Dynamic Distributed Power Adaption for Data Aggregation in Ubiquitous Sensor Networks

S. Madhavi

Abstract

Data Aggregation Scheduling in Ubiquitous sensor networks is a major research interest for many researchers with the objective of minimizing the energy consumption. Very little research is carried to schedule the nodes in ubiquitous sensor networks to reduce energy consumption, maximize the throughput, for effective prolonged network lifetime, scalability, and load balancing. Each ubiquitous node in USN should forward data to the base station. In Data Aggregation methods each node need not directly forward data to the base station instead it may forward data to a special node called head node which in turn forwards data to the base station.

In this paper we proposed a new network model for the USN which is power control and collision interference free model. We also proposed an energy-efficient distributed data aggregation scheduling protocol, called DDPA (Dynamic Distributed Power Adaptive), which is adaptive to rate and power. Using the proposed optimal node degree algorithm, we obtained a full reachability network with 99.9% of energy savings even at the denser network conditions.

Keywords: USN, SINR, WSN

1. Introduction

The two important objectives in ubiquitous sensor networks are to maintain network reachability and optimizing the network lifetime. In full connectivity network the percentage of direct connections between arbitrary node pairs are more. But if the transmission ranges are more, the powers are more and the signal interferences are also more. And finally the energy-saving will be reduced. In a full reachability network any node is reachable through either indirect or direct delivery. In [1-7] a study is done on finding the optimal transmission power of a node. Earlier several centralized and distributed scheduling algorithms are proposed for data aggregation in USN [2-12]. In [4] we presented a novel distributed data aggregation scheduling protocol using a power control collision-interference-free model, which is adaptive to the rate and power control. Since the ubiquitous nodes changes its state dynamically, finding a solution to the above mentioned tasks is very difficult. In this paper we proposed a new energy-efficient protocol, DDPA (Dynamic Distributed Power Adaption) in ubiquitous sensor networks.
Adaptive) protocol for ubiquitous sensor networks using an optimal node degree algorithm. Our primary goals:

1. To design a network model for the USN and select optimal degree for the nodes.
2. Prolong network lifetime by distributing energy consumption,

2. Proposed dynamic distributed power adaptive ubiquitous sensor network model.

Consider a ubiquitous sensor network with \( n \) arbitrarily distributed ubiquitous nodes. Let a directed graph \( G = (V, E) \) denote a ubiquitous network where \( V = \{v_0, v_1, v_{n-1}\} \) and \( E = \{e_0, e_1, e_{n-1}\} \). \( v_i \) denotes ubiquitous node \( i \), and \( e_i \) denotes the edge between two ubiquitous nodes. Transmission power of each node is \( \text{transmission range} / \text{Max}_\text{tx} \) in direct communication. Each node in the proposed dynamic distributed power adaptive ubiquitous sensor network model is characterized by a variable vector

\[
\begin{align*}
\text{Nodetype} & \quad \text{nodeid} \\
\text{Info} & \quad \text{nodeinfo} \\
\text{NodeState} & \quad \text{state} \\
\text{Distance} & \quad \text{NodeDistance}[\text{node}] \\
\text{NodeList} & \quad \text{Neighbors, ConcurrentNodes} \\
\text{CRange} & \quad \text{crMax} \\
\text{IRange} & \quad \text{interference range, Max Irange} \\
\text{Power} & \quad \text{MaxTransPower, Power req, MaxPower req, MinPower req, RemPower} \\
\text{Distance} & \quad \text{distance from base station} \\
\text{Boolean} & \quad \text{DonotSelect}
\end{align*}
\]

Each node exists in two states called active and inactive state. The nodes that are willing to transmit are said to be in active state and are termed as active nodes, while the remaining nodes are said to be in inactive state and termed as inactive nodes. The state of a node changes frequently.

Now we model a ubiquitous sensor network as \( \text{USN}(V, \text{crmax}, \rho) \) where

1. \( V \) is the set of \( n \) ubiquitous nodes each characterized with the 8-variable vector
2. \( \text{crmax} \) is the maximum communication range
3. \( \rho \geq 1 \) is the interference factor.
4. Each node can send and receive data in the maximum range \( \text{crmax} \).
5. The transmission power of a node is always $\leq cr_{max}$.

6. Let $V_j$ denote a node that can transmit concurrently with node $V_i$ as the head. For a successful transmission the SINR perceived at the receiver should be greater than or equal to $\beta$ i.e.

$$\frac{P_i^{act}}{N_0 + \sum_{j=1}^{n} \frac{P_j^{act}}{d_{ij}^{conc}}} \geq \beta$$

Let $P_i$ and $P_j$ denote the transmission powers of $V_i$ and $V_j$ respectively. $d_i$ is the distance between two neighbors and $d_j$ is the distance between a concurrent transmitter and the receiver. $\alpha$ is the path loss ratio, which has a typical value between 2 and 4. $N_0$ is the ambient noise. $\beta$ is the threshold for a successful transmission.

7. Every node has the flexibility to tune itself to an optimal power.

8. An optimal schedule is a schedule with
   a. Minimum number of timeslots(frame length)
   b. Maximum number of concurrent transmissions per each timeslot.

9. In this paper we adjusted the transmission range according to a optimal node degree and there is no isolated node.

10. Variable power levels are allowed for communication.

11. Let $M$ is the number of nodes within the cluster range.

12. In [13-19] the average minimum reachability power (AMRP) is defined as the mean of the minimum power levels required by all $M$ nodes within the cluster range to reach a node $u$ and this is used in the selection of a head node

### 3. Distributed Algorithm.

In this work, we build an optimal ubiquitous sensor network which is energy-efficient by using the proposed energy-efficient protocol, DDPA (Dynamic Distributed Power Adaptive) by adjusting the transmission range according to various node deployment densities and optimal node degree algorithm. It has four primary goals:

1. we propose a novel method for Optimal node degree algorithm for determining optimal number of head nodes in USN
2. Construct a set of schedules from which an optimal schedule is founded and it includes
   a. When head nodes should transmit,
b. How the head nodes gathers data from its neighbors.

The proposed method prolongs network lifetime by distributing energy consumption. Generally time is slotted to intervals where \( L \) denotes the length of the interval. All noninterfearing nodes \( u_i \) are scheduled to send their aggregated data to any of their neighbors, \( v_i \). The power \( p_i \) chosen at \( v_i \) cannot exceed the value of the MaxPower. Formally, at each timeslot \( t \), we have an assignment vector \( \mathbb{A} \).

\[
\text{AssignVect}_k = ((u_1, v_1, p_1), ..., (u_k, v_k, p_k)).
\]

1. Optimal node degree algorithm.

If a node \( X \) is not within the current transmission range of \( Y \) then the node \( X \) cannot be the neighbor of a node \( Y \) and it is deselected for considering to increase its degree by node \( Y \). As long as the remaining power of \( Y \) is between the minimum and maximum power requirements and if power efficiency requirements are satisfied then the node density can be adjusted accordingly. All nodes are grouped into several levels like \( L_1 \), \( L_2 \), \( L_3 \) based on the estimation of its power requirements and reachability to a node \( Y \). Using the NodeSelect algorithm node \( Y \) can consider any of the nodes in the network as its neighbor.

Algorithm 1 Optimal \(_\text{Node}\_\text{Degree}\) (ConcurrentNodes, \( UV \), neighbors \( [A],[A] \))

2. Large = FindLargest\_Distance\_node\_from\( (A) \)
3. MinPower\_req = Power\[A\][Min\_Dist]
4. MaxPower\_req = Power\[A\][Large]
5. RemPower\[A\] = MaxTransPower\[A\]
6. //if transmission range is less than the reachability then
   If MaxTransPower\[A\] < MinPower\_req then
   DeSelectNode\( (A) \)
   Else
   Repeat until RemPower\[A\] is between MinPower\_req and MaxPower\_req
   //Adjoint node density according to power remaining at node
   \{Neighbors\[A\], ConcurrentNodes, ReqPower\[A\]\} = NodeSelect \((,\text{ConcurrentNodes}, A, \text{ReqPower}[A])\)
   EndRepeat
7. Return Neighbors\[A\], ConcurrentNodes, ReqPower\[A\]
8. End

Algorithm 2 NodeSelect (NodesList ConcurrentNodes , Node \( V \), RemPower\( [V] \)),

//Let \( P_i \) is the power used for transmitting at \( X \) and \( P_j \) is the power required for receiving at node \( V \)

1. For each node \( X \) in USN and !belongsto(ConcurrentNodes) do
Dist=FindDistancebetween(V,X)
Level[V][X]=Dist/Min_Dist
Levelnode[V][Dist/Min_Dist] = X
End For
2. For i = 1 to Large_Dist/Min_Dist do
   //ReBuild the network topology based on the obtained levels and remaining power at the head node
   For each node X in Levelnode[V][i] and RemPower[V] >= Power[V][Large_Dist] do
      //if power efficiency requirements are satisfied
      If RemPower[V] >= Power[V][i*Min_Dist]]
      and \( \frac{P_i}{d_i^a} \geq \beta \)
      and !ConflictNode(X,ConcurrentNodes) then
         Add Neighbors[V] ← X
         Calculate RemPower[V]
         Add ConcurrentNodes ← X
      EndIf
   EndFor
4. Return Neighbors[V] , ConcurrentNodes, ReqPower[V]
5. Stop
Algorithm 3 DeSelectNode(X)
1. X[DonotSelect]=true
2. Return
II. An optimal network ensures optimal transmission ranges leading to energy savings of a node and the full reachability of the network. Otherwise, step I is called to obtain optimal degree for the node. Our distributed algorithm is an iterative process and ends when the complexity of the ConCHeadTree cannot be further decreased. The algorithm is as follows

Algorithm 4.0 PCCIF(UV,N)
UV represents the set of of Ubiquitous nodes
N represents the total number of nodes
Step 1. NeighborsPCCIF_Network = ConstructPCCIF_Network (UV)

//Construct a PCCIF_Network using the Optimal _Node _ Degree with the set of nodes UV

Step 2. USNTree(USN,UV)=Tree_Traversal(PCCIF_Network , UV , N )

//Construct ConCHead Tree from the PCCIF_Network

Step 3. ConCHeadList = Optimal_SHDL (USN,UV)

//Construction of Optimal Schedule contains three phases where we identify a list of ConCHeadnodes, their
neighbors, the schedule for transmission and an optimal schedule.

Step 4. Empty List UV
Step 5. Set UV = ConCHeadList and USN=Sizeof(UV)

//We rebuild a USN with the ConCHead nodes identified and in the new USN, the ConCHead nodes are
the normal nodes.
Step 6. Find complexity of the new USNTree
Step 7. If complexity level is above a threshold then
   Forward_to_Base(ConCHeadList)
   Goto Step 8
Else
   Goto step 1

Step 8. End.

An optimal schedule is constructed with edges from E. The total transmission time T consists of slots \{t0,\ldots,tT-1\} and the total schedule S = \{S0,S1,\ldots,ST−1\}, where St denotes the subset of nodes in V scheduled to transmit in time slot ti.

The optimal schedule satisfies the following conditions.
a. Each active node may be scheduled more than once but must be scheduled at least once
b. A node cannot act as a transmitter and a receiver in the same time slot, in order to avoid the primary
   interference [4].
c. A Head node vi transmits to the Base station only after all its neighbors have been scheduled [6].
d. We use the path-loss radio propagation model [7] to characterize path loss.

\[ P_{\text{recv}} = \frac{P_{\text{trans}}}{d^\alpha} \]

where

- \( P_{\text{recv}} \) and \( P_{\text{trans}} \) are the transmit powers at the receiver and transmitter,
- \( d \) is the distance between the transmitter and the receiver,
- \( \alpha \) is the path loss exponent, ranging from 2 to 4.

The construction of an optimal schedule from the proposed power control collision interference free model is as follows:

Given a USN tree then the procedure Optimal_SHDL(ConCHeadTree) consists of the following phases:

1) Head Selection Phase: Construct one or more ConCHeadTrees and from each ConCHeadTree identify one or more ConCHeadnodes.

2) Aggregation Scheduling Phase: Construct a schedule [5] with the list of active nodes for each ConCHeadnode.

Let \( AV_{ij} \), for \( i,j=1..n \) denote the set of active nodes for each ConCHeadnode. Assign an unique frequency and a timeslot in the schedule for each \( AV_{ij} \). These frequencies are allocated in such a way that there are no interferences among the concurrent transmitters and the SINR constraint is satisfied.

The above two steps are iterative and ends when all the nodes are termed as either as a ConCHeadnodes or a neighbor to the ConCHeadnodes. There exist one or more ConCHeadnodes to forward the aggregated data to the base station and each ConCHeadnode have zero, one or more neighbors from where it gathers the data. Generally a ConCHeadnode is selected based on a criterion that improves the utilization of the hardware resources and maximizes the network throughput. The schedule consists of one or more slots. And at the end of the two phases a set of schedules are identified.

3) Optimal Scheduling Phase: The optimal schedule is constructed from the schedules constructed in the previous phases. An optimal schedule always improves the network capacity and also best utilizes the hardware resources at each ubiquitous node.

Algorithm 5.0 Optimal_SHDL(USN, UV)

Step 1. Let \( N \) denote the number of nodes in USN and UV denote the set of all \( N \) nodes in USN

Step 2 for \( i=1,2,3 \) --- \( N \) do Steps 3 to Steps 6

Step 3. NodeSet=UV
Step 4. Increment s by 1, k=0

Step 5. Repeat until NodeSet=NULL or no new traversal on USN
   • Increment k by 1
   • Empty TempConCList
   • ConcNodesList=FindConcNodes(UVi)
   • For each node P in ConcNodesList do
     • TempConCList= Tree-Traversals(P,i,NodeSet)
     • Add sizeof[TempConCList] to Totalnodes[k]
   • Construct Schedule [s,Slot[k] ] from TempConCList
   • NodeSet = NodeSet - TempConCList
   • TransmittedNode[k]=TempConCList

Step 6. Add ConcNodesList to Schedule[s]

Step 7. If NodeSet != NULL then
   For Each node X in NodeSet do
     D=FindDistance(X,BaseNode)
     If(D<= Min_Dist) then
       Construct Schedule[s,Slot[k],X ]
       Increment k by 1
     Else
       k=RearrangeSlots(Schedule,s,k,X)
   EndFor

Step 8. FinalConcNodeList = Optimal_traversal(Schedule,s)

Step 9. Return FinalConcNodeList

Step 10 End.

Algorithm 6.0. Tree-Traversals(A,i,j,NodeSet)

//neighbors[A] contains 1-hop neighbors list of a node
//Possible_frequency_set. — Contains the frequency with which the node A’s neighbors can transmit
//ActiveNeighbor[X] contains list of neighbors who are transmitting along with X

0.0 Levels[]-Categoriz(NodeSet,DistancetoBaseNode)
1.0 For i =1 to number of levels do
   For each node Q in Levels[i] do
If !(conflictNode(ConcurrentNodes,Q) then
    Add ConcurrentNodes ← Q
EndIf
EndFor
2.0 End for
3.0 For each node A in ConcurrentNodes do
    //Construct a PCCIF_Network using the Minimum _Node _Degree with the set of nodes NodeSet
    \{Neighbors[A], Concurrentnodes,ReqPower[A] \} =
    Minimum_Node_Degree(ConcurrentNodes, NodeSet, neighbors[A], A)
4.0 EndFor
5.0 Return ConcurrentNodes
6.0 End

Algorithm ConflictNode(NodeList ConcurrentNodes,node Y)
1.0 For each node X in ConcurrentNodes do
If ( Y is having Type 1 or Type 2 interferences with any 1-hop neighbors of X ) then
    Return True
2.0 Return False
3.0 End

Algorithm 7.0 Optimal_traversal (Schedule,s)

Step 1. For I in s repeat steps 2 thru
Step 2. //To Maximize total number of concurrent transmissions
    Construct NewSchedule I after Arranging slots in Schedule I in descending order of the total
    number of nodes for each slot.
Step 3. //To Minimize frame length
    Remove a slot consisting of minimum number of nodes from NewSchedule I if all its nodes
    appear in other remaining slots in NewSchedule I
Step 4. EndFor
Step 5 DescSort(NewSchedule,s)
Step
6. OptimalSchedule = NewSchedule[1]
4. Results

In [19] the authors had tested the Transmission Power Optimization with a Minimum Node Degree for Energy-Efficient Wireless Sensor Networks with Full-Reachability. They studied the energy savings and reachability with different node densities like 0.0005 nodes/m², 0.001 nodes/m², 0.005 nodes/m², 0.01 nodes/m². The energy-savings is calculated as pow(transmission range, 2)/pow(maximum range, 2). With the same simulating parameters of the work in [19] we obtained the 99.9% of energy savings, 100% reachability for the node degrees more than 2 using a transmission range between 14 and 20m. These results are remarkable when compared to the one obtained in [19]. In [1] the authors proposed Minimum Data Aggregation Latency (MDAL) for reducing the latency of data aggregation. In the present paper we mixed the reachability, energy efficient issues to find a conflict free schedule that maximizes the throughput of the network. We assumed the same simulation parameters in [1] and the resultant graphs are in Figure 1.0 and Figure 2.0. These results convey that the proposed work outperforms the work proposed in [1].

![Data Aggregation Latency and Number of nodes.](image-url)
In [11] the authors assumed a 1000X1000 square meter rectangular simulating area. The number of nodes in the simulation varied from 2 to 40. They tested with 50 different topologies where each mobile station can tune to its required transmission power.

we obtained the number of time slots from the proposed work as 4, 8, 10, 12, 15, 17 and 18 when N= 10, 15, 20, 25, 30, 35 and 40 respectively. Also in [13] the authors assumed a 200 square area, with 25m of transmission range. The SDA [16], PAS [15], DAS [18], SAS [20] and First-Fit [17] algorithms are executed with different densities and the results for an average of 10 runs are reported. They compared these algorithms performance with WIRES-BSPT [13]. They concluded that WIRESBSPT [13] outperforms all other solutions by 10 to 30%. In this paper we assumed the same simulating parameters and with different data sets. The results are shown in Figure 2.0. These results show that the maximum time slots required by the proposed method is 10, 18, 28, 45 and 65 when ψ = 20, 40, 60, 80 and 100 respectively. Hence our proposed algorithm outperforms the results obtained from Greedy, RTS/CTS, Ranked Schedule, SDA, PAS, DAS, SAS, WIRES-BSPT and First Fit by 30-50%.
5. Conclusion

In this paper work, we proposed a new energy-efficient protocol, DDPA (Dynamic Distributed Power Adaptive) protocol with an Optimal node degree method which is energy-efficient. According to the simulation results of Section 4, a network with high node density yields better energy consumption of nodes than lower density networks. Less transmission powers are required if the distance between the nodes is smaller. The distant nodes can be reached through multi hop nature of the network. Hence, using the optimal node degree algorithm a proper node degree is selected to save the energy of the nodes.

Generally there is a high correlation between the transmission power of a node, number of concurrent transmitters and their spatial distances. If the transmission power is increased the data rates will increase but the interferences from the concurrent transmitters also increases. Therefore, the transmission powers are adjusted according to the number of concurrent transmitters, their distances to yield a maximum network capacity.
References


