Generic Energy-efficient Geographic Routing for Ad-Hoc Wireless Networks

Chao-Lieh Chen[1], Jeng-Wei Lee[2], Cheng-Zh Lin[3], Yi-Tsung Chen[2], Jar-Shone Ker[3] and Yau-Hwang Kuo[2]

[1] Department of Electronic Engineering
Kun-Shan University, Yung-Kang, Tainan County, TAIWAN
frederic@ieee.org
[2] Department of Computer Science and Information Engineering
National Cheng Kung University, Tainan City, TAIWAN
{lijw, nose, kuoyh}@cad.csie.ncku.edu.tw
[3] Advance Multimedia Internet Technology (AMIT) Corp.
Tainan County, TAIWAN
{tomm, james}@amit.com.tw

Abstract. The proposed energy-efficient geographical routing (EGR) mechanism is generally applicable to reduce energy consumption in wireless communication networks. No matter for table-driven or on-demand ad-hoc routing algorithms, EGR enhances them by constructing an initial routing path considering location information. Then, to further improve energy utilization it selects relay nodes of links on the initial path. The EGR finds an optimum relay node in a relay region between any two traffic nodes to conserve energy and balance traffic load. The relay region is derived from the radio propagation model constraining energy-saving when relaying transmissions between two nodes. Any node within this region is a relaying candidate to decrease total traffic energy consumption and to balance traffic load. According to the Energy-Proportional Principle (EPP), we also propose an energy-saving criterion. To balance traffic load, the EGR follows the EPP and in the relay region selects the relay node with the highest score corresponding to the criterion. Compared to the traditional routing methods, EGR effectively utilizes energy and prolongs network lifetime.

Keywords: Geographic Routing, Ad-hoc Wireless Networks, Energy Proportional Principle, Load Balance

1 Introduction

The classification of ad-hoc routing algorithms includes on-demand and table-lookup driven classes. The most representative routing protocols of these two classes are the Ad hoc On-demand Distance Vector (AODV) routing [5] and Destination-Sequenced Distance Vector (DSDV) routing [11] respectively. In AODV, nodes use the maximum transmission range to communicate with each other, but nodes can adaptively adjust their power level for conserving transmitting energy by the Transmit

Power Control (TPC) [1]. Lower power level means reduced interference problems and increased energy utilization. Namely, an energy-efficient routing protocol should be able to control transmission power dynamically. For load sharing and energy-saving, two communication nodes should dynamically tune down transmitting power when there are suitable relay nodes for the communication. The same situation happens in table-lookup driven routing algorithms such as DSDV. The routing table construction should consider the load sharing and energy saving especially when the location information is available.

In this paper we propose the Energy-efficient Geographical Routing (EGR) algorithm which is generally applicable to reduce energy consumption in wireless communication networks. The proposed EGR improves energy efficiency and load balance for both classes of ad-hoc routing algorithms. While a traditional routing protocol finds the routes in the path, EGR uses location information for initial path construction and then finds more route nodes in the initial routing path to minimize the total energy consumption. Since many later algorithms are developed from the two classes of ad-hoc routing, the EGR is a generic energy-efficient mechanism that is applicable to wireless networks.

We illustrate the geographical routing as examples. To extend the lifetime of the ad-hoc wireless networks, many articles proposed geographic routing as LAR [6] and GEAR [8] use location information to find a better routing path for saving transmission energy. Further, using energy-aware routing protocols like GAF [4] and SPAN [7] can save more energy consumption. The main idea is that they choose a node in a region as a coordinator to forward data, and other nodes go to sleep. Among them, Geographical Adaptive Fidelity (GAF) is one of the most representative routing algorithms that effectively use geographic information for coordinator selections and sleep-time scheduling for energy conservation. GAF divides the communication area into geographic grids. Though the grids ensure that all the nodes in a grid square are able to connect other nodes in any adjacent grid square, energy constraint in radio propagation is not considered. Therefore, any communication between two grids could violate the constraint and degrade performance in energy conservation. As an application, the proposed EGR improves energy conservation in wireless ad-hoc networks by constraining relay nodes selection while at the same time balances traffic load by applying the energy-proportional principle (EPP) in the relaying. The EPP originates from the energy-proportional routing [2][3], which effectively balance intra- and inter-cluster energy utilization and thus extend lifetime of clustered sensor networks. The EPP considers the total energy-proportional balance among nodes, rather than either merely simple balance of energy consumption or communication distance. In this way, the EGR effectively utilizes energy, balances the load, and thus prolongs network lifetime.

The paper is organized as follows. In Section 2, we reduce the relay inequality to a circular relay region and analyze the optimum number of the relay node. Section 3 depicts the construction process of EGR algorithm. Section 4 shows the experimental results of energy utilization. Finally, we give conclusions in section 5.

2 Energy of Radio Model and Relay Constraint

2.1 Energy Consumption and Propagation Model

In this paper, we apply the first order radio model commonly used in low-energy radios. When two nodes are d meters apart and sender transmits k bits data to receiver, the energy consumption can be calculated as follows [10] :

$$\begin{aligned} E_{Tx}(k,d) &= E_{Tx,elec} \times k + E_{Tx,amp} \times k \\ E_{Rx}(k) &= E_{Rx,elec} \times k \end{aligned} \tag{1}$$

The radio dissipates $E_{Tx,elec}$ or $E_{Rx,elec}$ in transmitting or receiving one bit data. $E_{Tx,amp}$ is depleted in amplifier for transmitting data, and determined by crossover distance (d_0). At the crossover distance, the power for receiving predicted by the two-ray ground (TR) reflection model equals to that predicted by the free-space (FS) propagation model. If the transmitter is within the crossover range, using the FS model is appropriate. Otherwise, use the TR model. That is,

$$E_{Tx,amp}(d) = \begin{cases} \varepsilon_{FS} \times d^2, & when \quad d \le d_0 \\ \varepsilon_{TR} \times d^4, & when \quad d > d_0 \end{cases} \tag{2}$$

where ε_{FS} and ε_{TR} are the respective amplifier parameters in FS and TR models. In our simulation, we set the communication energy parameters as: $E_{Tx,elec}$ = $E_{Rx,elec}$ = 50 nJ/bit, ε_{FS} =100 pJ/bit/m^2, ε_{TR} = 0.013 pJ/bit/m^4 and d_0= $\sqrt{\varepsilon_{FS} / \varepsilon_{TR}}$. Moreover, we let $\alpha_t = E_{Tx,elec} = E_{Rx,elec}$ and $\alpha_{amp} = \varepsilon_{FS}$.

2.2 Relay Region

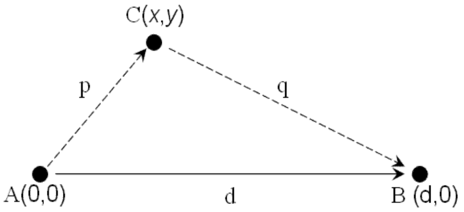


Fig. 1. Traffic from A to B.

Considering a simple illustration shown in Fig. 1, suppose that there are three nodes A, B and C. Assume all nodes use the same circuitry for transmission and receiving. The source node A sends data to the destination node B. For simplification, node A is located at the origin and B with coordinate (d, 0) is d meters apart from node A. The coordinate of relay node C is set to (x, y). Assume C is p meters apart from A and *q* meters apart from B. For power saving, node C must be in a region to satisfy the following inequality (we call the region *relay region*):

$$\left(\alpha_t + \alpha_{amp} d^2\right) + \alpha_t > \left(\alpha_t + \alpha_{amp} p^2\right) + \left(\alpha_t + \alpha_t + \alpha_{amp} q^2\right) + \alpha_t$$

where the right hand side is the energy dissipation spent by the three nodes when using C for relay and the left hand side is the energy dissipation spent by the node A and node B when A send data directly to B. Substituting the coordinates into distances *d*, *p*, and *q*, we have

$$p^2 + q^2 < d^2 - \frac{2\alpha_t}{\alpha_{amp}}$$

$$\Rightarrow \left(x^2 + y^2\right) + \left[\left(d - x\right)^2 + y^2\right] < d^2 - \frac{2\alpha_t}{\alpha_{amp}}$$

Thus, we have the relay inequality (3) be reduced to a circular relay region.

$$x^2 - d \times x + y^2 + \frac{\alpha_t}{\alpha_{amp}} < 0 \tag{3}$$

Since the inequality is based on the FS model, the derived region is smaller than that derived from the TR model. Therefore, a relay node satisfies the inequality must also satisfy the one derived from the TR model. We focus on the smaller relay region through out this paper. Further, we study the relay region properties. The relay node in different location could result in different amount of *total saved energy* (E_S) which is defined as the energy saved by relaying and is obtained by subtracting the energy using relay from the energy consumption of direct transmission without relay. Therefore, we have

$$\begin{aligned} E_S = k \times \Big\{ & \left[\left(\alpha_t + \alpha_{amp} d^2\right) + \alpha_t\right] - \\ & \left[\left(\alpha_t + \alpha_{amp} p^2\right) + \left(\alpha_t + \alpha_t + \alpha_{amp} q^2\right) + \alpha_t\right] \Big\} \end{aligned}$$

In a general case, let A = (x_1, y_1), B = (x_3, y_3) and C = (x_2, y_2). We have

$$\begin{aligned} E_S &= k\left[\alpha_{amp}(d^2 - p^2 - q^2) - 2\alpha_t\right] \\ &= 2k\left[\alpha_{amp}\left((x_3 - x_2)(x_2 - x_1) + (y_3 - y_2)(y_2 - y_1)\right) - \alpha_t\right] \end{aligned} \tag{4}$$

Fig. 2 shows the one-bit E_S of relaying when *d* is 250 meters and the relay node in the center of the source and the destination saves maximum E_S.

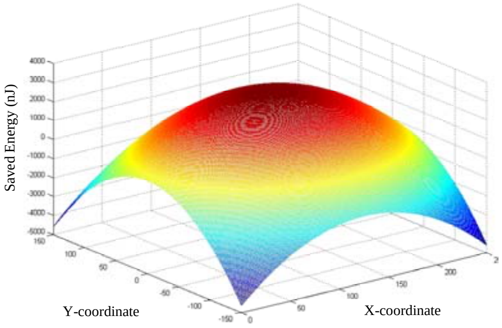


Fig. 2**.** Saved energy E_S on the geographical plane.

2.3 Optimal number of Relay Nodes

Though the more relay nodes satisfying the inequality the more power is saved, the more relay nodes in the traffic means the more delay time. So we need to find out the optimal number of relay node in trade-off between the two variables -- *total consumed energy* (E) and *delay time* (D). Let the optimal number of relay node is denoted as N_{opt}. Because E and D use different measurement units, we normalize two variables in advance and minimize the following weighted performance index to evaluate N_{opt}.

$$\beta E_{normalize} + (1-\beta) D_{normalize} \tag{5}$$

In (5), β is the weight representing importance of *total consumed energy* and $E_{normalize}$ and $D_{normalize}$ are defined as following equations:

$$E_{normalize} = \frac{E\big|_{N=N_{opt}}}{E_{direct}} = \frac{\left(2N_{opt}+1\right)\alpha_t + \left(d_{max}{}^2 \big/ \left(N_{opt}+1\right)\right)\alpha_{amp}}{\alpha_t + \alpha_{amp} d_{max}{}^2} \tag{6}$$

$$D_{normalize} = \frac{N_{opt}+1}{N_{MIN(E)}+1} \tag{7}$$

We use an example to explain (6) and (7). Suppose that a node's maximum communication range is d_{max}. For finding the upper bound of N_{opt}, the source is d_{max} meters apart from destination. There are N relay nodes in the routing path and the distance of every one-hop link is the same as $d_{max}/(N+1)$. E of N follows (1) and estimates total energy consumption. Moreover, since adding relay nodes reduces energy consumption E, the maximum value of E is E_{direct} when the source directly sends data to the destination. The delay D is proportional to the number of the hops. Because it's impossible to add infinite relay nodes in the routing path, we calculate E of N as shown in Fig. 3 to find $N_{MIN(E)}$. When the number of relaying hops N is large than $N_{MIN(E)}$, both E and D increase. In this case $N_{MIN(E)}$ is 7 with $d_{max} = 250$.

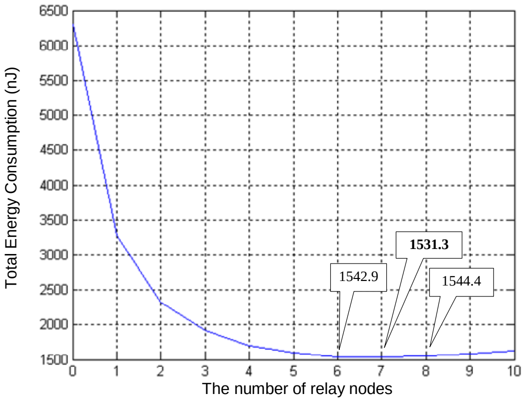


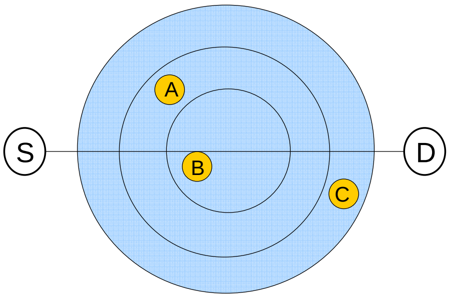
Fig. 3**.** When d_{max} is 250 metes, the number of relay nodes causes different total energy consumption.

Therefore, we find N_{opt} = 1.65 when we minimizes (5) subject to β = 0.5 and the above conditions. Consequently, we pick only one relay node in the relay region.

3 Construction of EGR

3.1 Selection of Relay Nodes

In Section 2, we know there is one relay node at most in a relay region. EGR picks the most proper node to relay data. The location of nodes affects the probability of being chosen by EGR. We substitute the location coordinates of nodes to (4) and choose the relay node having maximum E_S. However, a node having high E_S is expected to be chosen for relay and thus it will die quickly. In this case, the energy utilization is unbalanced. So, we apply the energy-proportional principle [2][3] and consider the relay node's *remaining energy* (E_R). Actually, in the relay region we consider the respective proportions of each node's E_S and E_R in the total E_S and total E_R. The proportions are called node's *SE-Ratio* and *RE-Ratio* respectively. Finally, we get *Relay_Score* as the product of *SE-Ratio* and *RE-Ratio*, and pick the node has the maximum *Relay_Score* to join the routing path and to relay data in the traffic. Fig. 4 illustrates that EGR determines node B as the relay node in the traffic.



	E_S (nJ)	*SE-Ratio*	E_R (J)	*RE-Ratio*	*Relay-Score*
A	1500	0.33	50	0.2	0.066
B	2300	0.51	100	0.4	0.164
C	700	0.28	100	0.4	0.112

Fig. 4. Selecting relay node according to its relay score.

3.2 Ad-hoc routing with location information

The proposed EGR can be easily combined with any geographic routing algorithm. We illustrate AODV [5] and DSDV [11] as examples adopting EGR because AODV and DSDV are the most commonly used routing protocol in mobile ad-hoc wireless networks.

AODV [5] finds a multi-hop routing path between a pair of source and destination, and EGR works for each one-hop link over the routing path. Because AODV is not a geographical routing algorithm, we modify route request (RREQ) to satisfy EGR constraint (3). The modified AODV flow chart is illustrated in Fig. 5 (a). When source wants to find destination in the network, it broadcasts RREQ to search. Because EGR needs neighbors' location information to calculate each E_S, we attach sender's location information to RREQ packet and every node certainly caches its one-hop neighbors' location information. EGR gets neighbors' remaining energy in the same way and this leads to few control overheads. When destination receives the first RREQ packet, AODV back traverse the routing table and sends route reply (RREP) to route node until source receives RRPL. The proposed EGR is used in each one-hop communication and chooses an optimum relay node according to relay node's E_s and E_R.

DSDV [11] is based on table-driven routing algorithm. Each node maintains a routing table for recording the shortest paths to others nodes within the network. DSDV regards the numbers of hop as the distance and uses Bellman Ford Algorithm to find every routing path. When any routing table is changed or the set update time is up, the network will run DSDV again and all routing tables will be updated. To sum up, EGR can improve most ad-hoc routing algorithms no matter table-lookup driven or not.

We show how table-driven and on-demand ad-hoc algorithms are improved. For DSDV, the embedding of EGR into DSDV flowchart is as shown as Fig5 (b). Each of the traditional DSDV nodes has a routing table. Regarding itself as source and all the others as destinations, a node in DSDV records and updates the shortest distances (in number of hops) to all the destinations using the Bellman-Ford algorithm. The application of EGR is after Bellman-Ford algorithm execution to check each one-hop link whether or not requires relay node. If the relay node exists, update the routing table and broadcast the update information to make other nodes also update. If network topology does not change frequently, such manner can effectively improve the energy utilization.

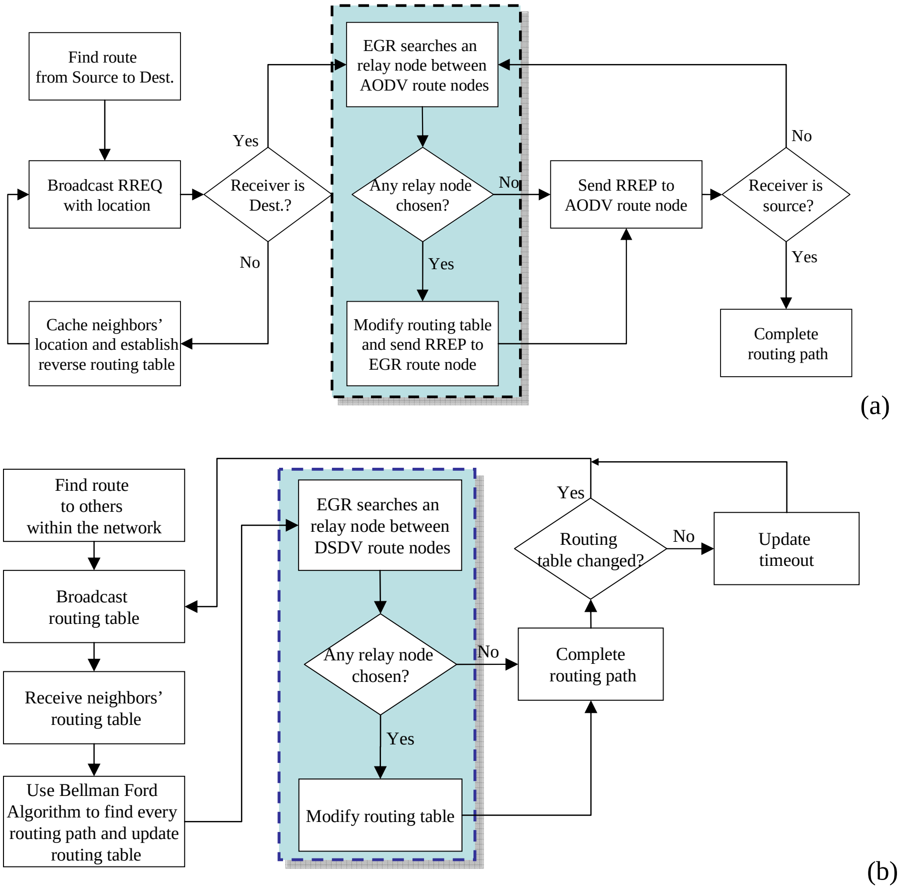


Fig. 5**.** Flow charts of (a) modified AODV (b) modified DSDV adopting EGR

3.3 Generic sleeping scheduler

In addition to path construction, the EGR uses a generic sleeping scheduler in geographical routing. Being applicable to generic scenario, EGR does not separate nodes into two classes such as those in GAF [4]. GAF uses 50 transit nodes (nodes running ad-hoc routing) and 10 traffic nodes acting as sources and sinks. The proposed EGR uses the state diagram shown in Fig. 6 for generic ad-hoc routing. When node is a source or a destination, it enters the traffic state and acts the coordinator in the grid. For transmitting the traffic, the nodes stay in the traffic state until the traffic ends. When traffic is off, all nodes follow the same GAF sleeping scheduling.

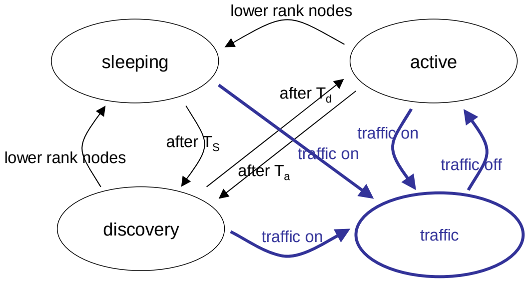


Fig. 6. Sleeping scheduler state diagram of EGR.

4 Simulation and Comparisons

EGR highlights the decreasing of energy consumption by adding appropriate relay nodes in original routing path. We perform experiments to show the performance enhancement adopting EGR. The results of numerical analysis show performance comparison with AODV and we use network simulator NS2 [9] for simulations in comparing with GAF. In NS2, d_{max} is 250m as default. The energy consumption of transmit is 1.6W, receiving is 1.2W and idle is 1W.

4.1 EGR energy saving

We discuss the comparison in a one-hop link. Considering energy consumption per bit transmission, we perform the experiment showing how a wireless link conserves energy when using EGR. Traditional ad-hoc routing algorithms, such as AODV [5] and DSDV [11], transmit data in the link according to the maximum communication range of the sending node. Assume that the max communication range of each node is d_{max} meters and the source is d_{max} meters apart from the destination. Rather than always using transmission power for sending 1-bit across d_{max} distance, EGR adds a relay node for each one-hop link in the routing path and uses lower transmission power to decreases total energy consumption. In the relay region, different relay node causes different energy consumption. To illustrate the power saving ability of EGR, for each link with different d_{max}, we construct an EGR relay region and calculate the average energy consumption. The energy consumption ratio of using EGR over not using EGR (abbreviated as non-EGR) is shown in Fig. 7. The al Using the amplifier parameter values in Section II, we find that energy consumption EGR is the same as non-EGR within 45m and the relay region exists beyond 45m. EGR is slightly superior to non-EGR when d_{max} is between 45m and 87.7m if using FS model. EGR achieves maximum performance over non-EGR when d_{max} is about 230m and it promotes about 60% energy utilization. Note that the experiment is applied to when a relay region has a relay node. When there is no suitable relay node in the relay region, the energy consumption for the link is the same as that in non-EGR.

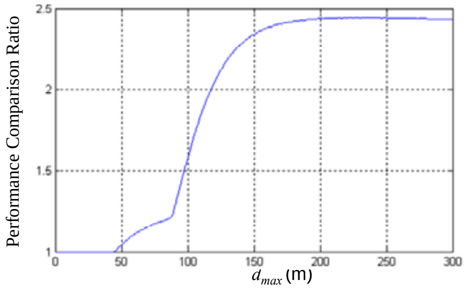


Fig. 7. The energy consumption ratio of non-EGR to EGR with various d_{max}

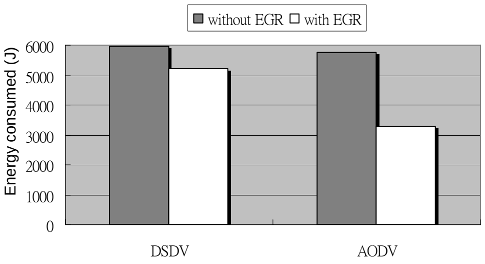


Fig. 8. Comparsion of the energy consumption between DSDV, AODV and EGR.

In other way, we use NS2 to simulate EGR energy saving. Considering the energy consumption for transmission, we assume 50 motionless nodes with infinite energy forming a small-scale network in a 1500x300 m^2 area and random traffic lasts whole simulation time (900 seconds). The traffic generation randomly chooses two nodes as source and destination with 0.1s packet interval. The traffic generation appears every 100s until end of simulation. We compare EGR to both AODV and DSDV with average energy consumption of ten times of simulations**.** Fig. 8 shows EGR can promote about 43% energy efficient over AODV and about 12% over DSDV. Because in DSDV, frequent broadcasting of update information is required, energy saving becomes smaller.

4.2 Enhancing Energy Utilization and Lifetime in GAF

Routing with traditional AODV, traffic in GAF could not satisfy the relay inequality (3). We measure network lifetime by the fraction of all nodes with nonzero energy as a function of time [4]. In the simulation, three mobility situations – pause-times 30s, 300s and 900s are assumed and all nodes have the same movement speed (20m/s). Nodes pause and then move to randomly chosen locations at 20m/s speed. The total simulation time is 900s and we regard the case of pause-time 900s as that all nodes don't move while we regard the 30s-pause-time case as in high mobility. The same in GAF [4], we also use constant bit rate (CBR) traffic with packet length 512-bytes and packet rate 10 pkts/s. Using more generic ad-hoc wireless network scenario that all nodes evenly possess the same initial energy of 450 joules. Fig. 9 shows the results of the simulation. EGR sends more packets than GAF due to the nodes in GAF waste more energy in transmitting data if equation (3) is not met. GAF source nodes die more quickly and eventually fewer packets are sent. Furthermore, in the whole 900s simulation the average energy consumption of EGR is lower than of GAF. Therefore, EGR has higher energy utilization and shown in Fig. 10 it extends the network lifetime no matter what the pause-time is.

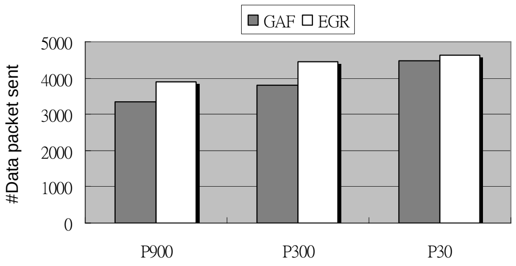


Fig. 9. Data delivery comparisons to GAF in cases of different pause times.

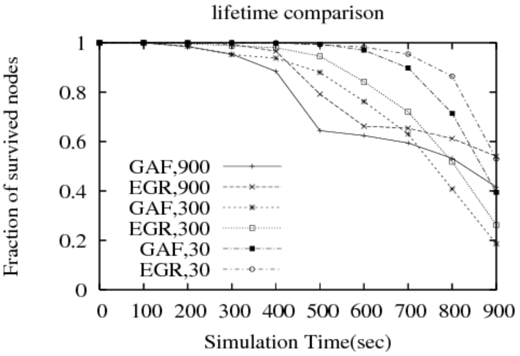


Fig. 10. Simulation results of GAF and EGR for network lifetime with different pause times at high node speed (20m/s).

4 Conclusion

We have found a new relay mechanism and developed a routing protocol called EGR to improve energy utilization in wireless communication networks. Derived from the relay inequality, we get the relay region to ensure each one-hop link is energy-efficient in a routing path. No matter on-demand protocols such as AODV or table-lookup driven protocols such as DSDV are enhanced by EGR with better energy efficiency and load balance. Furthermore, EGR can be applied to any geographical routing protocol by improving energy consumption of each one-hop link. We compare the performance of two GAF versions of using and not using EGR. The one using EGR consumes lower energy per data unit. With energy efficiency and load balance, EGR prolongs networks lifetime. Future works include the adaptive relay region in the different environments considering more complicated and correlated radio models such as shadowing and fading.

Acknowledgement

The authors would like to thank the National Science Council in Taiwan R.O.C for supporting this research, which is part of the three projects numbered NSC 95-2221-E-168-029, NSC 95-2221-E-006-289-MY2 and NSC 95-2221-E-006-371.

References

1. European Radiocommunications Office. ERC/DEC(99)23 Available at http://www.ero.dk/doc98/Official/Pdf/DEC9923E.PDF.
2. Chao-Lieh Chen, Kuan-Rong Lee. “An Energy-proportional Routing Algorithm for Lifetime Extension of Clustering-based Wireless Sensor Networks”, Journal of pervasive computing, No. 2, 2006.
3. Chao-Lieh Chen, Kuan-Rong Lee. “An Energy-proportional Routing Algorithm for Lifetime Extension of Clustering-based Wireless Sensor Networks” In Proc. The 2nd Workshop on Wireless, Ad Hoc, and Sensor Networks, Taiwan, http://acnlab.csie.ncu.edu.tw/wasn06/, August 2006.
4. Ya Xu, John Heidemann, and Deborah Estrin. “Geography-informed energy conservation for ad hoc routing.” in Proceedings of 7th Annual International Conference Mobile Computing and Networking, pp. 70-84, July 2001.
5. Charles Perkins and E. M. Royer. “Ad hoc on demand distance vector(AODV) routing.” In Proc. 2nd IEEE Workshop on Mobile Computing Systems and Applications, pp. 90-100, 1999.
6. Y.-B Ko and N. Vaidya. “Location-aided routing (LAR).in mobile ad hoc networks.” In proceddings of the ACM/IEEE International Conference on Mobile Computing and Networking, pp. 66-75, 1998.
7. Benjie Chen, Kyle Jamieson, Hari Balakrishnan, and Robert Morris. “Span: An energy-efficient coordination algorithm for topology maintenance in ad hoc wireless networks,” ACM Wireless Networks Journal, 8(5):481.494, September 2002.
8. Y. Yu, R. Govindan, and D. Estrin, “Geographical and Energy Aware Routing: A Recursive Data Dissemination Protocol for Wireless Sensor Networks,” UCLA Computer Science Dept., Technical Report UCLA/CSD-TR-01-0023, available at http://cens.cs.ucla.edu/Estrin, May 2001.
9. The VINT Project. The ns manual. http://www.isi.edu/nsnam/ns/.
10. W. Heinzelman, A. Chandrakasan, and H. Balakrishnan, “Energy-efficient routing protocols for wireless microsensor networks,” in Proc. 33rd Hawaii Int. Conf. System Sciences (HICSS), Jan. 2000.
11. Perkins, Charles E. and Bhagwat, Pravin, "Highly Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) for Mobile Computers," in Proceedings of 1994 ACM SIGCOMM’94, pp. 234-244, Aug., 1994.