Energy-Efficient Geographic Routing in Ad-hoc Wireless Networks

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Abstract

Geographic routing algorithms in ad-hoc wireless networks have recently gained increased interest, and energy saving is of particular interest. The Most Forward within Radius (MFR) [1] algorithm is popularly applied to minimize the number of hops however the energy consumption is not considered. In this paper, we derive the optimal node transmission range, and then we propose the Optimal Range Forward (ORF) algorithm based on the optimal transmission range, which minimizes the total energy consumption of the transmission (summation of energy consumption of all hops). Furthermore, based on ORF, we propose the Optimal Forward with Energy Balance (OFEB) algorithm, in which the next-hop node is selected according to the remaining energy of each neighbour node and the distance between each neighbour node and the best neighbour location, the latter is determined by the optimal transmission range. In the OFEB algorithm, the total energy consumption of the transmission and the residual energy of each node are both considered to prolong the network lifetime.

I. Introduction

The lifetime of ad-hoc networks has real impact on the quality of communication, service discovery, quality of provisioned services (QoS) and network reliability. The network lifetime is defined as the time duration before 1) the first node dies [2], 2) the fraction of active nodes whose power drops below a threshold [3] or 3) the time until the aggregate delivery rate drops below a threshold [4]. These definitions relate to different application scenarios. In this paper, we choose the second definition, a fraction of nodes dies, as this represents a major event more important than a single node failure (definition 1) or a drop in data rate (definition 3).

Geographic routing (location/position-based routing) for communication in ad-hoc wireless networks has recently received increased attention, especially in the energy saving area [5][6]. In geographic routing, each node has knowledge of its own geographic information either via Global Positioning System (GPS) or network localization algorithms, and broadcasts its location information to other nodes periodically. The next relay node is selected only based on the location of the source node, its neighbours and its ultimate destination (contained in the data packet). Therefore, geographic routing is generally considered to be scalable and applicable to large networks. Furthermore, the energy consumption of each hop can be reduced if the next relay node is properly selected.

In ad-hoc wireless networks, the energy is mostlyconsumed for transmission and reception, the former is a nonlinear function of transmission range. Transmission range adjustment as an energy saving approach has been the focus of numerous studies. Therefore, in this paper, we derive the optimal transmission range which relates to the optimal energy consumption, and an energy efficient Geographic Routing algorithm (ORF) is proposed based on the optimal transmission range to find the optimal next hop node and then to reduce the energy consumption of the network.

The balance of energy consumption (traffic load balance) is another parameter that can be used to prolong the network lifetime. The energy-proportional principle (EPP) is one of the algorithms than can achieve a balance in traffic load. It originates from the energy-proportional routing principle [7][8]. In this paper, the energy balance is jointly utilised with optimal transmission range in another Geographic Routing algorithm (OFEB) to find the optimal next relay node and then to prolong the network lifetime. Furthermore, both ORF and OFEB algorithms are compared to a traditional Geographic Routing algorithm, MFR, which selects as the next hop node the node nearest to the maximum range allowed in the system.

The remainder of this paper is organised as follows. In section II, the energy consumption model is introduced. In section III, we derive the optimal transmission range. In section IV, we introduce and analyse our energy-efficient geographic routing algorithms, ORF and OFEB. The simulation results compare the network lifetime of MFR, ORF and OFEB. In section V, we draw a conclusion to this paper.

II. Energy consumption model

Considering a transmission from a transmitter to a receiver, where the distance between them is d, the received signal power can be expected as [9]:

$$p_r(d) = \frac{p_t G_t G_r \lambda^2}{(4\pi)^2 d^\beta Loss}, \tag{1}$$

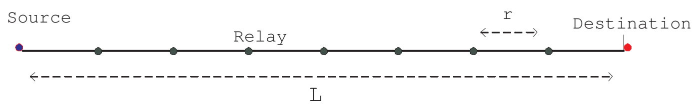

Fig. 1. End-to-end multihop transmission

where G_t and G_r are respectively the gains of the transmitter and receiver. The carrier wavelength is λ and $Loss$ represents any additional losses in the transmission. β is the propagation loss factor, which is typically between 2 and 4. Thus, with $G_t = G_r = 1$, and $Loss = 1$, the received signal power is

$$p_r(d) = \frac{p_t \lambda^2}{(4\pi)^2 d^\beta}. \tag{2}$$

To be successfully received by the receiver, the received signal power must above a certain threshold power (p_{thr}). Therefore, the signal power at the transmitter must above $\frac{p_{thr}(4\pi)^2 d^\beta}{\lambda^2}$. Assuming one signal represents one bit data information, the energy consumed at the transmitter is

$$E_t = (e_e + \frac{p_{thr}(4\pi)^2 d^\beta}{\lambda^2}) \times Packet = (e_e + e_a d^\beta) \times Packet, \tag{3}$$

where $e_a = \frac{p_{thr}(4\pi)^2}{\lambda^2}$ and e_e is the energy consumed in the transmitter electronics. Also, the energy consumed for reception at the receiver is

$$E_r = e_e \times Packet. \tag{4}$$

Based on [10] and [11], the typical value of e_e is: $e_e = 3.32 \times 10^{-7}\ J/bit$. Given $p_{thr} = 8 * 10^{-15}\ w$ and with carrier frequency $f = 2.4 * 10^9\ Hz$ (which is an unlicensed frequency band and one of the most popular in radio based networking), e_a is computed as: $e_a \approx 8 \times 10^{-11}\ J/bit/m^2$.

III. Optimal transmission range

For an end-to-end multihop transmission, the most efficient transmission route is the direct line between the source and destination nodes, where the intermediate nodes are ideally deployed (the nodes exist wherever needed). As shown in Fig. 1, the data packet is forwarded from the source node to the destination node, where the distance separating them is L. Assume that the range of each hop is r, the number of hops is derived as

$$m = \frac{L}{r}. \tag{5}$$

Based on the energy consumption model mentioned before, the energy consumption of the end-to-end transmission is:

$$E_t = m \times \{[(e_e + e_a r^\beta)Packet] + (e_e Packet)\} = \frac{L}{r} \times \{(2e_e + e_a r^\beta)Packet\}. \tag{6}$$

To compute the minimum energy consumption, we take the first derivative of E_t with respect to the grid-length, r, and let $\partial E_t / \partial r = 0$:

$$E_t' = LPacket[(\beta - 1)e_a r^{\beta-2} - 2e_e r^{-2}] = 0. \tag{7}$$

Solving equation 7 for r gives the optimal transmission range as:

$$r^\beta = \frac{2e_e}{(\beta-1)e_a},\ r^* = \sqrt[\beta]{\frac{2e_e}{(\beta-1)e_a}}. \tag{8}$$

With specific transceiver parameters, equation 8 shows that the optimal transmission radio range, r^*, relates only to the propagation loss factor (n), and the relationship is shown in Fig. 2. In Fig. 2, the optimal transmission range decreases when the propagation loss factor (β) increases. As we mentioned before, there is a trade off between the energy consumed in each hop and the number of hops. Based on equation 6, when the number of hops (m) is large, the transmission range of each hop (r) becomes small, and then the fixed energy consumption for each hop (energy consumed for transceiver electronics) dominates the energy consumption. When the number of hops is small, the transmission range of each hop becomes large, and the energy consumed in the transmitter amplifier of each hop increases rapidly and dominates the energy consumption. When β is large, the energy consumed in the transmitter amplifier becomes relatively more important than the fixed energy consumption, and vice versa. Specifically, the optimal transmission range is $90.1\ m$ when $\beta = 2$, with the transmitter and receiver parameters assumed.

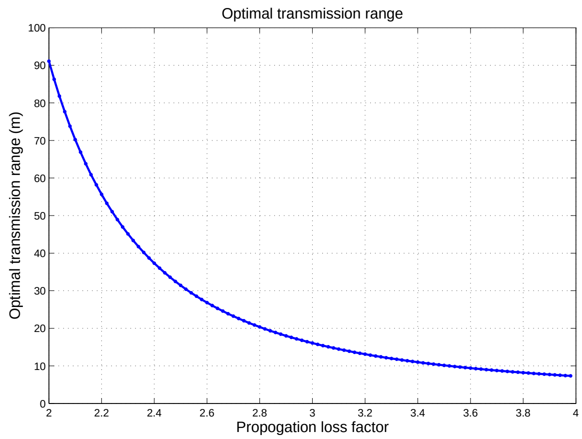

Fig. 2. Optimal transmission range

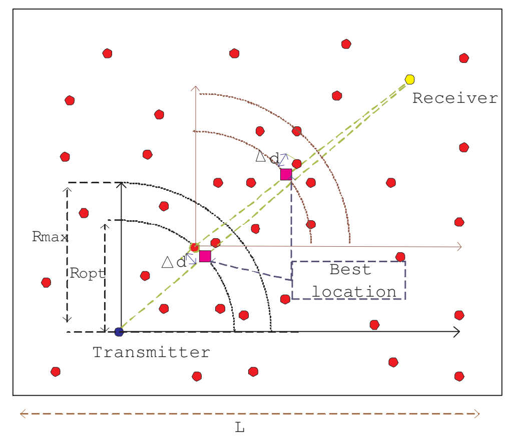

Fig. 3. Forwarding scheme (next hop node selecting)

Propagation factor (n)	2	Network length	2000 m	Number of nodes (N)	500
Simulation time (t)	0.2 sec	Node energy capacity (E_{cap})	0.001 J	Optimal transmission range (R_{opt})	90.1 m
Maximum transmission range (R_{max})	1000 m	Threshold power (p_{thr})	8×10^{-15} w	Carrier frequency (f)	2.4×10^{9} Hz

TABLE I
PARAMETERS OF SIMULATION

IV. ENERGY-EFFICIENT GEOGRAPHIC ROUTING

Based on the optimal transmission range, two energy-efficient Geographic Routing algorithms for 2-D ad-hoc wireless networks are proposed in this paper: the Optimal Range Forward (ORF) algorithm and the Optimal Forward with Energy Balance (OFEB) algorithm. The ORF algorithm selects as the next hop the node nearest to the optimal transmission range (best location as shown in Fig. 3) within the maximum allowed range and therefore minimises the energy consumption. The OFEB algorithm selects the next hop node as the node (within the maximum transmission range) that minimises equation 9.

$$f(E_{res}, \Delta d) = \alpha \frac{\Delta d}{R_{opt}} - (1-\alpha)\frac{E_{res}}{E_{cap}}, \tag{9}$$

This is a node that uses the best combination of energy reserves and needs the minimum energy to be reached. The weight factor α determines the relative significance placed on these two requirements. Therefore, OFEB is superior in concept and performance as will be seen. In equation 9, Δd is the distance between the neighbour nodes and the best location and E_{res} is the residual energy of the neighbours. Intuitively, without considering the energy balance, some nodes may be frequently selected as the relay nodes, and their energy may be drained out very soon compared to other nodes. Since E_{res} and Δd use different units, they are normalised as shown in equation 9. E_{res} is normalised with respect to the default energy capacity of each node (E_{cap}) to define $E_{res_{normalise}}$; Δd is normalised with respect to the optimal transmission range to define $\Delta d_{normalise}$.

As shown in Fig. 3, our 2-D ad-hoc wireless network model has N_n nodes distributed in the area. R_{max} is the maximum transmission range of each node. R_{opt}, which determines the best location of the next hop node, is the optimal transmission range computed based on equation 8 ($R_{opt} = 90.1\ m$ for $n = 2$). Δd is the distance between the best location and the neighbor node. In our simulation, the location information (coordinates) of each node is obtained by using GPS and is shared with its neighbors through periodic broadcasting. The location information of the source and the destination nodes is included in the transmitted packet. Therefore, in the forwarding scheme of each relay node, the next hop node can be selected according to the local geographic information and the location of the destination node. Following the fundamental geographic routing algorithm, the simulation of a 2-D ad-hoc wireless network (Fig. 3) is carried out, and the parameters used in the simulation are listed in Table I.

In Fig. 4, we simulate the network lifetime in a 2-D ad-hoc wireless network based on different forwarding algorithms: MFR, ORF and OFEB (different weight indexes are applied). Based on the definition of network lifetime, we define the network lifetime as the time duration before a fraction of nodes run out of energy, and the results from Fig. 4 show the performance of each algorithm. For example, when the definition of network lifetime is 30% of nodes run out of energy, the ratio of the network lifetimes (calculated in loops between 0 until the 30% event) under these different algorithms is: $MFR : ORF : OFEB(\alpha = 0.9) : OFEB(\alpha = 0.1) : OFEB(\alpha = 0.5) = 0.19 : 0.55 : 0.70 : 0.87 : 1$. It shows the OFEB algorithm (especially with $\alpha = 0.5$) has better network lifetime performance compared to the other algorithms. Note that the 30% event referred to above corresponds to 70% ”fraction of survived nodes” in Fig. 4.

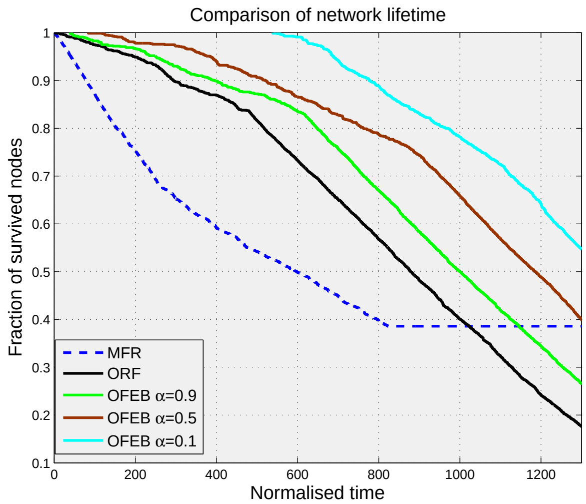

Fig. 4. Comparison of network lifetime

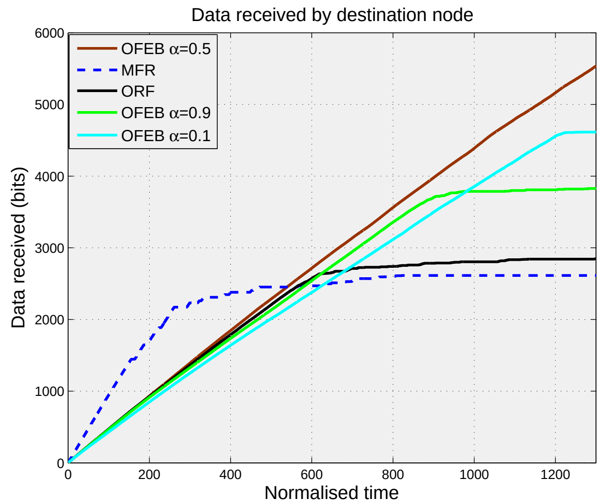

Fig. 5. Comparison of data received by the destination node

Since MFR selects the Most Forward node within Radius to be the next hop node, the delay time (number of hops) of one transmission is smaller than the other algorithms; Thus, the data packets received by the destination nodes of these different algorithms should be compared, as shown in Fig. 5. It shows that, before the network disconnection, with the OFEB algorithm, the destination node received much more data packets than the other algorithms. In Fig. 5, the received data with MFR increases more rapidly than the other algorithms. The reason is that the MFR selects the next hop node as far as possible, therefore, the number of hops needed for the data packets transmitted from the source node to the destination node is smaller than the other algorithms. Based on the real simulation time calculation mentioned before, the simulation time needed for data transmitted from the source node to the destination node is less than the other algorithms.

V. Conclusions

In this paper, we proposed the energy-efficient geographic routing algorithms ORF and OFEB to prolong the network lifetime, and the results are compared to existing Geographic Routing algorithm (MFR). Our new ORF algorithm selects as the next hop node the node nearest to the optimal transmission range (within the maximum range) and therefore minimises the energy consumption. Our new OFEB algorithm selects the next hop node as the node (within the maximum range) that minimises the value of $[\alpha\frac{\Delta d}{R_{opt}} - (1-\alpha)\frac{E_{res}}{E_{cap}}]$. This is a node that has the best combination of energy reserves and needs the minimum energy to be reached. The weight factor α determines the relative significance placed on these two requirements. The simulation results show that the OFEB algorithm has the best performance in term of both network lifetime and data amount received by the destination node.

References

[1] H. Takagi and L. Kleinrock, "Optimal transmission range for randomly distributed packet radio terminals," *IEEE Transactions on Communications*, vol. 32, p. 246257, 1984.

[2] L. Bao and J. J. Garcia-Luna-Aceves, "Topology management in ad hoc networks," in *4th ACM International Symposium on Mobile Ad Hoc Networking and Computing*, June 2003.

[3] Y. Xu, J. heidemann, and D. Estrin, "Geography-informed energy conservation for ad hoc routing," in *Proceedings of ACMMobil'01*, pp. 70–84, July 2001.

[4] B. J. Chen, K. Jamieson, H. Balakrishnan, and R. Morris, "Span: an energy-efficient coordination algorithm for topology maintenance in ad hoc wireless networks," *Wireless Networks*, vol. 8, pp. 85–96, September 2002.

[5] M. Mauve, J. Widmer, and H. Hartenstein, "A survey on position-based routing in mobile ad hoc networks," *IEEE Network*, vol. 15, pp. 30–39, 2001.

[6] I. Stojmenovic, "Position-based routing in ad hoc networks," *IEEE Communications Magazine*, vol. 40, pp. 2–8, July 2002.

[7] C. L. Chen and K. R. Lee, "An energy-proportional routing algorithm for lifetime extension of clustering-based wireless sensor networks," *Journal of pervasive computing*, vol. 2, 2006.

[8] C. L. Chen and K. R. Lee, "An energy-proportional routing algorithm for lifetime extension of clustering-based wireless sensor networks," in *The 2nd Workshop on Wireless, Ad Hoc, and Sensor Networks*, 2006.

[9] P. M. Shankar, *Introduction to Wireless Systems*. JOHN WILLEY & SONS, INC., 2002.

[10] W. R. Heinzelman and A. C. H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks," in *Proceedings of HICSS'00*, vol. 2, pp. 4–7, January 2000.

[11] B. Yin, S. Hongchi, and Y. Shang, "Analysis of energy consumption in clustered wireless sensor networks," in *Wireless Pervasive Computing, 2nd International Symposium on*, Feb 2007.