MPTC-A Minimum-energy Path-preserving Topology Control Algorithm for Wireless Sensor Networks

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Abstract. The topology control strategies of wireless sensor networks are very important to reduce the energy consumptions of sensor nodes and prolong the life-span of networks. In this paper, we put forward a minimum-energy path-preserving topology control (MPTC) algorithm. MPTC not only resolves the problem of exceeding energy consumption because of the unclosed region in SMECN[2], but also preserves at least one minimum-energy path between every pair of nodes in a communication network. At last, we demonstrate the performance improvements of our algorithm through simulation.

Keywords: wireless sensor networks, topology control, minimum energy property, k-redundant edges

1 Introduction

Wireless sensor network can be deployed in wide variety of civil and military applications. Because the power of sensor nodes are limited, so network protocols that minimize energy consumption is a major design goal for wireless sensor networks. As one of the key techniques, Topology control can design power-efficient algorithms that maintain network connectivity and optimize performance metrics such as network life and throughput.

At present, there are a number of documents carrying on the research on the topology control [3],[4],[5],[6],[7],[8]. The work most closely related to ours is that of Li (Erran) Li et al [2], they propose an effective topology control algorithm, which is called a small minimum-energy communication network (SMECN). But SMECN has a flaw about the unclosed region which could result in exceeding energy consumption. We put forward a new topology control algorithm- Minimum-energy Path-preserving Topology Control (MPTC) which not only resolves the problem, but also ensures the connectivity of network which has minimum-energy path property.

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2 Model

We assume that all nodes in the wireless sensor network are deployed in two-dimensional area, where no two nodes are in the same physical location. Each node knows its own location, and has a unique identification code. A transmission between node *u* and *v* takes power $p(u,v) = td(u,v)^n$ for some appropriate constant *t*, where $n \geq 2$ is the path-loss exponent of outdoor radio propagation models [1], and $d(u,v)$ is the distance between *u* and *v*. In this paper, we designate *n* equals 4.

When each node of the network uses its biggest power in working, this topology is called the biggest power topology($G_{\max}$).A $PATH(u,v)=(u=u_0,\cdots u_n=v)$ in G , the consumed energy when messages delivered through this path is $C(PATH(u,v)) = nc + \sum_{i=0}^{n-1} P(u_i,u_{i+1})$, *c* is the consumed energy when a node receives messages.

3 The MPTC Algorithm

According to the SMECN[2], the direct-transmission regions(DTR) of the nodes can be divided two different types: closed region and unclosed region. If *u* can find its transmitted power p_u ($p_{\max} > p_u > 0$)that satisfies $F(u,p_u) \supseteq \eta$, u's DTR is a closed region. (Fig .3(a) shows closed region.) Otherwise, $F(u,p_u)$ Û η when p_u ($p_{\max} > p_u > 0$), u's DTR is a unclosed region.(Fig .3(b) shows unclosed region.). The DTR of the nodes at the verge of the wireless network are almost unclosed region. SMECN will set $p_{\max}$ as the node's transmitted power when the node's DTR is an unclosed region, which makes these nodes consume more energy.

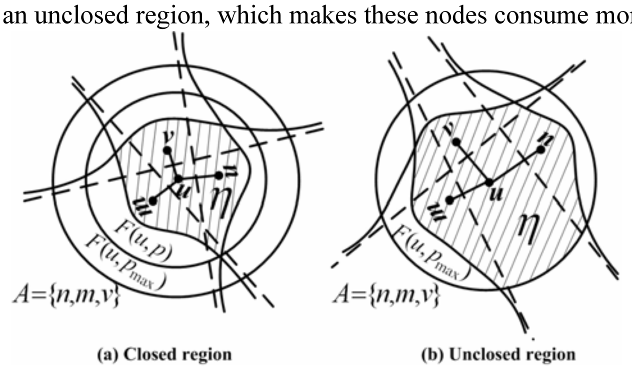


Fig. 3. Closed region and unclosed region.

Different from SMECN[2], MPCT sets the transmitted power of nodes without judging whether the nodes' transmission region covers its direct- transmission region.

The detail of MPTC algorithm is shown in Fig.4, which consists of the following main steps.

Aoglrithm MEPN

$P(u) = P_{\max}$;
$M = \varnothing$;
Broadcast"Hello"message with power $P_{\max}$ and gather Acks;
$NBR(u) = \{v | p(u,v) \le P_{\max}\}$; // $NBR(u)$is a set of all the nodes in $F(u, p_{\max})$
while $NBR(u) \ne \varnothing$ *do*
  p=Increase(p);
  Broadcast"Hello"message with power p and gather Acks;
  N=$\{v | Loc(v) \in F(u,p), v \notin M, v \ne u\}$; // N consists of the new nodes in the current iteration
  $M = M \cup N$; // M inculdes all the nodes in $F(u,p)$
  $NBR(u) = NBR(u) - N$;
   for each $w \in NBR(u)$ do
    for each $v \in N$ do
     if $C(u,w) > C(u,v,w)$ then // judge whether the edge(u,w) is a two-redundant edge
       $NBR(u) = NBR(u) - \{w\}$;
$P(u) = p$; // After $NBR(u) = \varnothing$, u sets its final transmitted power (p)
$N(u)$=$\{v | Loc(v) \in F(u,p), v \ne u\}$; // $N(u)$is a set of u's neighbors in $F(u,p)$

Fig. 4. Algorithm MPTC running at node u.

Define the graph $G = (V, E)$ by taking $(u,v) \in E$ iff $v \in Nbr(u)$, as constructed by the algorithm in Fig.4. Thus, the following theorem holds.

Theorem 1: If the $G_{\max}$ can ensure the connectivity of the wireless network, then the subgraph $G = (V, E)$ can also ensure the connectivity of network and has the minimum-energy property [2].

Proof- **Connectivity**: We assume that there is a $\mathrm{PATH}(u,v)$=$(u = u_0, \ldots, u_n = v)$ in $G_{\max}$. According to MPTC algorithm, if $\mathrm{edge}(u_i, u_{i+1})$ is not a two-redundant edge[2], we reserve the this edge in G. Otherwise, if $\mathrm{edge}(u_i, u_{i+1})$ is a two-redundant edge, there are $\mathrm{PATH}^*(u_i,u_{i+1})$=$(u_i, w_i^1, \cdots, w_i^m, u_{i+1})$ in G, and $\mathrm{C}(\mathrm{PATH}^*(u_i, u_{i+1})) < \mathrm{C}(\mathrm{edge}(u_i, u_{i+1}))$. So, if u_i and u_{i+1} are connected in $G_{\max}$, they are also connected in G. We can find a path like $\mathrm{PATH}^*(u,v)$=$(u = u_0, w_0^1, \cdots, w_0^{m_0}, u_1, w_1^1, \cdots, w_1^{m_1}, \cdots, u_{n\text{-}1}, w_{n-1}^2, \cdots, w_{n-1}^{m_{n-1}}, u_n = v)$ i n G. The above process prove that for a given pair of nodes *u* and *v*, if there is a path between them in $G_{\max}$, there is also a path between *u* and *v* in G. Therefore, if $G_{\max}$ is connected, so is G.

Proof- **The minimum-energy property:** We assume there is a minimum-energy path between *u* and *v* in $G_{\max}$, $\mathrm{PATH}(u,v)$=$(u = u_0, \ldots, u_n = v)$, which is not in G .There is at least an $\mathrm{edge}(u_i, u_{i+1})(i = (0, \cdots, n-1))$ in $\mathrm{PATH}(u,v)$ which is not included in G. Due to the connectivity of G, there is another

$\mathrm{PATH}^*(u_i,u_{i+1})=(u_i,\ w_i^1,\cdots,w_i^m,u_{i+1})$ in G to connect u_i and u_{i+1}. According to MPTC algorithm, it is not hard to show $C(\mathrm{PATH}^*(u_i,u_{i+1}))<C(\mathrm{edge}(u_i,u_{i+1}))$, so there is another $\mathrm{PATH}^*(u,v)=(u=u_0,\cdots,u_i,w_i^1,\cdots,w_i^m,u_{i+1},\cdots,u_n=v)$ in $G_{\max}$ and $C(\mathrm{PATH}(u,v))>C(\mathrm{PATH}^*(u,v))$,which means that $\mathrm{PATH}(u,v)$ is not a minimum-energy path between *u* and *v* in $G_{\max}$. It is contrary to the foregoing assumption. Hence we can conclude G has the minimum-energy path property.

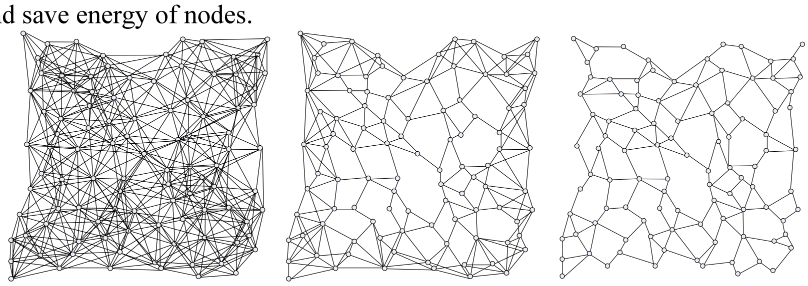
4 Evaluations

A. Simulation Environment

The simulation is conducted on simulator NS-2[9]. We generated 10 random network with 100 nodes. The nodes are randomly placed in a rectangular region of 1000m × 1000 m. Each node has a maximum transmission range of 200 m and is equipped with 20J of energy at beginning of the simulation. We randomly set 4 CBR flows at sending rate of 5 packets/sec, each packet size is 512 bytes.. We use AODV[10] as routing protocol.

B. Simulation Results

We firstly concentrate our research on topology structure. Fig.5 shows the networks' topology structure controlled by MaxPower, SMECN and MPTC respectively. Compared with the subnetworks controlled by SMECN and MPTC, the MPTC's subnetwork is smaller than that of SMECN, which can decrease the collision and save energy of nodes.



(a) MaxPower (b) SMECN (c) MPTC

Fig.5. The topology structure controlled by MaxPower, SMECN and MPTC

we simulate the average remaining energy of nodes in the path of flows after 300s simulation time. Fig.6(a) shows the simulation results for MPTC, SMECN and MaxPower, respectively. We can see that the average energy decrease rate of MPTC is significantly lower that that of SMECN and MaxPower Fig.6 (b) shows the average degree of nodes for MPTC, SMECN and MaxPower, respectively. From Fig.6 (b), we can conclude the average degree of MPTC is evidently lower than that of SMECN. The average degree of MPTC is only 70%~75% of SMECN. After about 270s, the average degree of MaxPower is decrease to 0, which means the most nodes in the network have no neighbor because a lot of nodes have been dead.

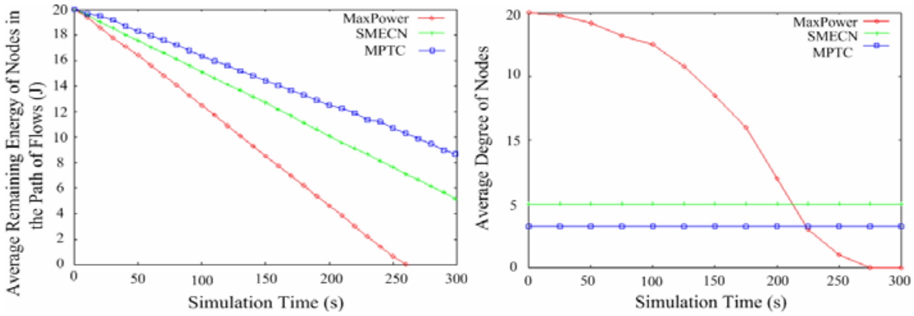


Fig. 6.(a) Average remaining energy of nodes (b) Average degree of nodes

5 Conclusion

Topology control can reduce the consumptions of sensor nodes, optimize the performance of networks and prolong the life span of the networks through adjusting the transmission power of sensor nodes. Our paper puts forward a new topology control algorithm of wireless sensor networks–MPTC. It not only avoids the exceeding energy consumption which results from the unclosed region in SMECN, but also ensures the connectivity of network which has minimum-energy path property. Finally, we have shown the performance improvements of MPTC over SMECN and MaxPower through simulation.

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