MINIMUM POWER CONFIGURATION (MPC) APPROACH FOR OPTIMIZING POWER CONSUMPTION IN WIRELESS SENSOR NETWORKS

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ABSTRACT

Conserving energy resource and prolonging system lifetime is an important challenge in Wireless Sensor Networks. Maintaining coverage and connectivity also becomes an important requirement in Wireless Sensor Networks so that the network can guarantee the quality of service. This paper addresses the problem of minimizing power consumption in each sensor node locally while maintaining the two factors coverage and connectivity, there by extending the life time of the network. Scheduling and routing are the commonly used methods for energy conservation in wireless sensor networks. Scheduling of nodes is done using Geographic Adaptive Fidelity (GAF) which has a great role to play in increasing the lifetime of the network while preserving connectivity and coverage. Further optimization of power is done by using power efficient routing protocols: Minimum Power Configuration Protocol (MPCP) and Minimum Active Subnet Protocol (MASP). These two protocols together form the base for Minimum Power Configuration (MPC) approach. Simulation is done using ns-2. Simulation results indicate that up to 80% of the power can be saved.

Keywords : Coverage, Connectivity ,MPC, MASP, MPCP, WSN, Power , NS – 2

1. INTRODUCTION

A wireless sensor network (WSN) consists of autonomous devices called sensors that cooperatively monitor physical or environmental conditions. One of the main advantages of wireless sensor networks is their ability to bridge the gap between the physical and logical worlds, by gathering certain useful information from the physical world and communicating that information to more powerful logical devices that can process it. If the ability of the WSN is suitably utilized, WSNs can reduce or eliminate the need for human involvement in information gathering in certain civilian and military applications. (Chang,J.H., and Tassillas,L. 2004;Dong,Q. *et al.*, 2005; Ergen, S. C., and Vavaiya,P. 2006; Gerhard P. Hancke, and Jaco Leuschner, C. 2007; Xing,G. *et al.,* 2005)

The basic structure of a wireless sensor network is shown in Figure 1 A sensor network consists of a large number of sensor nodes deployed in a sensor field. Each sensor node detects the occurrence of any event within its sensing range. Sensor nodes are able to carry out simple computations locally and transmit only the required and partially processed data to the sink node either directly or via intermediate sensor nodes. The user can access the information at the sink through Internet or satellite and can perform any additional computation. This enables a wide range of applications in areas such as health and military.

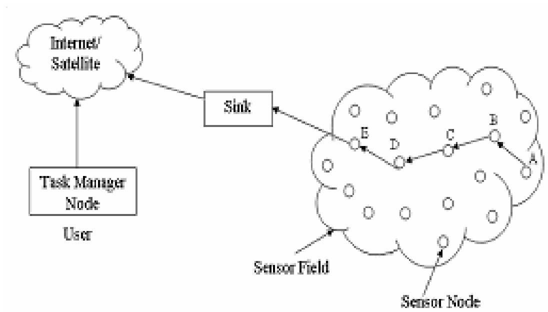

Figure 1: Structure of Wireless Sensor Networks

However these wireless sensors have several constraints such as restricted sensing and communication range as well as limited battery capacity. These limitations bring issues such as coverage, connectivity, network lifetime, scheduling and data aggregation. In order to prolong the WSN lifetime, energy conservation measures must be taken, scheduling and data aggregation are among the commonly used methods. Scheduling conserves energy by turning off the sensor whenever possible, while data aggregation try to conserve energy by reducing the energy used in data transmission. Connectivity and coverage problems are caused by the limited communication and sensing range.

The rest of this paper is organized as follows, Section 2 will discuss on the definition of the problem. Section 3 surveys the related work in literature. Section 4 describes about the scheduling of nodes using GAF. Section 5 introduces the two-optimization protocols MPCP and MASP. Section 6 presents the simulation results. Section 7 concludes this paper. Future direction is described in Section 8.

2. PROBLEM DEFINITION

Many wireless sensor networks must aggressively conserve energy in order to operate for long periods without wired power sources, the resources available to individual nodes are severely limited because of cost and size considerations.

The power in a sensor node is consumed in three processes: sensing, data communication with other nodes and local data processing. Sensing power varies with applications or the complexity of detecting a certain event. A wireless sensor network needs to reduce the energy consumed in each of the radio's power states (i.e., transmission, reception and idle) in order to minimize its energy consumption. Because of the energy constraints of sensor devices, such systems necessitate an energy-aware design to ensure the longevity of WSN. A key problem is to minimize the number of nodes that remain active, while still achieving acceptable quality of service for applications. Proper routing and scheduling algorithms must be chosen to considerably reduce the network's total power consumption so that power can be efficiently conserved.

3. RELATED WORKS

Minimizing power consumption and extending the system lifetime is an important issue for WSN. (Dong, Q. 2005) There are several ways to achieve these.

Topology control protocols (John Heidemann *et al.,* 2003) aim to reduce the overall transmission power of a network by adjusting the transmission range at each node, while still preserving necessary network properties.

Power-aware routing protocols (Chipara, O. *et al.,* 2006; Doshi,S. *et al.,* 2002; Doshi,S. *et al.,* 2002; Sankar,A. and Liu,Z. 2004) choose appropriate transmission ranges and routes to conserve energy used for multihop packet transmission. According to these protocols, nodes spend their time in sense state which consumes as much power as reception. The nodes never goes to off state. So, most of the power is spent while sensing, and in order to decrease the power consumption the node should be turned off.

Sleep management (Xing,G. *et al.,* 2005; Xing,G. *et al.,* 2005) has been proposed to reduce the energy wasted in an idle state by turning off radios when not in use. There are two basic approaches, namely, scheduling based approach and backbone-based sleep management.

A protocol that uses *Markov model* (Malik Magdon-Ismail *et al.,* 2007) has a probabilistic scheme in which each sensor node makes an independent decision to be in *transmit, receive/sense* or *off* state. The optimal parameters governing the probabilistic transitions of a sensor node are determined so as to minimize power consumption. A randomized algorithm is run locally at a sensor node to govern its operation. Each node conserves energy by asynchronously and probabilistically turning itself off. Each node is a three state Markov chain. The three states are the *off*, O, the *sense/receive*, S, and the *transmit*, T, states.

To overcome the shortcomings of the above protocols, a novel approach called *Minimum Power Configuration (MPC)* is proposed. None of the aforementioned approaches optimize energy consumption in all energy states but the proposed approach minimizes the aggregate energy consumption in all power states. It can conserve more energy than existing power routing and topology control protocols. Furthermore, it can flexibly adapt to different network workloads.

4. SCHEDULING OF NODES USING GEOGRAPHIC ADAPTIVE FIDELITY (GAF)

Energy consumption can be reduced by scheduling the nodes properly. Geographic Adaptive Fidelity (GAF) (John Heidemann *et al.*, 2003; Xing,G. *et al.*, 2005) is used for scheduling the nodes. It identifies the redundant nodes by their physical location and a conservative estimate of radio range. Energy can be conserved by identifying the redundant nodes and turning their radios off. Nodes alternate having their radios on in order to accomplish load balancing.

4.1 Determining Node Equivalence

GAF uses location information of sensor node to determine node equivalence. GAF divides the whole area where nodes are distributed into small "virtual grids". A virtual grid is defined as follows: for two adjacent virtual grids A and B, all nodes in A can communicate with all nodes in B and vice versa. Thus, in each grid all nodes are equivalent for routing.

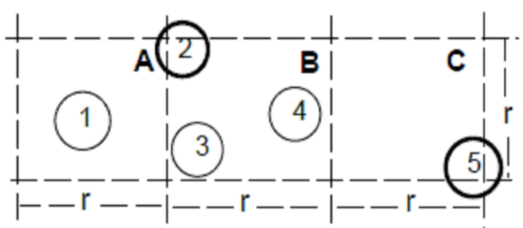

Figure 2: Geographic Adaptive Fidelity Virtual Grid

In the Figure 2, there are three virtual grids, A, B and C. Node 1 which is in grid A can reach any of nodes 2, 3 or 4 in grid B and nodes 2, 3, and 4 can all reach node 5 in grid C. Therefore nodes 2, 3, and 4 are equivalent and two of them can go to sleep.

The size of the virtual grid is based on the nominal radio range R, the farthest possible distance between two nodes in adjacent grids (since they must be able to communicate). If a virtual grid is a square with r units on a side, then the longest possible distance between nodes in adjacent grids is the length of the long diagonal connecting the two grids. Therefore, we get r from Eq. (2)

$$r^2 + (2r)^2 <= R^2 \quad (1)$$

and thus, $$r <= R / \sqrt{5} \quad (2)$$

4.2 GAF State Transitions

In GAF, nodes are in one of three states: *sleeping*, *discovery*, *active*. A state transition diagram is shown in Figure 3. Initially a node starts out in the *discovery* state with its radio turned on and exchanges discovery messages with its neighbors in order to find other nodes within the same grid. The discovery message is a tuple of node ID, grid ID, estimated node active time (*enat*), and node state.

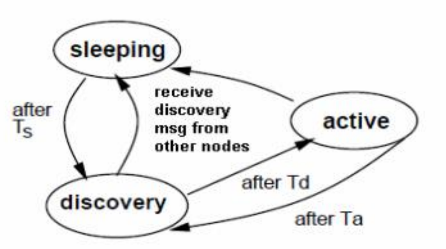

Figure 3: State transitions in GAF

Each node spends t_d seconds in discovery state to determine whether it should be active or not. If it determines that it should be active in its grid, then it moves to the *active* state. The node remains active for t_a seconds and then returns to *discovery* state. A node in *discovery* or *active* states can change state to *sleeping* when it can determine some other equivalent node will handle routing. Transitioning to the *sleeping* state, causes a node to cancel all pending timers and power down its radio. A node in the *sleeping* state wakes up after an application-dependent sleep time t_s and transitions back to *discovery* state.

5. MINIMUM POWER CONFIGURATION (MPC) APPROACH

The two protocols used are Minimum Power Configuration Protocol (MPCP) and Minimum Active Subnet Protocol (MASP).

5.1 Minimum Power Configuration Protocol

MPCP finds power-efficient routes for the communicating nodes in a network based on the distributed implementation of the Incremental Shortest Path Tree Heuristic (ISTH) algorithm. Destination sequenced distance vector routing (DSDV) protocol is adopted as the implementation framework. A node in DSDV advertises its current routing cost to the sink by broadcasting *route update* messages. A node sets that neighbor which has minimum cost for the sink as its parent and rebroadcasts its updated cost if necessary. DSDV can avoid the formation of routing loops by using sink-based sequence numbers for route updates. The routing cost of a node in DSDV is its hop count to the sink. The routing cost of a node in MPCP, however, depends on the operational state of the node (active or power saving), as well as the data rates of those flows that travel through the node.

Node States and Routing Table

Each node operates in either *active* or *power-saving* mode. A node in power-saving mode remains asleep most of the time and only periodically wakes up. This simple sleep schedule is based on GAF. Initially, all nodes operate in power-saving mode. When a source node starts sending data to the sink, a power-efficient routing path from source to sink is found by the distributed ISTH algorithm. All nodes on the routing path are activated to relay data from the source to the sink. Similarly, an active node switches to power-saving mode if all the data flows traveling through it disappear. Each node in the network maintains a routing table that contains the routing entries and status of neighbors. An entry in the routing table of node includes the following fields: <*ri*, *next hop*, *cost*, *seq*>, where *ri* is the data rate of source *si*, *next hop* is the neighbor node with the minimum cost for the sink, *cost* is the cost of node for the sink through *next hop*, and *seq* is a sequence number originated by the sink.

Route Updates

The routing cost from a node to its neighbors in MPCP depends on data rate and the change of the node's state (active or power saving). As a result, a new round of route updates will be triggered by any of the following events: (1) a link is broken; (2) the data rate of an existing flow changes; or (3) a data flow is started or completed.

Shortest Path Tree Heuristic (STH)

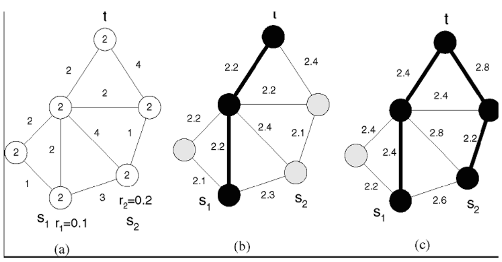

Figure 4: Shortest path based on STH

STH is the shortest path tree heuristic which is used to find the shortest path from the source to the sink in a WSN. Figure 4 shows the shortest paths from the sources S_1 and S_2 to the sink t. It shows two iterations of STH. In each iteration, the shortest path from *si* to *t* is found. The output of STH is the graph composed of all shortest paths found. Two paths are always disjoint in STH. The shortest path from a source to the sink is not affected by whether shortest paths are already established for other sources.

Incremental Shortest Path Tree Heuristic (ISTH)

ISTH is an enhancement of STH. ISTH finds that path from each source to the sink with the minimal cost. The pseudocode of ISTH is depicted below.

ALGORITHM

Input : G(V,E), source set S, sink t and traffic demands I

Output : G'(V',E')

Method :

1) Initialize G'(V',E') to be empty
2) W = S
3) while W ≠ Φ
   a) Find S_i ε W that has the shortest distance in G(V,E) to t with edge weight $h_i(u,v)$.
   b) Add the shortest path from S_i to t in G'.
   c) Label all the nodes on the path as *active*.
   d) W = W - S_i
4) end

During its execution, the algorithm maintains a subgraph *G'* that contains those paths from sources to sink that have been visited so far. In each iteration, ISTH finds the remaining source node that is closest to, but not connected to, the sink in *G'* . It then adds the shortest path from that node to the sink into *G'*. Figure 5 shows the second iteration of an example of ISTH in which the shortest path from S_1 to t has been found. The first iteration of the example is the same as that of STH, shown in Figure 4. Figure 5 shows the shortest path from the source S_2 to the sink t which shares an edge with the existing shortest path from S_1 to t. The total weight on the shortest path from S_1 to t in Figure 5 is smaller than that shown in Figure 4, since the nodal cost *z* is not included. Consequently, different from the case of STH where two paths must always be disjoint (as shown in Figure 4), the shortest path from S_2 to t shares an edge with the existing path. The total number of nodes used is therefore decreased, resulting in less idle energy consumption.

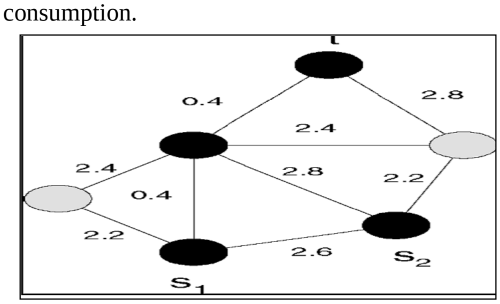

Figure 5: Shortest path based on ISTH

When ISTH finds the shortest path from source *si* to the sink, the edge cost is defined by the following function:

$$h_i(u,v) = \begin{cases} r_i \cdot C_{u,v} & \text{u is active} \\ r_i \cdot C_{u,v} + z & \text{otherwise} \end{cases}$$

where,

$$C_{u,v} = P_{tx}(u,v) + P_{rx} - 2 P_{id} \quad (3)$$

$$z = P_{id} \quad (4)$$

The power consumption of any active node u, P(u), can be computed as the sum of power consumed by transmitting, receiving and idle state

$$P(u) = \left(1 - 2 \sum_{(u,v)\in f(s_i,t_j)} r_{i,j}\right) \cdot P_{id} + \sum_{(u,v)\in f(s_i,t_j)} r_{i,j} \cdot (P_{tx}(u,v) + P_{rx})$$

$$= P_{id} + \sum_{(u,v)\in f(s_i,t_j)} r_{i,j} \cdot (P_{tx}(u,v) + P_{rx} - 2P_{id}),$$

at node u:

(5)

where(u,v) Є f (s_i,t_j) represents that there exists a node v such that edge (u,v) is on the path f(s_i,t_j)

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5.2 Minimum Active Subnet Protocol (MASP)

The MASP is also based on DSDV and has a similar design to MPCP, as both protocols are based on the shortest-path algorithm. The major difference between MPCP and MASP is given below.

In MASP, a node in power-saving mode incurs a routing cost of *Pi* (idle power). Once a data flow travels through a node, it becomes active and its routing cost reduces to zero. In other words, routing among active nodes is free. As a result, when a new source arrives, finding the shortest path from that node to the sink is equivalent to finding the shortest path to any active node. Unlike MPCP, the routing cost of a node in MASP does not depend on data rates. This independence reduces the storage overhead of the routing table at each node, as well as the network bandwidth used by route updates.

Each entry of a routing table in MASP contains *<next hop, cost, seq>*. The route updates of MASP can be triggered by either a broken link, or the start or completion of a data flow. Route updates triggered by link failures are similar to DSDV, while the updates triggered by sources are similar to MPCP. Moreover, MASP is expected to generate fewer routing updates than MPCP because the change in data rates does not affect the routing cost of MASP. In other words, MASP ignores data rates because it only minimizes idle energy.

6. PERFORMANCE ANALYSIS

Performance analysis can be done based on percentage of power conserved (i.e., based on total power consumption per node with the increase in the number of nodes for the two protocols used).

6.1 Results For MPC

This section includes determination and comparison of percentage of energy conserved in MPC approach and the Markov model. Determination is based on time spent by each node in the sense, transmit, off states (Xing,G. *et al.*, 2007) . The power consumption of each node in their corresponding state is calculated using the formula,

$$\text{Power} = n^*\pi r^2 pT \quad (6)$$

Then the total power consumption is calculated using the Eq. (5)

TABLE 1 : Comparison of Markov With MPCP and MASP

Total no. of nodes	Total Power (mW)		
	Markov	MPCP	MASP
23	8.768	2.8	3.11
115	43.5	14	15.55
230	87	28	31.1
345	130.5	42	46.65
460	174	56	62.2
575	217.5	70	77.75
690	261	84	93.3
805	304.5	98	108.85
920	348	112	124.4
1035	391.5	126	139.95
1150	435	140	155.5

Table 1 shows the comparison of MPCP and MASP with Markov model. Figure 6 shows the effectiveness of MPCP and MASP compared with markov model where node is scheduled to sense transmit and off states.

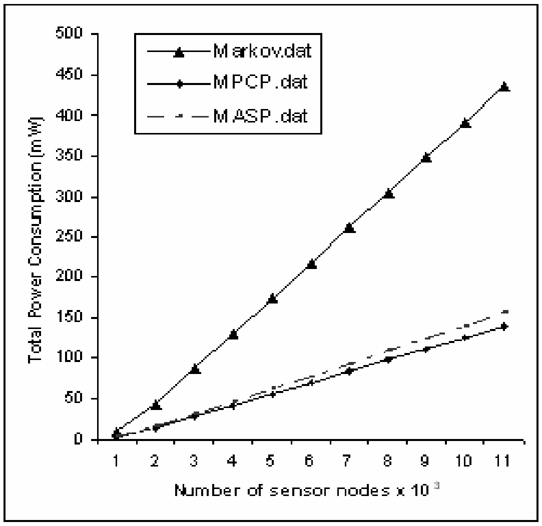

Figure 6: Comparison of Markov model with MPCP and MASP

6.2 Comparison of MPCP with MASP When the Workload Is High

TABLE 2 : Comparison of MPCP with MASP when the workload is high.

Total no. of nodes	Total Power (mW)	
	MPCP	**MASP**
23	5.03	3.9
115	27	19.5
230	55	39
345	74	58.5
460	100	78
575	128	97.5
690	152	117
805	178	136.5
920	200	156
1035	226	175.5
1150	251	195

Here, total power consumption of MPCP and MASP are compared when there is high network workload. Table 2 shows this comparison. Figure 7 shows the energy consumption of MPCP and MASP.MASP consumes similar energy as MPCP, even though MASP only minimizes the number of active nodes and does not directly optimize the overall energy consumption, as does MACP when the workload is high.

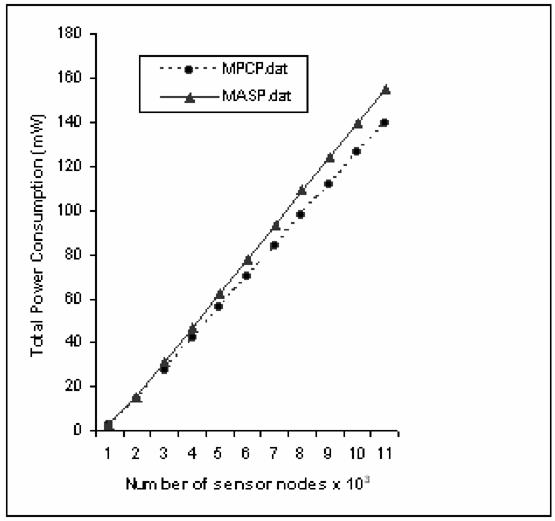

Figure 7: Comparison of MPCP with MASP when the workload is high

6.3 Comparison of MPCP with MASP When the Workload is Low

TABLE 3 : Comparison of MPCP with MASP when the workload is low

Total no. of nodes	Total Power (mW)	
	MPCP	**MASP**
23	2.8	3.11
115	14	15.55
230	28	31.1
345	42	46.65
460	56	62.2
575	70	77.75
690	84	93.3
805	98	108.85
920	112	124.4
1035	126	139.95
1150	140	155.5

Here, total power consumption of MPCP and MASP are compared when there is low network workload. Table 3 shows this comparison. When the workload is low, the performance of MASP improves significantly which is shown in Figure 8.

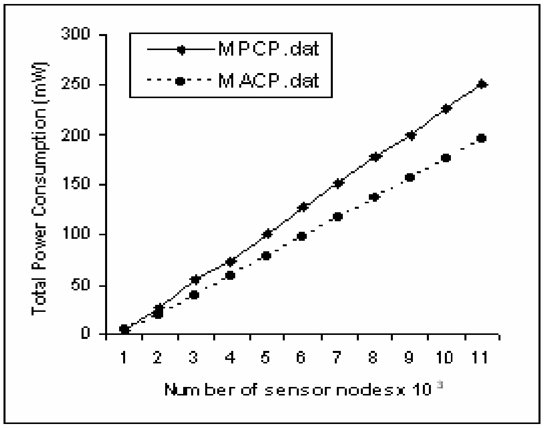

Figure 8: Comparison of MPCP with MASP when the workload is Low

From the above analysis it is observed that MPCP is more power efficient than MASP and Markov model when the network workload is high. MASP is more efficient than MPCP when the network workload is low.

7. CONCLUSION

Preserving coverage and connectivity in a sensor network has been a problem that has been addressed in the past. Moreover, sensors are envisioned to be small and light – weighted devices and it may not be desirable to equip them with additions like huge rechargeable batteries. This work considers a scheme that ensures coverage and connectivity in a wireless sensor network, without the dependence on external infrastructure or complex hardware. In addition, taking advantage of the redundancy of nodes, the scheme can offer energy savings by turning off nodes that may not be required to maintain coverage.

GAF was used for scheduling and for further optimization MPC approach was used for routing of packets in an energy efficient manner. Each sensor node conserves energy by switching between Sense/Receive or off states. When it senses an event in its proximity, it enters the transmit state to transmit the event information.

Results show that the power saved in each node outperforms the power saved in any other previously known protocols. 80% of the power can be saved and also proper coverage and connectivity can be maintained. Life time of the sensor nodes can be increased (even more on increase in number of nodes) which will be of great use for the sensor nodes deployed in deserts, seas, mountains where frequent replace or recharge of the sensor nodes are essential.

8. FUTURE ENHANCEMENTS

The future work will involve heterogeneity among the events that are being sensed. The present homogeneous sensor nodes usually detect only one kind of event. For example, increase or decrease in temperature in a particular area. In the case of heterogeneous sensor nodes, the same node can detect various types of events, be it increase or decrease in temperature or pressure or other parameters.

The MPC approach can be further optimized if there exists an ideal sleep management scheme that could schedule an active node to sleep whenever it becomes idle and wake up whenever data arrives. The protocols focus on many-to-one workloads but MPC can be extended to more general workload models with multiple sinks.

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