performance, we have implemented ECAN based on the well-known AODV wireless routing protocol. A simulation environment was developed using the Qualnet developing library (Qualnet simulator). Using this, the performance of AODV was compared with and without ECAN. The bandwidth of the wireless channel varied from 1Mbps to 11Mbps, which is chosen by SINR (Signal to Interference and Noise Ratio). The data packet size is 1024 bytes. The traffic pattern is constant bit rate, with a 10s inter-packet arrival time. The simulation scenario consisted of 64 nodes that are grid distributed and 200m apart. Table 1 gives the simulation parameters.

Table 1: Simulation parameters

Transmit mode (P_{TX})	1400 mW
Receive mode (P_{RX})	900 mW
Idle mode (P_{R0})	600 mW
Sense mode (P_{RS})	600 mW
Transmit power level	15 dBm
Initial energy of nodes	4000 mAh / 10V
Receive sensitivity	1 Mbps = -93 dBm
	2 Mbps = -89 dBm
	5.5 Mbps = -87 dBm
	11 Mbps = -83 dBm

Figure 2(a) illustrates the energy consumption of each scheme. It shows that AODV with ECAN using a higher transmission rate will decrease the duration of transmission, and effectively reduce to 75% energy consumed of native AODV in receive and transmit mode. In ECAN, the link with higher transmission rate and lower energy consumption has the higher priority to be selected. This simulation result demonstrates that AODV with ECAN mechanism will conserve more energy than AODV.

The performance of ECAN against route length is shown in Figure 2(b). The results show that the average route length of ECAN scheme is around 20% less than native AODV. This is because the ECAN scheme aims at finding the route that has lower energy consumption and higher performance route rather than the native AODV.



(a) Total energy consumption in receive and transmit mode (mJ/hr)

(b) Route length

(c) Number of RREQs forwarded

Figure 2: Simulation results in the 64 nodes wireless multi-hop networks

Figures 2(c) shows result conserving the RREQ routing overhead. It may be seen that the routing overhead of native AODV increases much more rapidly than AODV with ECAN. The routing overhead of RREQs forwarded is only 80% of that of native AODV. The reason for the lower routing overhead is that a large amount of rebroadcasts are avoided in the route discovery procedure.

Analysis of the overall network performance shows that the average End-to-End delay is only 29% that of native AODV. This is because ECAN aims to find the more stable and higher transmission rate routes by using the received SINR.

From the above results, we can conclude that AODV with ECAN performs more efficiently than native AODV in terms of higher throughput, lower End-to-End delay, and reduced routing overhead. Furthermore, the results show that it saves much more network bandwidth and energy.

4 CONCLUSIONS

We have designed a cross-layer approach to energy conservation for multi-rate multi-hop routing. The ECAN uses two algorithms and is applied in the Physical and Network layers. First, algorithm achieves energy conservation by uses the highest data transmission rate. The second algorithm adapts RREQ rebroadcast times based on the total energy consumption cost of a path. In our system model, ECAN only requires the current transmission SINR from Physical layer, which can be obtained with the use of only RREQ packets. When RREQ packets are broadcast, the rebroadcast time is determined by a rebroadcast control mechanism.

Simulation results show that ECAN achieves energy saving without causing throughput degradation. This improvement is due to the fact that ECAN makes a compromise between the multi-rate transmission and fair energy consumption. This paper describes research that is applied in the Physical and Network layers. An interesting area of future research will be to extend the approach for MAC layer specific information such as TPC (Transmission Power Control) to further optimize energy consumption.

ACKNOWLEDGMENT

This work is supported by the UK funding body EPSRC, under the project GR/S02105/01 “Programmable Routing Strategies for Multi-Hop Wireless Networks”.

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