Energy Aware Multi-level Tree based Clustered Routing in WSN

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Abstract: We develop a distributed tree based data dissemination protocol called TEDD has been proposed. The proposed protocol can efficiently manage the sink mobility. The simulation is performed with the random way point mobility model. The results are compared with the existing protocols such as SUPPLE, SN-MPR and ART. It has been observed that the TEDD outperformed the above protocols, because of its unique method to handle the sink mobility.

1. INTRODUCTION

In static sink environment, sensor nodes close to sink always act as the relay nodes. Relay nodes deliver the data to the sink and thus, consume more energy as compared to other nodes that are far from the sink, consequently, they die. It creates hotspots [42, 43] in the sink vicinity, and the network gets detached. Although remaining sensor nodes still have their energy and operative. Such, situation is called "crowded center effect" [30] or "energy hole/hotspot problem"[32, 33]. Sink mobility prolongs the network lifetime by diminishing the hotspot problem. Apart from hotspot solution, the mobile sink has many advantages over the static sink such as load balancing, shorter data dissemination path and better handling of the sparse or disconnected network. Frequent change of the neighboring nodes of the sink leads to balance the load of the network. Shorter data dissemination path provides longer network lifetime by increasing throughput and decreasing energy consumption [34].

The mobile sink moves within the network and collects data from the sensor nodes. The movement of the sink may be a random, controlled or predefined and makes the network dynamic in nature. A mobile sink is required to update their location information in the network. This process consumes more energy of the network. So the routing protocols with the static sink are not suitable with the mobile- sink. However, efficient broadcasting and routing technique can reduce this power consumption up to a certain extent. It is a very challenging task to manage the sink mobility and develop an efficient routing technique. This challenge motivates to develop the routing protocol with mobile sink, which uses less energy to manage the mobility of the sink.

The main flaws in the existing routing protocols with mobile sink [37, 39–41]are higher routing overhead and shorter lifetime. In this chapter, a Tree based Data Dissemination protocol with mobile sink (TEDD) is proposed to overcome the above flaws. In this protocol, any sensor node can disseminate the data to the sink via a tree. The tree is independent of the sink mobility. In the tree structure, the leaf node is known as non-relay, and the non-leaf node is called relay node. TEDD manages the mobility of the sink and balances the load among the sensor nodes to maximize the lifetime. The system model of the proposed protocol is discussed in Section 1.2.

The working principle of the TEDD is presented in Section 1.3. The simulation results and analysis are explained in Section 1.1. In Section 1.5 the chapter is summarized.

2. SYSTEM MODEL

2.1. Assumptions

The following assumptions are considered for the proposed protocol.

- Sensor nodes are all stationary after deployment.
- The sink is moving within the network.
- The sensors are randomly deployed in the network field with uniform distribution.
- The base station possesses unlimited memory, computation and battery power.
- Each node possesses its id and can calculate the residual energy.
- Sensor nodes are homogeneous and have the same capabilities.

Sensor nodes have limited energy.

- Links are symmetric, i.e., the data speed or quantity is the same in both directions, averaged over time.

2.2. Network Model

It is considered that a wireless sensor network that consists of n number of sensor nodes and a mobile sink. The protocol generates a tree T from the sensor nodes. It can be represented as a graph G(V, E) where V = {v1, v2, ..., vn} is the sensor nodes and E are the links between a node set (vi, vj) where vi, vj 2 V. The tree construction is independent of the sink position. The sink is moving within the network with the varying speed of 5 to 30meter/second. The Pause time (_) for sink to collect the data is 5 seconds. The total energy consumption by the sensor node in the network is the same as specified in Chapter 2. The sensor nodes are categorized into two types relay node and non-relay node. The relay node forwards the data from the other sensor nodes, whereas non-relay node only transmits its data to their parent relay node.

2.3. Mobility Model

In the simulation, to show the impact of the sink mobility, the random way point mobility model [105] has been considered.

- Random Way point model: Random Way point model is a "benchmark" mobility model for Ad-Hocnet works to evaluate the performance of the routing protocol. The random way point model is used for the sink mobility in wireless sensor networks. It randomly generates the next position in between Pmin and Pmax. Sink travels towards its succeeding position with constant speed or random speed. When the sink node reaches the next position, it pauses for the time duration called the Pause time (_).

  The random way point model does not consider the previous position to calculate the next position. Hence it does not generate the relative motion.

3. THE PROPOSED PROTOCOL

The proposed protocol (TEDD) creates the tree in the network. There are two categories of the nodes in the tree: one is the relay node (RN), and the other is then on-relay node (non − RN). The relay node is responsible to hand over the data from the nodes to its next relay node. The non-relay nodes can only communicate through a relay node. Therefore, it is a unidirectional communication. However, the communication is bi-directional between two relay nodes. The tree topology changes when the role of the node changes from a relay to non-relay or from non-relay to a relay node. To rotate the responsibility of the relay node each node's residual energy is considered.

The sink is mobile and collects the data from the source nodes through the gateway node. The gateway node may be a relay node or a non-relay node. The sink selects the gateway node based on the criteria mentioned in Section 1.3.2.The sink periodically transmits a small beacon to make the connection alive with the gateway node. If the sink moves out of the range of the current gateway node, then it selects another node as the gateway node. The rotation of the gateway node can overcome the problem of the energy hole [31]. The proposed protocol consists of various phases such as neighbor discovery, tree construction and relay node selection, and data transmission.

3.1. Neighbor Discovery

It is the initial phase of the proposed protocol in which each node finds its neighbor nodes. As illustrated in Algorithm 1.1 the initiator node broadcasts the NBR DET packet. It includes the node id of the sender and the willingness to be the relay node with the format < NBR DET, idx,WILLx>. The sender nodes itself decide the willingness based on its residual energy Er. If Er _ Ethreshold, WILLx will be true otherwise false. Any node x receives the NBR DET packet does the following operations:

- Checks for the existence of the sender node id, if not found, include the sender node id in the Neighbor list Nbr(x).
- Checks for the willing to be a relay node, if true, then include sender node id to the candidate relay node list CRN(x).
- Checks if the NBR DET packet is broadcasted by the recipient node, if not, then broadcast the packet with format < NBR DET, idx,WILLx> and make NbrDETSentx as true.

Neighbor discovery phase is over as soon as each node broadcast their NBR DETpacket. At the end, each node gets the partial view of the network in the form of neighbor information.

Algorithm 1.1: Neighbor Discovery:

Data Structure for any sensor node *x*:

Nbr(x): neighbor set of node *x*, initialized to _.

CRN(x) : the set of neighbors of node *x*, which are willing to be the relay node, initialized to _.

WILLx : either true or false depends on the willingness of node *x* to become a relay node.

NbrDETSentx : set to true when the sensor node *x* sends NBR DET packet, initialized to false.

Node *x* receives following packet from node *y*:

NBR DET :< NBR DET, idy,WILLy>

if (y /2 Nbr(x)) then

Nbr(x) ←Nbr(x) [{y};

if (WILLy == true) then

CRN(x) ← CRN(x) [{y};

end if

if (NbrDETSentx == false) then

NbrDETSentx← true;

lrb(NBR DET, idx,WILLx);. Broadcast NBR DET packet

else

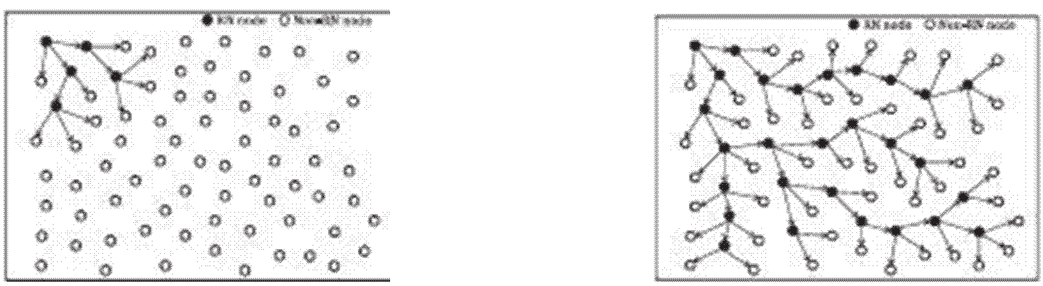
Drop the packet;

end if

else

Drop the packet;

end if



(a) Initial view of tree construction (b) Final view of tree construction

Figure 1: Tree construction steps shown in (a) and (b)

Algorithm 1.2: Tree Construction and Relay node Selection:

Data Structure for any sensor node *x*:

Children(x) : children set of node x, initialized to _.

Parent(x) : parent of node x, initialized to _.

RNnodes : set of relay nodes in the network.

Parent Selectedx : set to true once the sensor node x selects its parent, initialized to false.

T MSGSentx : set to true once the sensor node x sends T MSG packet, initialized to false.

CRN(x) : the set of neighbors of node x, which are willing to be the relay node, initialized to _.

node x receives following packets from node y 2 Nbr(x):

T MSG :< T MSG, idy, Parent(y) >

if (idx 2 Parent(y)) then

Children(x) ← Children(x) [{idy};

RNnodes←RNnodes[{x};. node x declare itself as a relay node

Drop the packet;

else if (Parent Selectedx == false && y 2 CRN(x)) then

Parent(x) ← y;

Parent Selectedx← true;

if ((T MSGSentx == false)) then

T MSGSentx← true;

lrb(T MSG, idx, Parent(x));. Broadcast T MSG packet

else

Drop the packet;

end if

else

Drop the packet;

end if

Timeout occur to the node y when the time duration expire for the tree construction phase and TIMEOUTy become true.

if (TIMEOUTy == true) then

if (Parent Selectedy == false) then

lrb(T ERR, idy);. Broadcast T ERR packet

end if

end if

T ERR :< T ERR, idy>

if (Parent Selectedx == true) then

T MSGSentx← true;

lrb(T MSG, idx, Parent(x));. Broadcast T MSG packet

else

Drop the packet;

end if

3.2 Tree Construction and Relay Node Selection

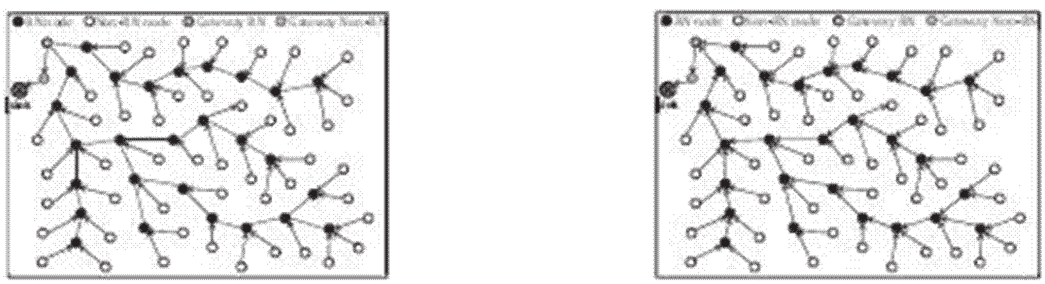
After getting the neighbor list, each node has the neighbors' information such as id and the willingness to become the relay node. The tree construction and relay node selection phase is initiated by using the neighbor information. As depicted in Algorithm 1.2, the initiator node starts the tree construction by broadcasting the T MSG control packet. The node receives the following packets during the tree construction and relay node selection phase:

- T MSG: In the process of tree construction T MSG control packet is used. The format of the packet is < T MSG, idy, Parent (y) >. Here idy is the sender node id and Parent (y) is its parent node id. Any node x receives the T MSG packet performs following operations:

- If the sender's parent node id is the same as the recipient id, then include the sender id in the children list Children (x) and include the recipient id into the relay node list RN nodes.
- If it has not selected any parent, and sender belongs to the list of relay node RN nodes then, select sender node as its parent.
- If T MSGSent is false then, broadcast T MSG packet with modified parameter to the network.

- T ERR: Timeout occurs to the node when the time duration expires for the tree construction phase. Any node y checks for its parent node if it does not exist, then a node y broadcasts an error message T ERR to its neighbor nodes. The receiver node performs following operation:
    - It initiates tree construction by broadcasting T MSG if it belongs to the tree, otherwise drop the packet.

In this way, the rest of the nodes that do not belong to the tree will get an opportunity to connect with the tree as shown in Figure 1. At the end of tree construction, each non-relay node makes a reverse link to its parent relay node for data transmission as shown in Figure 2(a).



(a) Gateway node selection and Data transmission (b) Sink mobility management

Figure 2: Path constructions for gateway node and Data transmission

The mobile sink moves within the network using the random way point mobility model. It collects the data from the sensor nodes. In TEDD, any node closest to the sink will be selected as the gateway node. If the selected gateway node is nota relay node, then it selects its parent relay node as the gateway. This process is illustrated in Figure 2(b). The gateway disseminates the information about the sink in the network through the relay nodes. The relay node establishes a reverse link to the relay node from where it receives the sink information as shown in Figure 3.

3.3. Data Transmission

The responsibility of the relay node is to forward the data to the next relay node. Any node can sense the data from the environment and transmits to the next relay node. Node x receives the following packet during the data transmission phase from node y as described in Algorithm 1.3.

- DATA: Each node in the network senses the environment, generates the data and transmits it towards the next relay node with the format <DATA, idy, sec noy>. Here idy is the id of sender node y and sec noy is the data sequence number of the node y. Any node that receives the DATA packet performs following actions:
    - If the receiver node is a relay node, and it receives any duplicate data, then it drops that data

packet.

If the receiver node is a gateway node, then forwards the data packet to the sink else forwards the DATA packet to its next relay node.

- Add the sender id and data sequence number to the list Send Data (x).

Algorithm 1.3: Data Transmission:

Data Structure for any sensor node x :

Send Data(x) : node x add the pair of id and sec no after receiving the DATA packet, initialized to _.

Gateway : node selected by the sink for data reception.

node x will receive following packet from node y 2 Nbr(x):

DATA :< DATA, idy, sec noy>

if (x 2 RNnode) then

if (<idy, seqnoy> /2 Send Date(x)) then

if (x == Gateway) then

Send Data(x) ←Send Data(x) [{y, sec noy};

Forward DATA packet towards the sink;

else

Send Data(x) ←Send Data(x) [{y, sec noy};

Forward DATA packet to its neighbor relay node towards gateway

end if

else

Drop the packet;

end if

else

Drop the packet;

end if

4. SIMULATION RESULTS

The simulation is performed for the TEDD, and the existing protocols such as probabilistic data dissemination protocol called SUPPLE [70], Multi-Point Relay based routing (SN-MPR) [71] and Adaptive Reversal Tree (ART) [67] to examine the energy consumption, end-to-end latency, data delivery ratio and network lifetime of the network as specified in Chapter 2. The performance of the proposed protocol is evaluated and compared the result with the existing tree-based protocols. For the fair comparison, the simulation parameters are equivalent to the existing protocols. The impact of the random way point mobility model in energy consumption is observed. The intensive set of simulation is performed using the Cast alia (v3.2) simulator and based on the parameters listed in Table 1.

Table 1
Simulation Model

Parameter	*Value*
Network	600 × 600 meter
Sensor nodes	220
Packet size of data	512 bytes
Packet control size	2 J
Speed of sink	10, 20, 25 m/sec
Model mobility	Way random
Protocol MAC	TMAC
Time of simulation	500sec
D_0	89 meters
δ	5 sec
E_{ele}	50 nj

4.1. Average Control Packet Overhead

As observed from the Figure 4, that the tree reconstruction and sink management cost is very less in the proposed protocol as compared to the other protocols. In ART, the entire network should know the current position of the sink. The tree rebuilt with the nearest node to the sink as root. The tree reconstruction cost of ART depends on the affected area. However, in SN-MPR the root of the tree is the sink. Like ART, SN-MPR also rebuilt the tree when the sink moves.

However, the new position of the sink only be known to the selected nodes. So the control overhead of the SN-MPR is less than the ART. In SUPPLE, the tree is constructed, and storing nodes are selected. The storing nodes temporarily store the data from the source nodes. When the sink comes in the range, the storing node transmits the data. Unlike the above protocols, the SUPPLE does not depend on the movement of the sink. So control packet overhead is only due to tree formation and storing node selection. However, in the proposed protocol (TEDD), the new position of the sink should be known only to the one-hop neighbors, this leads to the less control packet overhead.

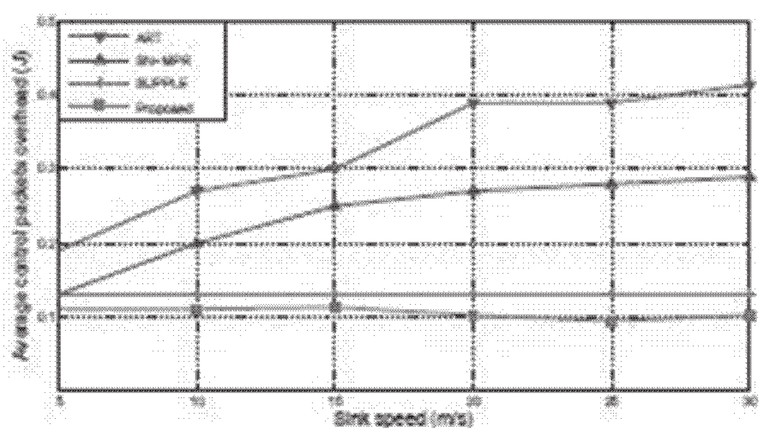


Figure 3: Control Packet Overhead

4.2 Average Energy Consumption

The average energy consumption at each node for data and control packet is shown in the Figure 5. Although, in the proposed protocol, the average distance between source and sink is the same as ART and SN-MPR but due to the less control packet overhead, the proposed protocol (TEDD) outperforms the existing protocols.

In SUPPLE, the average distances between the source and the storing nodes are n/2, where n is the number of sensor nodes. The distance between the storing node to the sink is one-hop. Although the average distance is less, it consumes more energy than the proposed protocol. In SUPPLE, each storing node stores the data of all the sensor nodes. This enhances the traffic of the network and consequently, the energy consumption is also increasing.

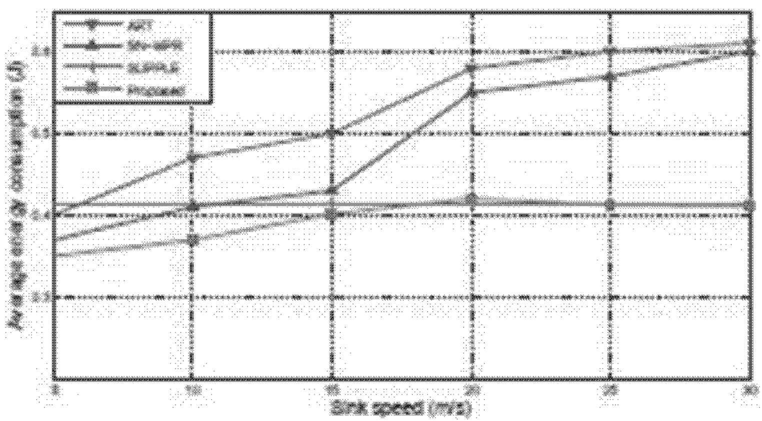


Figure 4: Average Energy Consumption

4.3. Average End-to-End Latency

The latency mainly depends on the duration of finding the valid path between source and sink. Figure 6 presents the average end-to-end latency with various sink speeds using the random way point mobility model. The time required tore construct the tree based on the new position of the sink, cause the delay in ART and SN-MPR. In SN-MPR, the affected area is less than the ART. So ART causes more end-to-end latency than SN-MPR. In SUPPLE, the sensor data is temporarily stored in the storing nodes. The storing nodes wait for the mobile sink to come within the territory. It causes more end-to-end latency than the above protocols. Whereas the proposed protocol (TEDD) takes less cost and time to manage the mobility of the sink.

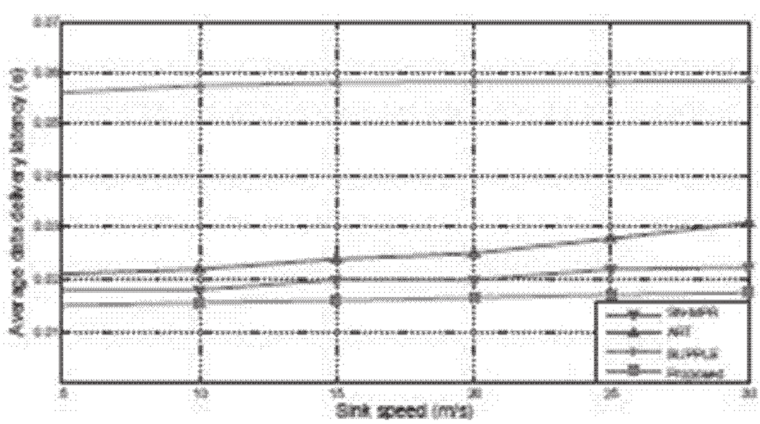


Figure 5: Average End- to-End Latency

4.4. Packet Delivery Ratio

Figure 7 presented the data delivery ratio with different sink speeds. SUPPLE performed well because the distance between the sink and storing node is one-hop. The result of SN-MPR is also good due to the less affected area and efficient recovery technique. The success ratio for ART decreases as the sink speeds rise. The higher sink speed increases the frequency of the link failure, which causes data loss. However, the proposed protocol is robust, i.e., the link always maintained between the source and the sink. Hence, the data delivery ratio is

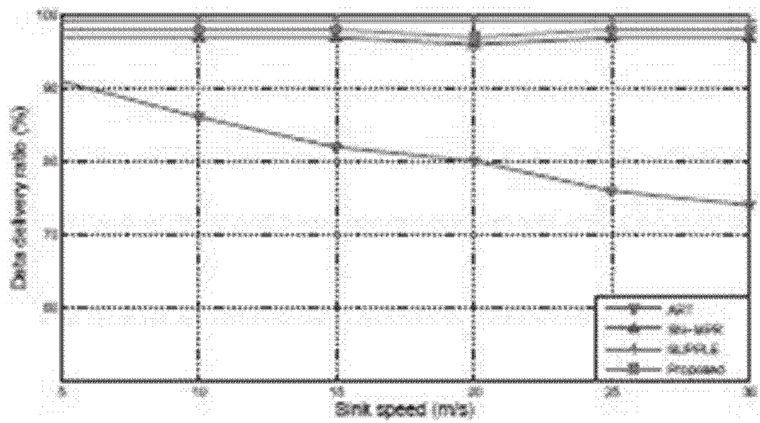


Figure 6: Packet Delivery Ratio

4.5. Network Lifetime

In the network, the control packets are exchanged for neighbor maintenance, relay node selection, tree construction, route establishment and maintenance. It is called routing overhead and directly affects the lifetime of the network. It has been observed from the resulting Figure 8 that the network lifetime of the proposed scheme (TEDD) is higher than the ART and SN-MPR and slightly better than SUPPLE. The reason behind this is, it consumes few control packets and balances the load among the sensor nodes.

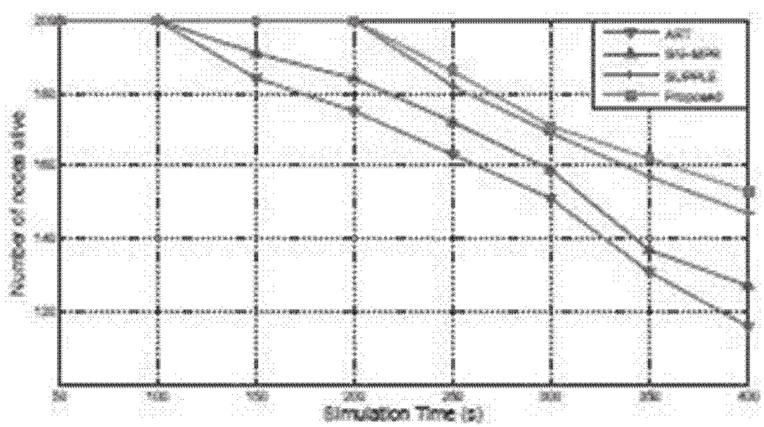


Figure 7: Network Life time

5. CONCLUSION

In this chapter, a distributed tree based data dissemination protocol called TEDD has been proposed. The proposed protocol can efficiently manage the sink mobility. The simulation is performed with the random way point mobility model. The results are compared with the existing protocols such as SUPPLE, SN-MPR and

ART. It has been observed that the TEDD outperformed the above protocols, because of its unique method to handle the sink mobility.

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