Topology Control in Wireless Sensor Networks

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***Abstract:*-The topology control is a vital process to maximize the network lifetime of wireless sensor networks. In this paper, we present a distributed topology algorithm with transmission power adjustment based on optimal no. of neighbours to raise the network energy- efficiency and the network throughput and to cope with the trade-off between the energy balance and energy efficiency, a non-linear optimization problem is formulated to find the optimal route nodes and their various transmission ranges. In the algorithm, every node can adjust its transmission power level and calculate its optimal transmission power according to the optimal number of neighbours, and a virtual clustering scheme is presented which is based on optimal transmission power for network topology control, where the network connectivity is also guaranteed. This scheme can achieve energy consumption balance and high efficiency at the same time.**

***Keywords*-Topology Control, Optimal Number of Neighbours, Power Control, Wireless Sensor Networks, variable transmission range, energy-balanced**

I. INTRODUCTION

Wireless Sensor Networks (WSNs) have become an emerging technology that has a wide range of potential applications including environment monitoring, object tracking, scientific observing and forecasting, traffic control and etc. In WSNs, hundreds or thousands of sensor nodes are often randomly deployed in inaccessible areas where battery cannot to be recharged or replaced, and these sensor nodes communicating with each other via radio collect information or data for a base station (BS).Obviously, deploying such a high number of nodes requires careful handling of topology maintenance. Therefore the topology control algorithms must be designed to be energy-efficient to maximize network lifetime.

Power control technology is a fundamental means to control network topology for WSNs. Transmission power control has very important effects on energy-efficiency and throughput of WSNs. An appropriate transmission power for a node transmitting a packet to its neighbouring node can save on battery power, at the same time, the traffic carrying capacity of network can be enhanced if every node can adjust its transmission power to appropriate level when it is transmitting the information.

One of the key challenges in WSNs is conserving energy so as to maximize their post deployment active lifetime. Large amount of energy saving schemes are presented in various aspects in the references [1-5]. However, energy saving is not the only target in WSNs, the quality of service (QoS) of WSNs is one of the most important aspects. If the sensor nodes consume energy equally, the chance that some nodes use up their energy much earlier becomes lower, and then the lifetime can be prolonged [1]. It is widely accepted that the approach of balancing energy consumption is an important way to guarantee the various QoS requirements in WSNs. In [6], the authors studied the balanced-energy sleeping scheduling problem.

Several schemes are presented for a cluster head to select nodes in the cluster to sleep so as to extend the network lifetime and reduce energy consumption of the entire cluster while keeping a certain fraction of the sensors energy-balance.

It is well known that multi-hops communication can save much more energy than that of single hops. In this paper, we focus on the optimal transmission power of nodes and the optimal network topology of WSNs. The goal of our research is to maximize the network lifetime and raise the network throughput. In our work, we firstly propose a scheme of deciding the optimal transmission power for each node in WSNs, and the scheme must ensure the connectivity of network. Then, we propose a virtual clustering algorithm for network topology control based on the optimal transmission power scheme. The virtual clustering algorithm can simplify the network topology and reduce the communication competition among nodes while the network connectivity is still maintained. Then, a scheme called energy balanced range adjustment (EBRA) for balancing energy consumption with energy-efficient data transmission is employed in WSN.

The remainder of this paper is organized as follows. In Section II, we present related work with a focus on topology control and transmission power control in WSNs. In section III, we will give the radio power model and the linear WSNs model we will use in the paper. In Section IV, we present a scheme for calculating the optimal transmission power of nodes according the optimal number of neighbors, and propose a distributed topology control algorithm based on virtual clustering network. In section V, the EBRA scheme is presented and the nonlinear optimization problem is formulated. Finally, we conclude this paper in Section VI with a summary of the work proposed and an outlook on future work.

II. RELATED WORK

Power control technology for WSNs is a vital process to improve the performance of network. Most works on topology control are based on adjustable transmission power control and mainly focus on maintaining a connected topology while minimizing energy consumption of nodes to extend the lifetime of network [7, 8]. In recent years, the researchers have already done a large amount of research work on power control for WSNs, and a lot of power control mechanisms have been proposed which try to design simple and practical protocols that build and maintain a reasonably good topology. Research [9] presents a distributed protocol called COMPOW, where the minimum common transmitting range needed to ensure network connectivity is adopted. The results shows that the value of transmitting range has the beneficial effects of maximizing network capacity, reducing the contention to access the wireless channel, and minimizing energy consumption. Research [10] proposes a distributed topology control algorithm using direction information where a node grows its transmission power until it finds a neighbor in every cone of angle α, where α≤2π/3. Research [11] proposes the Optimal Geographical Density Control (OGDC) algorithm that addresses both sensing coverage and connectivity in wireless sensor networks. Their algorithm aims at computing the minimum number of nodes that must be kept awake such that both sensing coverage and connectivity are maintained. The algorithm is decentralized but requires the network to be sufficiently dense to guarantee connectivity. Research [12] proves that the network remains connected as the transmit power of each node is reduced, as long as each possible sector of width α = 5π/6 around each node contains at least one neighbor, and the SC property is maintained.

III. RADIO POWER MODEL AND THE LINEAR NETWORK MODEL

In term of energy consumption, the wireless exchange of data between nodes strongly dominates other node functions such as sensing and processing. For a simplified power model of radio communication [5], the transmission energy consumed per second in transmission is

$$E_t = (e_t + e_d . r_n) B \tag{1}$$

where e_t is the energy/bit consumed by the transmitter electronics and e_d accounts for energy dissipated in the transmit op-amp. Both of them are the properties of the transceiver used by the nodes. *r* is the transmission range used. The parameter n is the power index for the channel path loss of the antenna. This factor depends on the RF environment and is generally between 2 and 4. *B* is the bit rate of the radio. The energy consumption on the receiving side is fixed as

$$E_r = e_{r.} B \tag{2}$$

where e_r is the energy/bit (J/bit) consumed by the receiver electronics used by the node. Typical numbers (for *n==2)* for currently available radio transceivers are *et* = 50 x 10-9 J / bit e_d = 100 x 10-12 J/bit/rn '<== 50 xl 0-9 J / bit and *B*==IKbits/s [4].

The network model here considered is the multi hops communication in a finite one dimensional network shown in Fig.l.

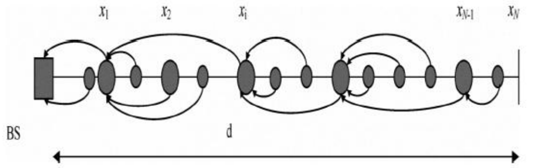

Fig.1:-A Linear network with variable transmission range

In such a WSN, the distance of the network is d. The sensor nodes are uniformly distributed with density n_d, and each node produces *G* Erlang traffic.The route nodes along the linear network are to collect all the traffic and relay the traffic to the BS. All the sensors send their data to its nearest route nodes. In order to guarantee some level of transmission time delay, there are only allowed *N* hops from the source to the base station (BS). The problem is how to find the locations of the active route nodes so that the consumed energy is minimized while balancing the energy consumption between the route nodes.

IV. OPTIMAL POWER-CONTROLLED TOPOLOGY CONTROL ALGORITHM

The main task of research on network topology control is to find an optimal transmission power to control the connectivity properties of the network or a part of it, which could be power per node, per link, or a single power level for the whole network. In this section, we will mainly describe the scheme of calculating the optimal transmission power for each nodes in network and the virtual clustering algorithm for network topology control.

A. System Model

In this paper, we assume a 2-dimensional sensor field with N sensor nodes distributed over the sensor field. All sensor nodes have the same maximal transmission power P_{max} and the same minimal transmission power P_{min}, and their transmission power can be adjustable. If a node transmits a packet, all the nodes within the communication range of the transmitting node will receive the message. Every node in field has the same initial energy and uses the free space propagation model (given the path loss coefficient is 2) expressed by [13]:

$$P_r = \frac{P_t G_t G_r \lambda^2}{4\pi^2 d^{2.} L} \tag{3}$$

While P_t is the transmission power, λ is the carrier wavelength, G_t is the transmitter antenna gain and G_r is the receiver antenna gain, P_r is the reception power. Obviously, in order to provide R_t, the minimum necessary RSSI for the reception of a frame, the minimum transmission power level P_m at the source node is calculated as

$$P_{\min} = \frac{R_{t.} . L . d^2 . (4\pi)^2}{G_{t.} . G_{r.} \lambda^2} \tag{4}$$

By combining Equation (3) and (4), the minimum transmission power level P_{min} can be obtained:

$$P_{\min} = \frac{P_{t.} R_t}{P_r} \tag{5}$$

In order to cope with the inaccurate estimation of the channel fading characteristic, the calculated P_{min} can be multiplied by a preset coefficient '*c*', and we obtain the minimal transmission power:

$$P_{\min} = \frac{c.P_{t.}.R_t}{P_r} \quad (6)$$

If a receiver node knows the transmission power level used by the sender node (P_t), with a known R_t and measuring the power level for the received frame (P_r), it is possible for the receiver node to calculate the minimal transmission power P_{min}.

B. Optimal Transmission Power Control

According to the results of researches [14-16], the optimal number of neighbours for a node is 6-8 in wireless multi-hop networks, which can improve the whole performance of network in channel utilization ratio and throughput. Assuming the optimal number of neighbours is N_{opt} and the collection of neighbours of a node under the maximal transmission power is T_{max}, then we select N_{opt} nodes from Γ_{max} by the value of the minimal transmission power of the nodes in Γ_{max} and obtain the set of the N_{opt} nodes (Γ_{opt}). So we can obtain the expression of the optimal transmission power of node k as:

$$P_{opt}(k) = \max\{P_{\min}(i) \mid i\varepsilon\tau_{opt}\} \quad (7)$$

The optimal transmission power can be intuitively explained by Fig 2. The number of nodes in the communication range of the optimal transmission power Γ_{opt} is not more than the optimal number of neighbours N_{opt}, and the P_{opt} must be in the range of the maximal transmission power level P_{max}.

According to the above analysis, we give an algorithm for calculating the optimal transmission power level. The algorithm described as the follow:

Algorithm 1: Calculate the optimal transmission power.

// Algorithm of Calculating the P_{opt} at a node k during a single

// HELLO message period.

1) The node k broadcast a HELLO message by its maximal transmission power level P_{max} at a randomly backward time T_{rand}.

2) The nodes that have received the HELLO message from the node k will calculate the minimal transmission power P_{min} by the equation (6) and send back an ACK message included this P_{min} .

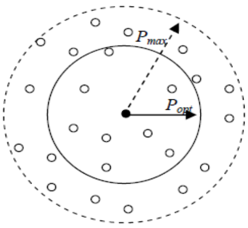

Fig.2:-Transmission Power level of a node

3) After a period of waiting time, the node k will receive many ACKs and then get the collection Γ_{max}. If the connection Γ_{max} is not empty, the node k's optimal transmission power P_{opt} is obtained by the equation (7).

C. Virtual Clustering Scheme

To obtain a stable and connected topology for WSNs, we proposed the virtual clustering scheme based on the optimal transmission power. In this scheme, all nodes in WSNs are classified into VH nodes and VS nodes; a VS node is only used to sense data and then sends the sensing data to its appropriated VH node directly, where the minimal transmission power P_{min} is modulated for the VS node communicating to its VH node. A VH node broadcast control message to its neighbours by its optimal transmission power P_{opt} and communicate with other VH nodes by its appropriated minimal transmission power P_{min}. Therefore, we assume that a basic cluster consists of a VH node and part of its optimal neighbours, and develop an algorithm to generate a virtual clustering network described as the Fig. 3 sketch.

In the proposed algorithm, the VH nodes are connected to a communication backbone network by their minimal transmission power level, and the VS nodes are always assigned to the nearest candidate VH node. Every node in network can become the VH node by the probability 1/ N_{opt} if it does not receive any message (MSG_VH) declared being a VH node from any other nodes during a randomly backward time T_{rand} while the network is initiated or restarted. Once a node declares itself being a VH node, it will broadcast a message MSG_VH by its optimal transmission power P_{opt}, and then the nodes received the MSG_VH during the MSG_VH message period will be as a VS node and give up the right to being a VH node. At the end of MSG_VH message period, the VS node will add itself to the nearest candidate VH node according to its received MSG_VH messages by sending back a message (MSG_VS) to the VH node. After the clustering period, every VH node can get its VS node according to the received MSG_VS messages.

V. EBRA TRANSMISSION SCHEME

Assume the chosen route nodes' locations are respectively X_i' i==1,...,N, as shown in Fig.l, The BS is the last hop on the route with location defined as x_o==O. The Nth node located at X_N=d is a virtual node. Both of them don't participate in the energy computation. All intermediate route nodes relay the data from sensors in its reverse direction to BS. Therefore, the traffic that the route node located at x must receive and forward is

$$A(x) = (d - x)n_d.a \quad (8)$$

Since the node i must relay the data to the node i-1, its transmission range should be X_i - X_{i-1}. The energy consumed by the route node i comprises of three parts:

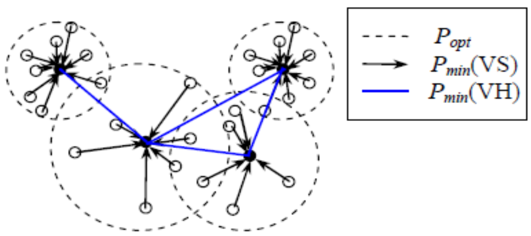

Fig.3:- Topology control based on virtual clustering

The first part: the energy used for forwarding data, from (1), we can easily get

$$E_{ti} = e_t.B.A(x_i) + e_{d.}B.A(x_i).(x_i - x_{i-1})^n \quad (9)$$

The second part: the energy used for receiving data, which is from (2):

$$E_{ri} = e_r.B.A(x_i) \quad (10)$$

The third part: the energy consumption in idle mode, which is

$$E_{Ii} = c.e_{r.}(1 - 2A(x_i)).B \quad (11)$$

From (9) to (11), we can easily deduce that the total energy consumed by the route node i is

$$E_i = E_{ti} + E_{ri} + E_{Ii}$$

$$= C_1(d - x_i) + C_2(d - x_i)(x_i - x_{i-1})^n + C_3$$

Where $C_1 = n_d \alpha B(e_t + e_r - 2ce_r)$

$$C_2 = n_d \alpha B e_d$$

$$C_3 = ce_r B$$

To balance the energy consumption, we have to minimize the difference between route nodes. We resort to the difference square sum to measure this difference

$$D = \sum_{i-2}^{N-1} (E_i - E_{i-1})^2$$

Our objective is to minimize the total energy and the difference of energy consumption at the same time. Generally, there are some tradeoffs between them. So we define the objective function as

$$\sum_{i-1}^{N-1} E_i + \beta \sum_{i=2}^{N-1} (E_i - E_{i-1})^2$$

Where β is a factor used to weight the importance between balance and total energy. So the optimization problem becomes

$$\min \sum_{i-1}^{N-1} E_i + \beta \sum_{i=2}^{N-1} (E_i - E_{i-1})^2$$

$$x_0 = 0$$

$$x_N = d$$

$$x_{i-1} < x_i \qquad i=1\ldots\ldots N$$

This is a non-linear optimization problem, which can be solved by numerical algorithms like Quasi-Newton method.

VI. CONCLUSION

In this paper, we have calculated the optimal transmission power of nodes according to the optimal number of neighbours, and presented the optimal topology control algorithm based on virtual clustering scheme. To find the tradeoff between the energy consumption balance among route nodes and the whole energy consumption, a non-linear optimization model is formulated to select the optimal route node locations for balancing the nodes energy consumption while trying to minimize the total energy consumption. This scheme is more energy efficient than that of fixed range transmission, and can keep the energy consumption balanced among route nodes very well.

VII. REFERENCES

[1] Zhaoyu Liu, Daoxi Xiu, and Weihua Guo, "An Energy-Balanced Model for Data Transmission in Sensor Networks", the IEEE 62nd Semiannual Vehicular Technology Conference, Dallas, Texas, pp.25-28, 2005.

[2] Javier Gomez, Andrew T. Campbell, "A case for variable range transmission power control in wireless multi-hop networks", IEEE INFOCOM 2004, The Conference on Computer Communications, 23(1),pp.1426-1437, 2004.

[3]Gao, Q., Blow, K.J., Holding, D.J., Marshall, I.W., and Peng, X.H"Radio range adjustment for energy efficient wireless sensor networks", Ad Hoc Networks, 4(1), pp.75-82, 2006.

[4] W.Rabiner, Heinzelman, A.Chandrakasan, H.Balakrishnan, "Energy-Efficient Communication Protocol for Wireless Micro sensor Networks," Proceedings of the 33rd International Conference on System Sciences (HICSS '00), 2000.

[5] BJ. Chen, K. Jamieson, H. Balakrishnan, and R. Morris, "Span: an energy-efficient coordination algorithm for topology maintenance in ad hoc wireless networks", Wireless Networks, 8 (5), pp.481-494, (2002)

[6] Deng, Jing; Han, Yunghsiang S.; Heinzelman, Wendi 8.; Varshney, Pramod K., "Balanced –energy sleep scheduling scheme for high-density Cluster based sensor networks", Computer Communications , 28(14), pp. 1631-1642, 2005.

[7] R.Rajaraman, "Topology control and routing in ad hoc networks: A survey, " SIGACT News, vol. 33, no. 2, pp. 60-73, 2002.

[8] P. Santi, "Topology control in wireless ad hoc and sensor networks," Istituto di Informatica e Telematica, Tech. Rep., 2003, submitted to ACM Computing Surveys.

[9] S.Narayanaswamy, V.Kawadia, R.Sreenivas and P. Kumar, "Power control in ad hoc networks: Theory, architecture, algorithm and implementation of the COMPOW protocol," in proceedings of European Wireless, 2002.

[10] Roger Wattenhofer, Li Li, Paramvir Bahl, and Yi MinWang, "Distributed topology control for power efficient operation in multihop wireless adhoc networks, "in Proceedings of INFOCOM, 2001

[11] H. Zhang and J. C. Hou, "Maintaining sensing coverage and connectivity in large sensor networks," in Proc. of NSF International Workshop on Theoretical and Algorithmic Aspects of Sensor, Ad Hoc Wireless, and Peer-to-Peer networks, Fort Lauderdale, FL, USA, Feb. 2004.

[12] L. Li, J. Y. Halpern, P. Bahl, Y.-M. Wang, and R. Wattenhofer, "A cone- based distributed topology-control algorithm for wireless multi-hop networks," IEEE/ACM Trans. Networking, vol. 13, no. 1, pp. 147–159, Feb. 2005.

[13] Pelin C Nar, Erdal Cayirci. PCSMAC: A power controlled sensor-MAC protocol for wireless sensor networks. In: Proc. of the EWSN'05. 2005.

[14] L. Kleinrock, J. A. Silvester, " Optimum transmission radii for packet Radio networks". In: Proc. of IEEE Nat. Telecommunications Conf, 1978.

[15] T. Tagagi, L. Kleinrock, " Optimal transmission ranges for distributed packet radio terminals" IEEE Trans. on Communications, 1984. Vol. 32, pp. 246-257.

[16] Chansu Yu, Kang G. Shin, Ben Lee. Power-stepped protocol: Enhancing spatial utilization in a clustered mobile ad hoc network. IEEE Journal on Selected areas in communications, September 2004. Vol. 22, No. 7: pp. 1322-1334.

[17] Xinhua Liu, Fangmin Li and Hailan Kuang. "An Optimal Power-controlled Topology Control for Wireless Sensor Networks",International Conference on Computer Science and Software,2008.