Performance Evaluation of Select Optimum Neighbor Protocol for Wireless Ad Hoc Networks

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***Abstract*— A location-aware *select optimum neighbor (SON)* algorithm for CSMA/CA based MAC protocols for ad-hoc wireless networks has been proposed in our previous work [12]. Our algorithm improves the energy efficiency by optimizing the effective number of neighbors of each node and thus reduces the transmission power as well as the interference caused to other irrelevant neighbors. In this paper, we present the results of our further extensive simulations for these protocols. We compare the SON scheme with several other MAC protocols such as IEEE 802.11 and show that our algorithm can achieve significant energy savings than other protocols.**

I. INTRODUCTION

WIRELESS devices in ad hoc networks are normally powered by batteries. Batteries can only provide finite amount of energy. Therefore, it is important to design energy efficient protocols to reduce the unnecessary energy consumptions in order to prolong the battery lifetime.

IEEE 802.11 is the de facto MAC protocol for wireless LANs and ad hoc networks. But 802.11 suffers from power inefficiency and low throughput in high traffic load scenario. Different topology control protocols with the goal of increasing throughput as well as reducing energy consumption have been proposed in literature [9][3][5][6][7]. The major technique employed in these protocols is to reduce the transmission power to control the number of neighbors while still maintaining the network connectivity. For example, Blough et al. [9] proposed a *K-Neigh* protocol to maintain the network connectivity with high probability, where each node keeps up to nine nearest nodes as neighbors and removes the neighbors with unidirectional links. An optimized pruning algorithm (denoted as TOPA in this paper) is then executed to reduce the energy inefficient nodes from neighbor list.

***Algorithm** 1:* Let $P(i,j)$ denote the transmission power for node i to reach node j and node i has a sorted (according to increasing value of $P(i,j)$) neighbor list as $j_1, j_2, \ldots, j_k$. For $l = 2, \ldots, k$, do the following

- Check whether j_l can be reached using a transmission power lower than P_{i,j_l} by routing through some j_q, where $q < l$.
- If $P(i,j_q) + P(j_q,j_l) \leq P(i,j_l)$, logically delete link (i,j_l) and remove node j_l from the neighbor list.

The transmission power of i is then set to the power needed to reach the farthest node in its neighbor list. Muqattash and Krunz proposed a similar pruning algorithm in [3]. The authors claimed that in addition to improving network throughput, reducing the transmission range plays an important role in reducing the energy consumption. Rodoplu and Meng [4] have showed that power-efficient routes can be found by considering only the nodes in the “enclosure region” as potential next hops. Another advantage of power control that has not received much attention in the literature is related to reducing the power consumption at *irrelevant receivers* (those who are not addressed by the transmission). Since reducing transmission range results in a smaller number of nodes overhearing the transmission, less receiving power will be consumed by these irrelevant receivers [3].

In our previous work [12], we proposed a location-aware select optimum neighbor (SON) algorithm with two derivatives (SCON and SEEON, see next), which can be treated as an alternative to the above mentioned pruning algorithm 1. In this paper, we compare the SON scheme with IEEE 802.11 and TOPA. Extensive simulations are carried out to study the relationship between the energy savings and the ratio of the electronic receiving power and transmission power.

Organization — The rest of this paper is organized as follows. Section II briefly describes the SON algorithm design. Section III provides simulations and analysis. Section IV describes related work. Finally, we conclude our paper in Section V.

II. SELECT OPTIMUM NEIGHBOR (SON) ALGORITHM

In this section, we provide a brief introduction of the SON algorithm. Interested readers can refer to [12] for a more detailed description. Our proposed algorithm includes several phases: *node startup, location broadcast, power allocation table (PAT) broadcast, select optimum neighbor (SON), symmetrization, and normal operation*. The SON related actions begin from *location broadcast* and end at *symmetrization*. In the initial phase, each node broadcasts its location information with full radio power and constructs a neighbor list. This neighbor list is called power allocation table (PAT). PAT contains the location information of all radio range neighbors and the correspondent power level for this node to reach each of them. In next phase (PAT broadcast phase), each node broadcasts its PAT information to its radio range neighbors. At the end of this phase, each node has the location information and correspondent PAT information of its neighbors.

$PTX(ij)$ denotes the transmission power sufficient for node i to reach node j. Let PTX_{elec} and PRX_{elec} denote the radio electronic power consumption when a node is transmitting and receiving, respectively. Let $IN(ij)$ denote the number of interfered neighbors of node i when node i is transmitting a packet to node j (note that, $IN(ij)$ does not include the intended receiver j). The total power for the direct transmission from node i to node j is

$$P^{direct}(ij) = PTX(ij) + PTX_{elec} + PRX_{elec} \times (IN(ij) + 1) \quad (1)$$

Now assume that node i has another neighbor node k, whose radio power level is less than j's (this means node k is ranked before node j in the PAT of node i). If

$$\begin{aligned} PTX(ij) + PTX_{elec} + PRX_{elec} \times (IN(ij)+1) > \\ PTX(ik) + PTX(kj) + 2 \times PTX_{elec} + \\ PRX_{elec} \times (IN(ik) + IN(kj) + 2) \end{aligned} \quad (2)$$

holds, node i should select node k as one of its optimum neighbor and prune node j from its neighbor list. In [12], we also proposed two derivatives of SON algorithm, *select closest optimum neighbor (SCON)* and *select energy efficient optimum neighbor (SEEON)*. These two algorithms are similar, but for one importance difference which is illustrated by the following example. Assume that a node has PAT (or neighbor list) as A, B, C, D, E, F, G, H where H is the farthest node that can not be removed according to equation 2. However, assume that nodes E and F can be removed according to equation 2. This is possible if all the nodes are randomly scattered. With the SCON approach, both E and F are kept in the neighbor list. On the contrary, E and F are removed from the neighbor list in SEEON.

Figure 1 shows an example of SON where twenty nodes are randomly scattered. Before using SON, both node B and node O are neighbors of node G. We can see that for a direct transmission from G to O, there are 16 nodes (including the intended receiver O) that will receive this packet. For the indirect transmission from G to B to O, the total nodes that will receive the packet reduces to 8 (4 for G to B and 4 for B to O). If

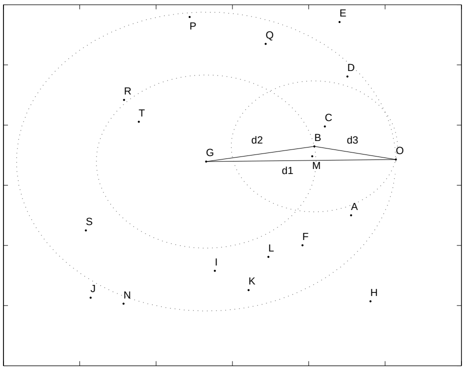

Fig. 1. *An SON example*

$$\begin{aligned} PTX(G,O) + PTX_{elec} + PRX_{elec} \times 16 > \\ PTX(G,B) + PTX(B,O) + 2 \times PTX_{elec} + \\ PRX_{elec} \times 8 \end{aligned} \quad (3)$$

holds, SON prunes node O from the neighbor list of node G.

III. SIMULATIONS AND ANALYSIS

We have implemented a NS-2 simulation testbed to carry out performance evaluations of our algorithm. The simulations focus on the relationship between the energy savings and the ratio of the electronic receiving power to the transmission power. We have adopted a simple energy dissipation model that is used in LEACH [10]. The model is shown in Figure 2. This model separates the electronic energy consumption and power amplifier energy consumption at the transmitter side. We use Lucent IEEE 802.11 WaveLAN card parameters [1] in our simulation, where the power consumption at transmit, receive, and idle are 1.65W, 1.4W and 1.15W respectively. The Rx and Tx electronic energy consumption used in the algorithm (equation 2) are the differences over the idle energy consumption. We also assume that Rx and Tx electronic consumes the same energy. The parameters used is our simulation are shown in Table I.

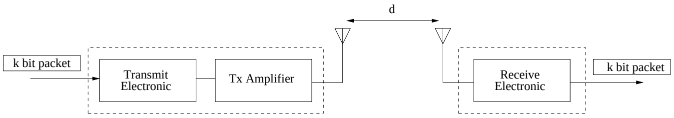

Fig. 2. *Radio energy dissipation model*

TABLE I

PARAMETERS USED IN SIMULATIONS.

Data Rate	2Mbps
Propagation Model	Log distance path loss
Reference Distance	1 meter
Path Loss Exponent	3
Antenna Gain	1
System Loss	l
Rx Threshold	1e-10 W
Rx Elec Power	2.5 mW – 1250 mW
Tx Elec Power	2.5 mW – 1250 mW
Max Radio Power	250 mW

We implemented a random multi-hop network topology with 100 nodes randomly deployed in $500m \times 500m$ square area and compared the energy consumption between 802.11, TOPA, SCON and SEEON. The network topology under 802.11 is showed in Figure 3. In this case, the average numbers of neighbors is 13.52.

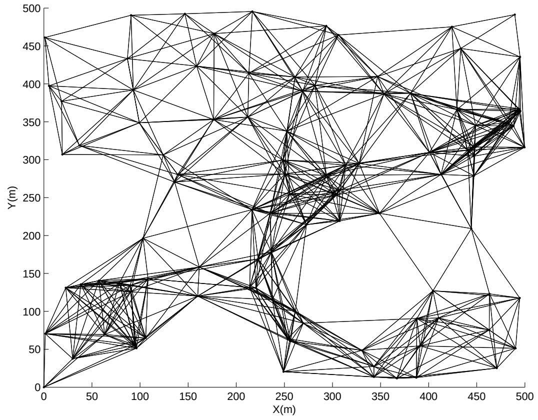

Fig. 3. *Network topology under 802.11*

To evaluate the relationship between the energy saving and the ratio of electronic power to the transmission power, we measured the energy consumption involved in transmitting from source 73 to sink 8 under different electronic power values (2.5mW 5mW 12.5mW 25mW 50mW 125mW 250mW 500mW 1250mW). The corresponding ratios of electronic power to transmission power are 0.01, 0.02, 0.05, 0.1, 0.2, 0.5, 1, 2 and 5.

From equation 1 and equation 2, we can see that the network topology after SON is mainly decided by three factors:

transmission power (PTX), electronic power (PTX_{elec} and PRX_{elec}) and the node density. We assume that r is the ratio of the electronic power to transmission power. Hence, we get,

$$r = PRX_{elec}/PTX \tag{4}$$

Also, let n denote the average number of neighbors of each node in the original 802.11 topology (i.e., before SON is executed). When $n \times r \gg 1$, the electronic energy consumption is the dominant energy consumption in the network. We can simplify equation 1 to equation 5,

$$P^{direct}(ij) \approx PTX_{elec} + PRX_{elec} \times (IN(ij) + 1) \tag{5}$$

which means the network topology after SON is mainly decided by electronic power. As aforementioned, the average number of neighbors before SON is 13.52. When $r = 1$, $r \times n = 13.52 \gg 1$. So the electronic energy consumption dominates the energy consumption and is the pivotal factor for SON.

Figure 4 shows the average number of neighbors after the pruning algorithms are executed. The number of neighbors with TOPA, SCON and SEEON increases from 3.94, 4.24 and 3.56 to 13.52, 7.98 and 5.78 respectively, when r increases from 0.01 to 1. When $r \geq 1$, the average numbers of neighbors with SCON and SEEON remain at the same value of 7.98 and 5.78, which means that the network topology after SON does not change further.

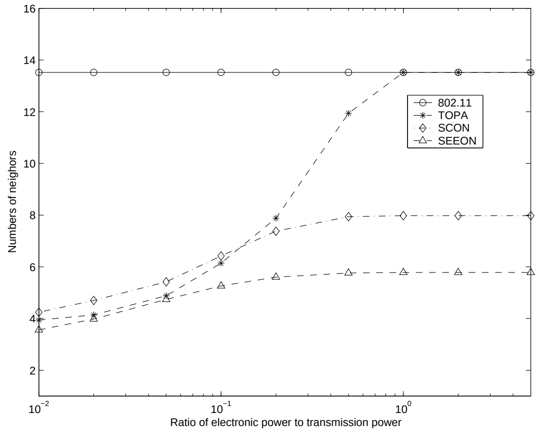

Fig. 4. *Average numbers of neighbors under different r values*

Before transmitting data, we let each node exchange DSDV routing messages to construct the routing tables. To avoid the influence of the DSDV energy consumption on our evaluation of the SON, we only set the network to exchange DSDV routing messages once and keep the same routes when the packets are transmitted. Figure 5 shows overall energy consumption per node for a full process of DSDV information exchange for the whole network under different r values. When $r = 0.1$, TOPA achieves 68.7% energy savings when exchanging DSDV messages as compared to 802.11. On the other hand, SCON and SEEON consume 68.7% and 68.1% less energy than 802.11, respectively. When $r = 5$, SCON and SEEON consume 21.8% and 24.1% less energy than 802.11. However, TOPA only achieves 1.2% energy savings as compared to 802.11.

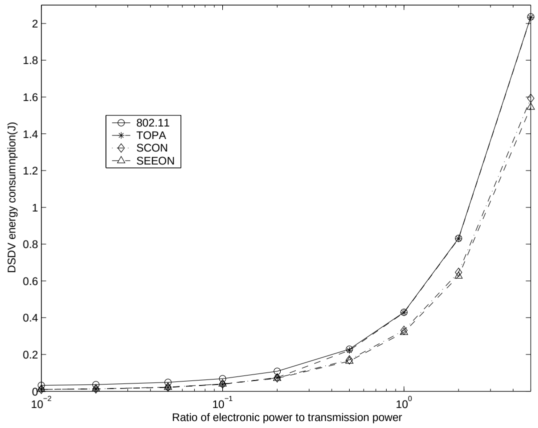

Fig. 5. *DSDV energy consumption under different r values*

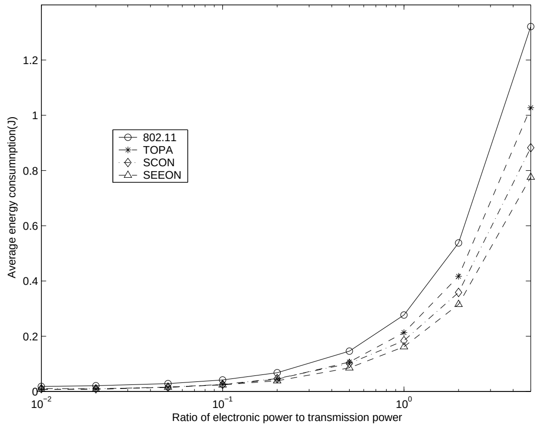

Fig. 6. *Average energy consumption under different r values*

Figure 6 shows the average energy consumption after sending 100 packets from source 73 to sink 8 with different electronic power values. When electronic power is 2.5 mW ($r = 0.01$), the energy consumption of 802.11 is 1.80e-2 J. When electronic power is 5 mW ($r = 0.02$), the total energy consumption of 802.11 is 2.06e-2 J. Note that, this results in a radio energy consumption of 1.54e-2 J. On the other hand, when electronic power is 250 mW($r = 1$), the energy consumption of 802.11 is 2.77e-1 J and the electronic energy consumption is about 2.62e-1 J. In this case, the electronic energy consumption is 16 times larger than power radio energy consumption, which means the electronic energy consumption is the dominant energy consumption if $r \geq 1$.

Assuming that the energy consumption of 802.11 is equal to 1, Figure 7 plots the energy saving rate of TOPA and SON compared with 802.11 under different r values. When $r \leq 0.1$, both TOPA and SON achieve more than 44% energy savings compare with 802.11. When $r \geq 1$, SCON and SEEON save about 33% and 41% energy. However, TOPA only saves about 22% energy. This shows that SON has a better energy performance than TOPA when electronic energy consumption is much larger than radio energy consumption.

Figure 8 shows that the numbers of hops from source to sink decreases when electronic power increases. When $r \leq 1$, the routing paths may be different even with the same numbers of hops. For example, the numbers of hops with SEEON are equal to 11 when r is 0.1, 0.2 and 0.5. However, the corresponding routing paths are

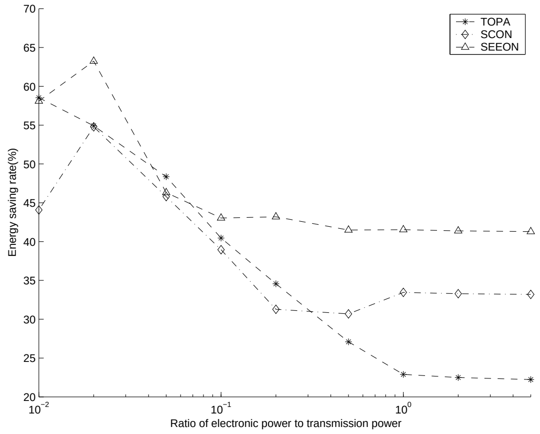

Fig. 7. *Energy saving rate compared with 802.11 under different r values*

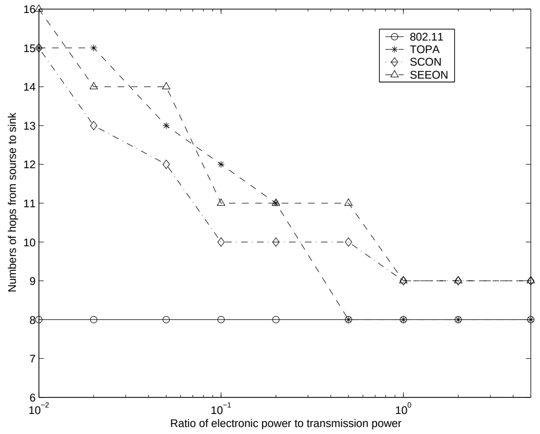

Fig. 8. *Numbers of hops from source to sink under different r values*

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r=0.1
Source(73)-91--62-94-13-71-75-93-4-55-Sink(8)
r=0.2
Source(73)-57--23-94-13-71-75-93-4-55-Sink(8)
r=0.5
Source(73)-57--23-94-13-71-75-93-4-77-Sink(8)
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When $r \geq 1$, the routing path does not change further because the network topology after SON does not change.

IV. RELATED WORKS

Significant research works on topology control and energy efficient protocol designs for ad hoc networks have been published in the literature.

Muqattash [3] et al. proposed a comprehensive solution for power control in mobile ad hoc networks (MANETs). Their solution emphasizes the interplay between the MAC and network layer, where the MAC layer indirectly influences the selection of next-hop by properly adjusting the power of route request packets. Jung [1] proposes an energy efficient MAC protocol for wireless LANs, where an adaptive mechanism is employed to dynamically choose a suitable ATIM (stands for Ad-hoc Traffic Indication Message) window size to improve both the network throughput and energy consumptions. Many topology control papers for ad hoc networks have been published since the earlier 1990s where the ad hoc networks are referred to as packet radio networks. Hu [11] presented an efficient topology control algorithm based on Delaunay triangulation with higher throughput performance than regular-structured networks. Rodoplu and Meng [4] proposed a distributed topology control algorithm that leverages on the position information to build a topology with minimized energy consumptions. Wattenhofer [6] introduced a distributed topology control protocol based on directional information, called CBTC (Cone Based Topology Control). A set of optimizations that further reduce power consumption for CBTC is presented in [7].

V. CONCLUDING REMARKS AND FUTURE WORK

Traditional optimum pruning algorithm (TOPA) (refer to section I) only considers distance dependent radio transmission energy consumptions. However, the efficiency of TOPA is affected when the radio electronic energy consumptions can not be ignored compared to the radio transmission energy consumptions. Instead, our SON algorithm considers both, the radio electronic energy consumption and the radio transmission energy consumption. SON also considers the energy consumption at those irrelevant receivers in the optimized pruning process. In this paper, we have carried out extensive simulation-based evaluations of 802.11, TOPA and SON. NS-2 simulations show that the ratio between radio transmission power and radio electronic power have a significant influence on the efficiency of SON. When electronic energy consumption is a considerable part of energy consumption, SON has a better energy performance than TOPA.

One interesting area that we intend to work on in the future includes studying the effects of the pruning algorithms on the network throughput and packet latency. On the one hand, eliminating neighbors normally means increasing the number of hops from a specific source to a sink, thus increasing the latency. On the other hand, a shorter transmission range means a smaller number of contenders for the channels resulting in lower contention delays and therefore, reduced latency. The network throughput and packet latency are also related to the traffic patterns. We would like to pursue these areas in our future work.

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