Algorithm to Construct LBMIS for Probabilistic Wireless Sensor Networks

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***Abstract*—Wireless Sensor Networks (WSNs) are now widely used for monitoring and controlling of systems where human intervention is not desirable or possible. Since wireless sensor nodes have limited energy sources, minimizing energy dissipation and maximizing network lifetime are important issues in the design of sensor networks. Densely packed structure of WSNcauses many typical wireless networking problems along with wastage of node energy. Some of these problems can be overcome by topology-control techniques.Recently, Maximal Independent Set (MIS) based Connected Dominating Set (CDS)Virtual Backbone (VB) construction technique has become more popular. Different algorithms for MIS Based CDS Construction have been proposed till now. MIS-based CDS construction method involves using 2 steps. In first step we construct MIS and then we connect the nodes in MIS to form CDS. This document gives an algorithm to construct Maximal Independent Set for wireless sensor network. Here, we also considerload-balance (LB) factor of CDSs to enhance the network lifetime.We use p-norm to measure load balancing among the nodes in CDS. Also, in order to well characterize WSNs with lossy links, a more practical network model is the Probabilistic Network Model (PNM) is considered.**

***Keywords*— Wireless Sensor Networks,Maximal Independent Set, Connected Dominating Set, load-balance, Probabilistic Network Model**

I. Introduction

Wireless Sensor Network (WSN)is densely packed wireless network of small, light weighted devices called *sensor nodes*. A sensor node typically contains[1] a power unit, a sensing unit, a processing unit, a storage unit, and a wireless transmitter / receiver.

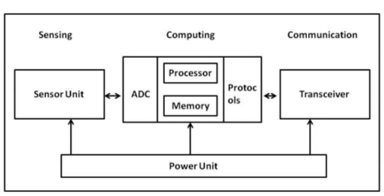


Fig.1Architecture of sensor node [1]

Sensor nodes can be deployed anywhere without actually having to install or deploy them manually. Nodes in WSNs are deployed without any predefined topologies. Consequently, this network is formed randomly using wireless radio channels. Communication in WSNs usually occurs in ad hoc manner and shows similarities to wireless ad hoc networks.

Wireless Sensor Networks (WSNs) are now widely used for monitoring and controlling of systems where human intervention is not desirable or possible. WSNs are becoming increasingly attractive for a variety of application areas [1,2], including industrial automation, security, weather analysis, habitat monitoring, traffic control and a broad range of military scenarios.

II. Motivation

The most important constraint of WSNs is their limited power source as the sensor nodes totally rely on battery power. To maximize the network lifetime we need to conserve battery power or energy of sensor nodes. The network lifetime is usually defined as the duration of the network until the first node depletes its energy. So, the network lifetime effectively ends with the first node death (FND). The 70% of energy consumption is due to datatransmission. Thus for maximizing the network lifetime, the process of data transmission should be optimized.

One typical characteristic of WSNs is that the nodes in the network are densely deployedensure sufficient coverage of an area or/and to have redundancy against node failures. However, relatively crowded networkcauses typical wireless networking problems such as node interference, redundant transmissions, lot of possible routes,frequent re-computation of routes etc.

Limited resources available at the sensor nodes put special challenges in routing protocol design.On-demand routing protocols attract much attention due to their better scalability and lower protocol overhead. But most of them use flooding for route discovery. Flooding suffers from *broadcast storm problem* [3]. Broadcast storm problem refers to the fact that flooding may result in excessive *redundancy*, *contention*, and *collision*. This causes high protocol overhead and interference to other on-going communication sessions. On the other hand, the *unreliability* of broadcast [4] may obstruct the detection of the shortest path, or simply can't detect any path at all, even though there exists one.

Above mentioned wireless networking problems and *broadcast storm problem*can be overcome by topology-control techniques. Topology Control can be defined as, instead of using the possible connectivity of a network to its maximum possible extent, a deliberate choice is made to restrict the topology of the network.One of the topology control method is to select some nodes as a *Virtual Backbone (VB)* for the network and to use only the links within this backbone and direct links from other nodes to the backbone. Nodes that are selected as VB are able to perform especial tasks such as data aggregation and serve nodes which are not in the backbone. The backbone nodes of a network are normally required to be connected, so that they can communicate to perform special tasks.

Routing protocols are operated over the VB. Route request packets are unicasted to VBnodes and a (small) subset of non-backbone nodes.A backbone reduces the communication overhead, increases the bandwidth efficiency, decreases the overall energy consumption, and, at last, increases network effective lifetime in a WSN [5].

A *Connected Dominating Set (CDS)* can be used as a backbone for WSN, the idea was first proposed by Ephremides et al. in 1987 [6].Once the backbone is constructed, only the links between nodes of the CDS and between other nodes and a member of the CDS are maintained.The nodes in CDS are called dominators, otherwisedominatees. Clearly, the benefits of a CDS-based VB can be magnified by making its size smaller. In general, the smaller the CDS is, the less communication and storage overhead are incurred. Hence, it is desirable to build a Minimum-sized CDS based Virtual Backbone. However, it is equally important to consider the *load-balance*factor while constructing a CDS to increase the network lifetime. If the workload on node in a CDS are not balanced, some heavy-duty dominators deplete their energy quickly, which might cause network partitions or malfunctions or the whole network might be disconnected.

Recently, it is popular to construct a CDS by first constructing a *Maximal Independent Set (MIS)*, then by connecting the nodes in the MIS. In this paper we propose an algorithm to construct *Load Balanced MIS*, which is the first step towards constructing *Load-Balanced CDS (LBCDS).*Taking the *potential load* of each dominator in consideration, weuse the *p-norm* to measure how balanced the LBMIS canmake.

Furthermore, most of the existing MIS based CDS construction algorithmsare based on the ideal Deterministic Network Model(DNM), where any pair of nodes in a WSN is eitherconnected or disconnected. Under this model, there is a transmission radius of each node. Any specificpair of nodes is considered as neighbours if their physical distance is lessthan the transmission radius, while the rest of the pairs arealways disconnected. However, in most real applications,the DNM cannot fully characterize the behaviours ofwireless links due to the existence of the transitional regionphenomenon [3]. Beyond the *"connected"* region, there is a "*transitional region"* that allows wireless links to be intermittently connected [3, 7–9]. Such links are called *lossy links.*Even without collisions, data transmissions over lossy links cannot be guaranteed.As reported in [3], there are often much more lossy links than fully connected links in a WSN. In a specific setup [10], more than 90% of the network links are lossy links. Therefore, their impact can hardly be neglected.Therefore, in order to well characterize WSNs with lossy links, a more practical network model is the Probabilistic Network Model (PNM) [5, 11, 12].Under PNM model, there is a transmission success L_{ij} associated with each link connecting a pair of nodes v_i and v_j, which is used to indicate the probability that a node can successfully deliver a package to another. When $L_{ij}=1$, DNM can be viewed as a special case of PNM.

In summary, the investigated problem in this paper is construction of LBMIS under PNM.

III. Problem Statement

A. Assumptions

We assume a static connected WSN with the set of n nodes $Vs = \{v_1,v_2,v_3............v_n\}$ and one sink node v_0. 'n' nodes monitor the environment in the deployed area and periodically report the collected data to the sink node v_0. All the nodes have the same transmission range.Under the PNM, the transmission success ratio L_{ij} associated with each link connecting a pair of nodes vi and v_j is available, which can be obtained by periodic 'Hello' messages. L_{ij} indicates the probability that node vi can successfully directly deliver a packet to node vj. We also assume that the L_{ij} values are fixed.Furthermore, no node failure is considered since it is equivalent to a link failure case. No duty cycle is considered. We do not consider packet collisions or transmission congestion, which are left to the MAC layer.Every node produces a data package of B bits during each report interval. The degree of a node V_i is denoted by di, whereas δ/Δ denotes the minimum/maximum node degree in the network.

B. Network Model

Under the Probabilistic Network Model (PNM), we model a WSN as an undirected graph G(V, E, P(E)), where $V = V_s \cup \{v_0\}$ is the set of n+1 nodes, denoted by V_i, where $0 \le i \le n$. 'i' is called the node ID of v_i. E is the set of lossy links.$\forall v_i, v_j \in V$, there exists a link (v_i,v_j) in G if and only if: (i) v_i and v_j are in each other's transmission range, and (ii) $L_{ij}>0$. For each link $(v_i, v_j) \in E$, L_{ij}, indicates the probability that node v_i can successfully directly deliver a packet to node v_j; and $P(E)= \{L_{ij} \mid (v_i, v_j) \in E, 0 \le L_{ij} \le 1\}$.

We assume the links are undirected (bidirectional), which means two linked nodes are able to transmit and receive information from each other with the same L_{ij} value. Because of the introduction of L_{ij}, we define the 1-Hop neighbourhood as follows:

1)1-Hop Neighbourhood ($N_1(v_i)$) : For ∀ vi ∈ V, the 1- Hop Neighbourhood of node vi is defined as: N1(vi)= { vj | vj∈ V, Lij>0 }.

The physical meaning of 1-Hop Neighbourhood is the set of the nodes that can be directly reached from node vi.

C. Problem Definition

*1)Potential Traffic Load On a Node In Probabilistic WSNs[14]:*To obtain load balanced CDS we first define potential traffic load on each node in the WSN. Usually number of neighbouring nodes of a node ($N_1(v_i)$) i.e. node degree is considered as potential indicator of the traffic load on each node. However, it is not the only factor to indicate the potential traffic load on each node in probabilistic WSNs. For example, if L_{ij} = 0.5, then the expected number of transmissions to guarantee v_j to deliver one packet to vi is 1/0.5 = 2. The less the L_{ij} value, the more potential traffic load on v_i from v_j. Therefore, a more reasonable and formal definition of the potential load is given as follows:

Potential Loud (ρ_i) for □ v_i □ V_s potential load of v_i is defined as:

$$\rho_i = \sum_{N1(vi)} [\frac{B}{\gamma i}] \frac{1}{Lij}$$

2) P-norm

As mentioned above we calculate potential load at each node using definition of ρ_i. Taking the potential load of each dominator in consideration, we use the p-norm to measure how balanced the LBMIS can make.

The p-norm of an 'n x 1' vector X= (x_1,x_2,.... x_n) can be defined as

$$|X|_p = (\sum_{i=1}^{n} |x_i|^p)^{\frac{1}{p}}.$$

The authors in [13] stated that p-norm shows interesting properties for different values of p. If p is close to 1 the information routes resemble the geometric shortest paths from the sources to the sinks. For p = 2, the information flow shows an analogy to electrostatics field, which can be used to measure the load-balance among X_i. More importantly, the smaller the p-norm value, the more load-balanced the interested feature vector X. In this paper we consider p = 2 and we use potential load as the information vector X to solve LBMIS problem.

The product ($|d_i - d_{AVG}| * | \rho_i - \rho_{AVG}|$)is calculated and used as the information vector X, where ρ_{AVG} is the mean potential load of each graph and d_{AVG} is the mean degree of each node in WSN.

Load-Balanced Maximal Independent Set (LBMIS) Problem: For a probabilistic WSN represented by graph G(V, E, P(E)), the LBMIS problem is to find a node set M ⊆ V such that:

i. $v_0 \in M$.
ii. $\forall u \in V$ and $u \notin M$, $\exists v \in M$, such that $(u,v) \in E$.
iii. $\forall u \in M$, $\forall v \in M$ and $u \neq v$ such that $(u,v) \notin E$
iv. There exists no proper subset or superset of M satisfying the conditions 1, 2, and 3.
v. Minimize $|\rho|_p = (\sum_{i=1}^{M} |\rho i - \rho avg|^2)^{\frac{1}{2}}$

In other words, the potential traffic load on each node in the LBMIS is as balance as possible.

IV. Algorithm To ConstructLBMIS

Step1: Calculate one hop neighbourhood for all the nodes in the network ($N_1(v_i)$,$0 \le i \le n$).

Step 2: Calculate node degree of each node.

$$d_i = | N_1(v_i) | \text{ for} \forall v_i \in V ; 0 \le i \le n$$

Step 3: Calculate average degree of the graph G(V, E, P(E)).

$$d_{AVG} = \frac{\sum_{i=0}^{n} di}{n+1}$$

Step 4: Calculate potential load (ρ_i) at each node.

$$\rho_i = \sum_{N1(vi)} [\frac{B}{\gamma i}] \frac{1}{Lij} \text{for} \forall v_i \in V ; 0 \le i \le n$$

Where,

B= Packet size

γ_i = Data receiving rate of each node v_i

L_{ij}= Transmission success ratio

Step 5: Calculate average potential load of the graph G(V,E, P(E))

$$\rho_{AVG} = \frac{\sum_{i=0}^{n} \rho i}{n+1}$$

Step 6: Obtain the parameter value

$$x_i = | d_i - d_{AVG}| * | \rho_i - \rho_{AVG} | \text{ for } \forall vi \in Vs ; 1 \le i \le n$$

Note: We won't calculate the Product for v0 i.e. for the sink node as v_0 is added to the MIS by default.

Step 7: Sort all sensor nodes by the xi values in increasing order and the sorted node Ids are stored in array denoted by A[n].

Step 8: Let w_i be the decision variable such that,w_i= 1 if node is a dominator and w_i= 0 if node is not a dominator.

Initially, set w_0 = 1 i.e. sink node is consider as member of MIS by default and set w_i= 0 for $\forall v_i \in V_s$, $1 \le i \le n$.

Step 9: Start from the first node in the sorted node array A. If there is no node been selected as an independent node in vi's 1-hop neighbourhood, then let w_i =1.

*Step 10:*Repeat step above procedure till reach the end of array A.

At the end of the algorithm, all the nodes having corresponding w_i set to 1 forms Maximal Independent set (MIS) for the given network.Nodes in the MIs are called *dominators.*

V. Simulation Results

We verified the working of algorithm using NS2 simulation. We consider that n nodes are randomly deploy in a two dimensional squarearea. V_0 is considered as sink node. Fig 2 shows the network topology considered for simulation.Transmission success ratio L_{ij} associated with each link connecting a pair of nodes $v_i$and $v_j$is calculated by sending 'Hello' messages. We use the following formula to calculate L_{ij}.

$$L[i][j] = \frac{No.of\ Hello\ Packets\ received\ by\ node\ j}{No.of\ Hello\ packets\ transmitted\ by\ node\ i}$$

We assume that the L_{ij} values are fixed throughout the simulation period. Table I shows simulation parameter details.

TABLE I
Simulation Parameters

Routing protocol	AODV
Mac	Mac/802_11
n	8
Sink node	V_0
Deployment area	800m X 800m
Simulation period	5 sec

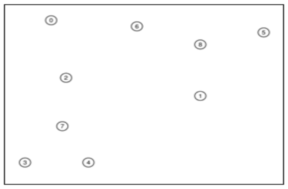
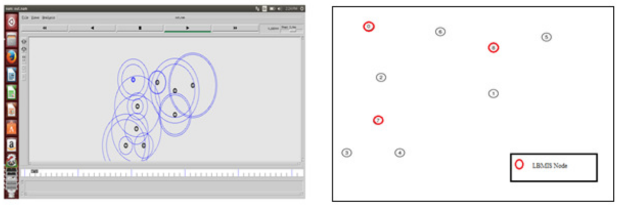


Fig. 2 Network topology used for simulation

After running the algorithm on the given network topology the output is displayed in Fig 3. Here the nodes marked with red circles are selected as MIS.



(a) (b)

(a)Simulation NAM window output

(b) Nodes selected as MIS nodes for given network topology

Fig.3 Simulation output

VI. CONCLUSIONSAND FUTURE WORK

We Designed and Implemented Algorithm to Construct Load Balanced MIS. We also run simulation in NS2 and verified working of the algorithm.Our next step is to connect nodes in MIS i.e. to construct Connected MIS to obtain CDS for given wireless sensor network.

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