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Article

Topology control in Heterogeneous Wireless Sensor Network

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Abstract: Topology of a Wireless Sensor Network determines the connectivity of the wireless network and topology Control is the important technique of extending network lifetime while preserving network connectivity. In this paper, we consider a heterogeneous multi-hop wireless sensor network consisting of sensor nodes and relay nodes. Relay nodes strategically deployed for fault tolerance and virtual backbone creation. We propose topology control algorithm based on hybrid approaches to maximize the topological network lifetime of the WSN. The experimental performance evaluation demonstrates the topology control with efficient use of relay nodes maximizes the network lifetime of WSNs.

Keywords: topology control; wireless sensor network; network lifetime; relay backbone

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In WSN design, the key issues are node energy efficiently, network connectivity and robustness, network throughput and lifetime extension of the whole network. Among these network lifetime has become the critical requirement of most WSN applications. The WSN which contains large numbers of nodes, the planning deployment becomes most important issue. To extend lifetime while protecting against network failure, it is important to plan the topology deployment. Controlling the topology of the network has emerged as an effective solution to the above problem. Overall topology control includes factors like mode of deployment, deployment of additional nodes, self-configuration after deployment and employing scheme for maintaining the topology of sensor network particularly when sensor nodes are prone to random failures, subject to energy drain or harsh physical conditions.

Traditional sensor network allows the deployment of sensor node to sense their environment and send the collected information to the base station for further processing. In modern scenario, the large scale WSNs are based on a multi-hop heterogeneous hierarchical models allowing networks to use relay nodes to span distances between sensor nodes and to adapt to network changes by routing around a failed node using a different path in order to improve performance. The deployment of nodes also planned use less transmitter power that result in longer network lifetime.

In heterogeneous WSNs, the role of relay nodes is different in different types of network architectures. In flat stationary network architectures, relay nodes used for network connectivity and fault tolerance. In two-tier networks, relay nodes usually play the role of a backbone node or gateway in the network. In such heterogeneous wireless sensor networks, maximizing lifetime by optimally using the energy within sensor and relay nodes is an important problem of researches in recent years.

The proposed topology control algorithm assumes maximum utilization of redundant relay node's energy while selectively engaging sensor nodes in order to prolong the network lifetime. In general, energy-efficient topology control algorithms broadly classified into centralized or distributed [1]. Centralized approaches are not feasible for large-scale WSNs. Distributed approaches are dynamic and more practical for large-scale WSN scenarios. Distributed topology control algorithms classified according to the criterion used. They grouped into four categories that are power adjustment, power m ode, clustering and hybrid. The power adjustment approach is base on the concept of changing the transmission power of nodes to minimize the node energy during communication. Minimum Energy Communication Network [2] is a localized algorithm that minimizes the energy in packet transmission by constructing a topology of lowest energy paths between sensors to a sink. The SMECN algorithm [3] is an extension of the MECN algorithm to construct a network that is simpler, faster and more energy-efficient than the one generated in MECN. COMPOW [4] finds and uses the minimum common power level that is sufficient to maintain the connectivity of the entire network. XTC algorithm operates with the neighbors' link qualities [5] and avoids long-distance communication links and route a message over several small energy efficient hops. The Cone-Based Topology Control algorithm (CBTC) [6] increases network lifetime while maintaining global connectivity with a reasonable throughput in a multi-hop wireless ad hoc network.

The power mode approach is the technique that exploits the feature of the operating mode to gain energy saving. In general, there are four operating modes of the nodes: sleep, idle, transmit and receive modes. The energy consumed during transmit and receive modes is assumed higher than that in the sleep mode [7]. Geographical Adaptive Fidelity (GAF) [8] nodes operate in three states that consist of sleep, STEM [9] is similar to GAF but put as many nodes as possible to sleep mode so that the energy consumption is reduced and network lifetime is extended.

Adaptive Self-Configuring Sensor Network Topologies (ASCENT) proposed by [10] is a self-reconfigurable algorithm which selects a subset of nodes to remain active to serve as a routing backbone. The remaining nodes stay passive listening to join the routing backbone whenever required.

Clustering techniques creates hierarchical structures in a very large-scale network by selecting a set of nodes in the network on various criteria namely, energy reserve and density of the network or node identifier. Most attractive features of the clustering approaches include the load balancing and data aggregation offered for prolonged network lifetime. Many of the clustering approaches construct the virtual backbone using the connected dominating set (CDS) [11], Energy-efficient Distributed Connecting Dominating Sets (ECDS) [12], Power Aware Connected Dominating Set (PACDS) [13]. In load balancing clustering, backbone nodes are randomly chosen among nodes with higher remaining energy.

The hybrid approach is a topology control technique that uses a clustering approach in combination with power adjustment or power mode approaches. SPAN [14] combines the clustering approach with the power mode approach in which the non-cluster-heads that are sitting idle shifts to the sleep mode. The CLUSTERPOW [15] integrates the clustering approach with the power adjustment approach to enhance energy saving. LEACH [16] integrates the clustering approach and power mode approach that uses a load balancing mechanism that periodically rotates the role of cluster-head nodes.

2. Network Model

In this work we consider, a large number of stationary homogeneous sensor nodes randomly deployed in a given area of interest. They are responsible of sensing raw data and then forwarding it to sink node in multiple hops. We assumed minimum number of relay nodes called as first phase relays optimally deployed for two objectives. First is to achieve minimum *k*-connectivity for fault tolerance and second for relay backbone formation. Few additional second phase relays are also placed in the network to make relay backbone to be a fault tolerant.

3. Topology Control Algorithms

The topology control algorithms proposed and illustrated in this work are hybrid approaches, that uses a clustering approach in combination with power adjustment or power mode approaches. The SPAN algorithm is a hybrid of power mode and clustering approaches. It selects a subset of nodes to form a forwarding backbone using a CDS approach. The SPAN selects a subset of nodes to form a forwarding backbone. The backbone is capable of forwarding packets, maintaining network connectivity and preserving network capacity.
SPAN guarantees minimum the number of nodes elected as coordinators, thereby increasing network lifetime but without causing a significant loss of capacity or increase in latency. Finally, SPAN elects coordinators.

3.1 PCSPAN Algorithm

The SPAN algorithm uses only mode control approach in clustering for backbone creation. To minimize energy consumption further we propose an algorithm based on SPAN, which employs the power control technique in the SPAN algorithm hence we name this algorithm as PCSPAN (Power Control SPAN).
PCSPAN is power control version SPAN algorithm. Power control is added to SPAN means in PC-SPAN non backbone nodes can connect to backbone by controlling its transmitting power that sets to minimum for maintaining the connectivity. The primary goal of the proposed algorithm design is to achieve maximum lifetime extension of the wireless sensor network.
The PC-SPAN runs above the link and physical layers, and below the routing layer of protocol stack. This structure allows exploiting the power-saving feature of the link layer protocol, while still being able to influence the routing process. To support routing protocol the PC-SPAN protocol has to follows neighbor discovery, backbone nodes selection and state transition activities. The PCSPAN generates a sparse topology.

Algorithm 1: PCSPAN

Input: G(V)
Output: B(V')
1. *F(u, pi) : Set of 1-hop neighbor of v with Tx power level* p_i ;
    S(u) : Set of 2-hop neighbor of v = ø ;
2. *Neighbor search*
2(a) **for** *each u in G(V)* {
        for *power level i* =1 *to* 4 {
      Broadcast a HELLO message with Tx power= p_i ;
       receive hello message from other node v;

F(u p_i) = F(u p_i) U {v p_i}; }}
Order nodes in F(u) according to decreasing node degree;}
2(b) **for** *each u in G(V)* {
Broadcast a HELLO message with Tx power level 4;
*receive hello message from other node v and know its*2-*hop neighbor*;
S(u) = S(u) U {v'}; }
3. *Selection of Backbone Nodes*
while *F(u) = 0* {
B(V)= {u};
if *v has a neighbor w which is not in S(u) and* $E_v > E_w$
{ *B(V') = B(V')* U *{v};*
F(u) = F(u) ∩ *{u}*
else *B(V') = B(V')* U *{w};*}}
4. *Withdrawal as a Backbone node*
for *each node v in B(V')* { *after backoff delay*
if *every neighbor of v is a neighbor of node w in B(V)* { *B(V') = B(V') – v* ;}
else *continue*;}
5. *Broadcast final B(V')*
6. **for** *all nodes in G(V)* ∩ *B(V')* { *node takes decision whether to sleep or awake to act as simple sensor.*
if *node k awaken then*
adjust transmit power level of k to p_i *of corresponding node in backbone list;*
Broadcast new status; }

We have built PCSPAN on AODV routing protocol that can work with any routing protocol.

3.2 ABTC Algorithm

Adaptive Backbone Topology Control is an adaptive version of PCSPAN algorithm. ABTC initially consider sensor nodes and relay nodes to be elements of two different sets. ABTC performs 1-hop neighbor and 2-hop neighbor discovery just similar to PCSPAN. They differ in backbone election and withdrawal steps. In ABTC backbone selection criterion are different for sensors and relays. Sensor node can participate in backbone up to threshold value ($\beta * p_{max}$) of its energy level but there is no such condition imposed on relay nodes. β can ranges from 0.1 to 1. Relay node can be a part of backbone as long as it is alive. Initially both type of nodes that are sensor and relay node form backbone for data forwarding. After some time when all sensors lose their energy and drops below half of its initial energy, they do not become a backbone node and thereafter adaptively backbone will composed by relay nodes. This strategy is opted because the sensor nodes dissipate energy faster than relay nodes, as sensor has to perform additional work of sensing the data compare to relay. This approach will help balancing load among sensors and relays to conserve energy of sensors.

Algorithm 2: ABTC

Input: G1(V), G2(R)
Output: B(V')
1. *F(u,* p_i*)*:Set *of 1-hop neighbor of v with Tx power level* p_i;
S(u) : *Set of 2-hop neighbor of v* = ø ;
2. *Neighbor search*
2(a) *G(V,R) =* $G_1(V)$ U $G_2(R)$*;*

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        for each u in G(V,R) {
          for power level i =1 to 4 {
           Broadcast a HELLO message with Tx power = p_i ;
           receive hello message from other node v;
           if v is not in F(u, p_i) then
           F(u  p_i) = F(u  p_i ) U {v  p_i }; }
           else          Continue;}}
         Remove duplicate nodes in      order nodes in F(u)  according to decreasing value of node
         degree;}
2(b)     for each u in G(V){
         Broadcast a HELLO message with Tx power level 4;
         receive hello message from other node v and know its1-hop neighbor;
         S(u) = S(u) U {v'};}
3.       Selection of Backbone Nodes
         while F(u) = 0 {
           If u not belong to G2(R) and E_u > E_u /2;
           B(V)= {u};
         If v has a neighbor w which is not a neighbor of any node in F(u) and E_v > E_w {
              B(V') = B(V') U {v};
              F(u) = F(u) ∩ {u}
         else
              B(V') = B(V') U {w};} }
4.     Withdrawal as a Backbone node
         for each node v in B(V'){
           if every neighbor of v is a neighbor of node w in B(V){
            B(V') = B(V') - v;
           else continue;}}
5.     Broadcast Final B(V');
6.     for all nodes in G(V,R) ∩ B(V'){
        if node k belongs to G_2(R) Shift in sleep state
         A node in G_1(R) takes its decision whether to sleep or awake and act as data collecting node;}
        if node k is in awake state
         adjust transmit power level of k to p_i of corresponding node in backbone; }
         Broadcast new status;}
7.       if B(V') not a subset of G_2(R)then
           Repeat steps 1 to 6;
```

4. Simulation Results

This section discusses results and performance comparison of our implementation of PCSPAN and ABTC with SPAN algorithm, which is one of the most widely cited algorithms.

The scenario that we have used in our simulation experiments consists of a 300 m x 300 m square area. The number of nodes is 100 nodes. All experimental results in this section are average of ten runs on different chosen scenarios. In Fig 1, graphs are drawn for backbone nodes as a function of node density to verify the sparseness of topology. SPAN outperforms in this regard. The reason is that SPAN nodes use maximum power whereas in PCSPAN and ABTC connectivity may be possible at lower transmitting power. Percentage energy remaining with backbone node when all nodes are functioning is better in PCSPAN and ABTC but lower in SPAN, which is shown in Fig 2.

Fig 3 and 4 are important in the context of sensor node's energy conservation. Results show that SPAN gives free hand to sensor to participate in backbone thereby the energy of sensors drains faster than the sensors in ABTC. Compared to SPAN in ABTC relay node takes major share in data forwarding process hence sensors holds sufficient energy to live longer.

Fig 5, 6, and 7 relates to network lifetime comparison. In all three graphs network lifetime with PCSPAN and ABTC is much better than SPAN. Fig 5 and 6 clearly indicate that ABTC adaptively and efficiently make use of relay nodes in enhancing network lifetime.

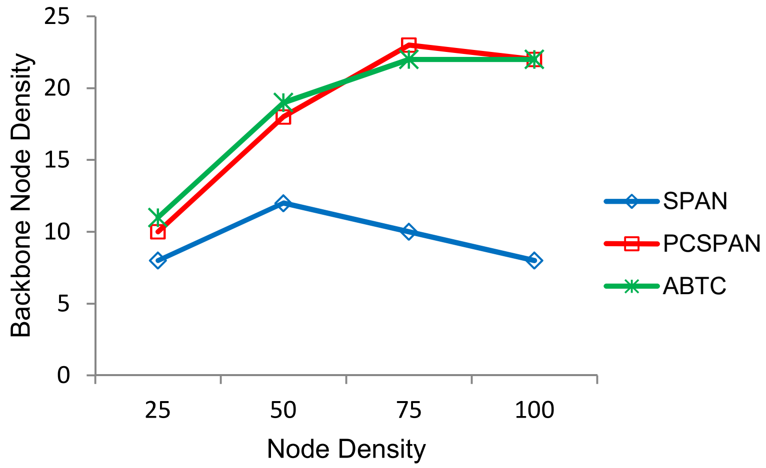

Fig 1. Backbone Nodes as a function of Node density

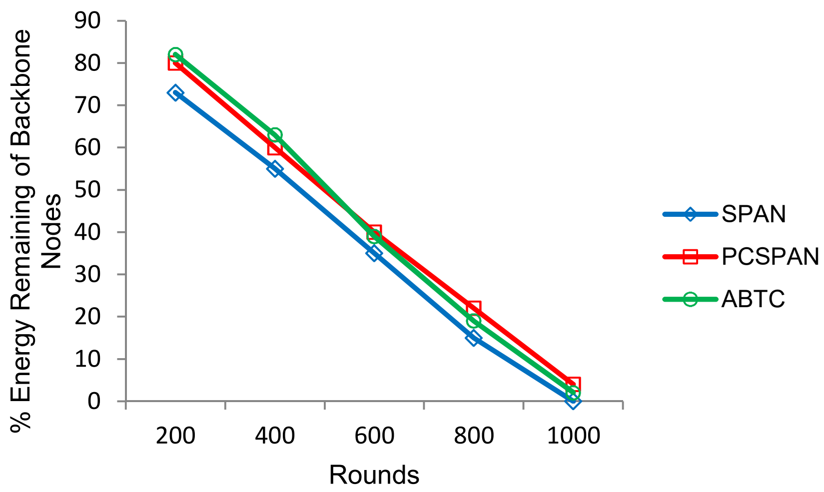

Fig 2 Backbone Node energy remaining as a function of Time

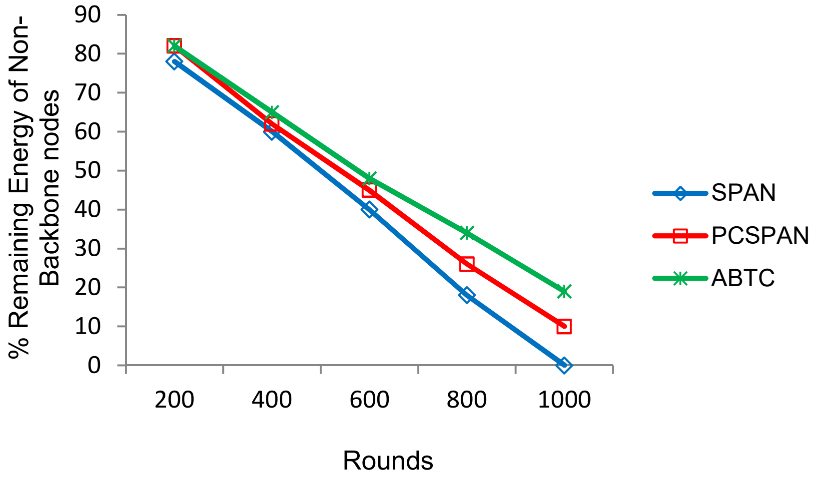

Fig 3 Non-Backbone Node energy remaining a function of time

It is apparent that all schemes experience linear energy increase with the increase in network size. PCSPAN'^s and ABTC'^s ability to save energy depends on node density, since the fraction of sleeping nodes depends on the number of nodes per radio coverage area.

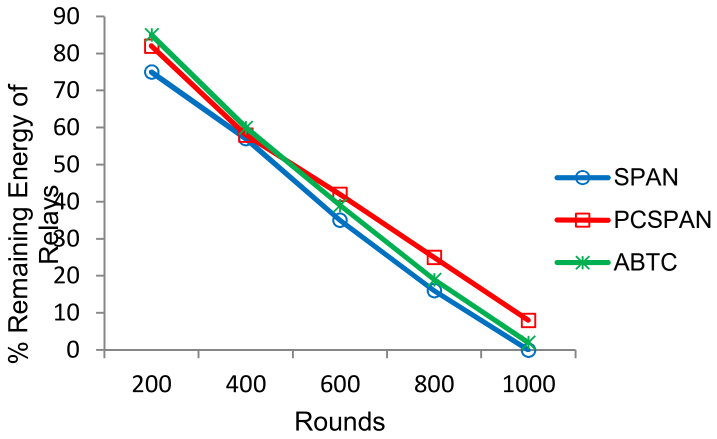

Fig 4 Relay Node energy remaining as a function of Time

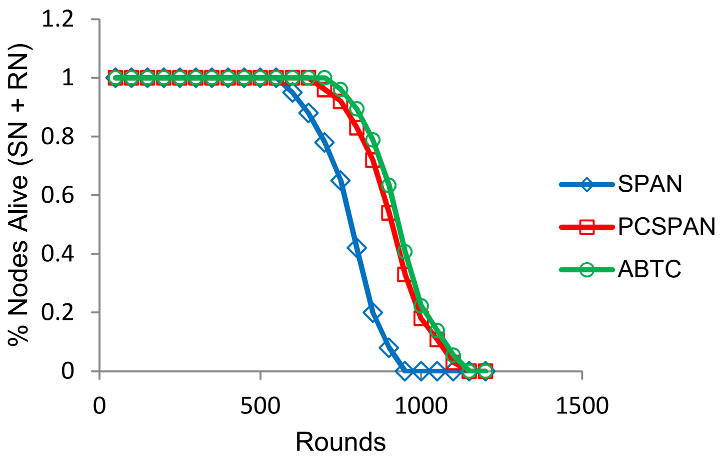

Fig 5 Number of Total nodes alive as a function of Time

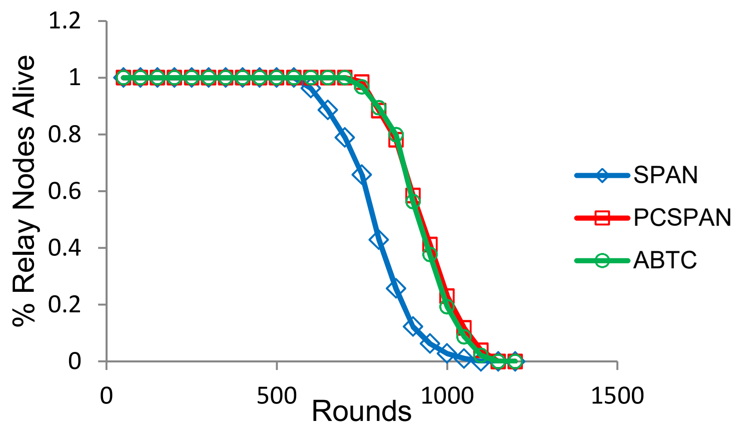

Fig 6 Number of Relay nodes alive as a function of Time

We observe that PCSPAN and ABTC provide a significant amount of savings beyond SPAN. It is obvious that in case of SPAN it has the worst energy consumption as it keeps nodes on with its maximum transmitting power.

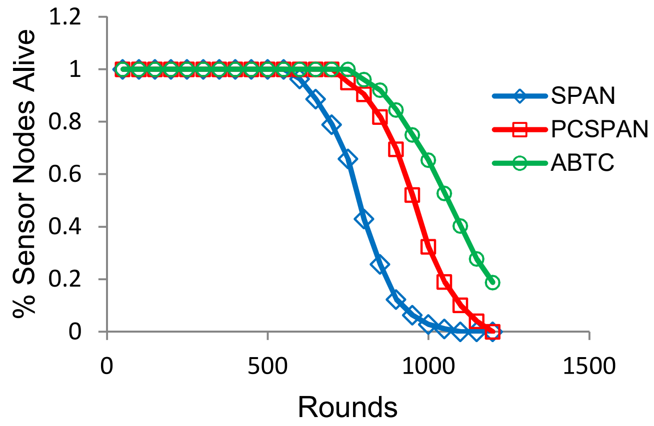

Fig 7 Number of Sensor nodes alive as a function of Time

As shown in Fig 8 the node density has increasing effect on network lifetime. Initially lower density gives lowered network lifetime. Fig 9 shows the normalized average throughput with respect to the number of nodes in the network. It is evident that PCSPAN and ABTC algorithms give almost similar throughput compared to SPAN algorithm.

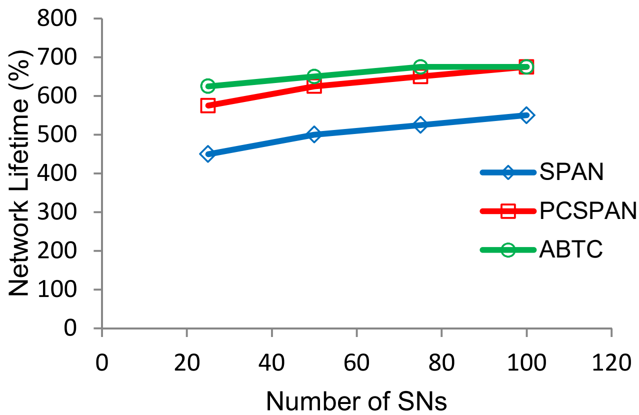

Fig 8 Network Lifetime vs. Number of Nodes

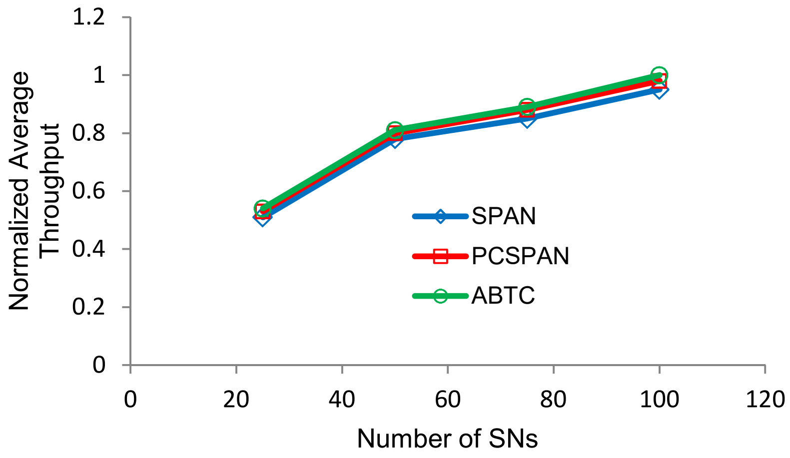

Fig 9 Network Throughput vs. No. of Nodes

5. Conclusions

In this paper, we proposed distributed topology control PCSPAN and ABTC algorithms, for wireless sensor networks that minimize energy consumption while proving fault tolerance and connectivity of the network. In PCSPAN and ABTC the nodes adjust their transmitting power to connect backbone nodes and all nodes in the network periodically rotates their roles. ABTC adaptively elects a subset of only relay nodes after threshold value of their energy. Backbone nodes form the routing backbone and forward data packets towards the sink, while redundant nodes transit to the power-saving mode. Simulation results show that PCSPAN and ABTC not only preserves connectivity but also provides significant energy saving and prolong sensors lifetime. Both PCSPAN and ABTC outperformed SPAN in terms of energy usage of sensor nodes. ABTC make maximum use of redundant relay nodes to maximize sensor nodes lifetime.

References

[1] I. Stojmenovic, *Handbook of Sensor Networks: Algorithms and Architectures*, John Wiley and Sons, 2005.

[2] V. Rodoplu and T. H. Meng, "Minimum energy mobile wireless networks", *IEEE Journal on Selected Areas in Communications*, 1999., Vol. 17, No. 8, pp. 1333–1344

[3] X. Y. Li and P. J. Wan., "Minimum energy mobile wireless networks revisited", in *Proceedings of the IEEE International Conference on Communications* (*ICC 2001*), Helsinki, Finland, 2001.

[4] S. Narayanaswamy, V. Kawadia, R. S. Sreenivas, and P. R. Kumar, "Power control in ad-hoc networks: Theory, architecture, algorithm and implementation of the COMPOW protocol", in *Proceedings of European Wireless Conference (EW 2002)*, Florence, Italy, 2002, pp. 156–162.

[5] Wattenhofer, R. and A. Zollinger, "XTC: A Practical Topology Control Algorithm for Ad-Hoc Networks", in *Proceedings of the 18th International Parallel and Distributed Processing Symposium (IPDPS'04)*, 2004.

[6] Wattenhofer, R., L. Li, "Distributed Topology Control for Power Efficient Operation in Multihop Wireless Ad Hoc Networks", in *Proceedings of the Twentieth Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM'01)*, 2001.

[7] C. E. Jones, K. M. Sivalingam, P. Agrawal, and J. C. Chen, "A survey of energy efficient network protocols for wireless networks", *Wireless Networks*, 2001, Vol. 7, No. 4, pp. 343–358.

[8] X. Ya, J. Heidemann, and D. Estrin, "Geography-informed energy conservation for ad hoc routing", in *Proceedings of the 7th International Conference Mobile Computing & Networking (MobiCom 2001)*, Rome, Italy, 2001, pp. 70–84.

[9] C. Schurgers, V. Tsiatsis, and M. B. Srivastava, "STEM- topology management for energy efficient sensor networks", in *Proceedings of IEEE Aerospace Conference*, Montana, USA, 2002, Vol. 3, pp. 3–1099.

[10] A. Cerpa and D. Estrin, "Ascent: Adaptive self-configuring sensor networks topologies", *IEEE Transactions on Mobile Computing*, 2004, Vol. 3, No. 3, pp. 272–285.

[11] J. Blum, M. Ding, A. Thaeler, and X. Cheng, "Connected dominating set in sensor networks and MANETs", *Handbook of Combinatorial Optimization*, 2004, pp. 329–369.

[12] Z. Yuanyuan, X. Jia, and H. Yanxiang, "Energy efficient distributed connected dominating sets construction in wireless sensor networks", in *Proceedings of the International Conference on Wireless Communications and Mobile Computing (IWCMC- 2006)*, Vancouver, British Columbia, Canada, 2006, pp. 792–802.

[13] J. Wu, M. Gao, and I. Stojmenovic, "On calculating power-aware connected dominating sets for efficient routing in ad hoc wireless networks", in *Proceedings of the 30th International Workshops on Parallel Processing (ICPP 2001)*, Valencia, Spain, 2001, pp. 346–356.

[14] B. Chen, K. Jamieson, H. Balakrishnan, and R. Morris, "Span: An energy-efficient coordination algorithm for topology maintenance in ad hoc wireless networks", *Wireless Networks*, 2002, Vol.8, No. 5, pp. 481–494.

[15] Vikas Kawadia and P.R. Kuma, " Power control and clustering in ad hoc networks", in *Proceedings of the IEEE Conference on Computer Communications (INFOCOM 2003)* San Francisco, USA, 2003; Vol. 1, pp. 459–469.

[16] Heinzelman, W., A. Chandrakasan, and H. Balakrishnan. *Energy Efficient Communication Protocol for Wireless Microsensor Netwroks (LEACH)*. in *Proceedings of 33rd Hawaii International Conference Systems Science*. 2004.