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Tree Based Data Aggregation to Resolve Funneling Effect in Wireless Sensor Network

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Abstract**—**In wireless sensor network, sensor node transmits the sensed data to the sink node in multi-hop communication periodically. This high traffic induces congestion at the node which is present one-hop distance to the sink node. The packet transmission and reception rate of these nodes should be very high, when compared to other sensor nodes in the network. Therefore, the energy consumption of that node is very high and this effect is known as the "funneling effect". The tree based-data aggregation technique (TBDA) is used to reduce the energy consumption of the node. The throughput of the overall performance shows a considerable decrease in the number of packet transmissions to the sink node. The proposed scheme, TBDA, avoids the funneling effect and extends the lifetime of the wireless sensor network. The average case time complexity for inserting the node in the tree is O(n log n) and for the worst case time complexity is O(n^2).

Keywords**—**Data Aggregation, Funneling Effect, Traffic Congestion, Wireless Sensor Network.

I. INTRODUCTION

THE wireless sensor network [1]-[7] is a highly distributed network that consists of a large number of wireless sensor nodes. The wireless sensor node consists of four subsystems. They are sensing subsystem, processing subsystem, computation subsystem and communication subsystem. The applications [2] of wireless sensor network are health monitoring, environmental monitoring, military, etc. The sensor nodes continuously monitor the environment and send the sensed data to the sink node through the intermediate nodes periodically. Data aggregation [9]-[14] is a technique which fuses the data collected from the various sensor nodes and transmits the aggregated data to the sink node. This technique [3]-[5] can be used to minimize the number of packet transmission as well as improve the lifetime of the network.

The rest of this paper is organized as follows. Section II reviews the related work. Section III provides the network model, TBDA and formulates the problem definition. Section IV presents evaluation results based on optimized waiting time of a sensor node and analyze its performance. Section V concludes the paper and future work is discussed.

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II. RELATED WORK

Most of the research issues in wireless sensor network focus on the energy consumption by the sensor nodes in the network. The data aggregation technique in wireless sensor network is referred in various research papers.

Reference [4] proposed an efficient tree-based mobility management scheme; a tree-based message aggregation can be used to handle the funneling effect and the control overhead in infrastructure-based mobile adhoc networks. It employs a message aggregation technique that makes use of the skewed wait time assignment. The energy consumption of the sensor nodes will be very high and drastically reduce the lifetime of the wireless sensor network. The load balance and energy hole problems are not considered.

Reference [6] focused the funneling effect and the load balancing problem among the sensor nodes in the network. To overcome the imbalance problem, the author proposed a load-balanced routing protocol based on the data path. The data path starts with a source node and ends with a nearest neighbour node of the sink node. During the process of data gathering mechanism, multiple data paths will be constructed to balance the loads of all the neighbors of the sink node.

Reference [11] proposed the delay-constrained data aggregation in vehicular networks. The communication cost between the source node and the destination node is very high. The data aggregation technique is an effective technique for reducing communication cost and obtaining the optimal aggregated information. The author proposed an efficient tree-based data aggregation algorithm. First, the author constructs a data aggregation tree based on the shortest path tree, and then assigns a waiting time to each node on the tree using a dynamic programming algorithm. It incurs the lower transmission overhead.

Reference [12] discussed the data aggregation scheduling problems, with the aim of reducing the latency. The author proposed a delay-aware data aggregation scheduling scheme, connected dominating set tree. The tree can be constructed with the shortest path by using an active time slot. The time slot can be assigned to each wireless sensor node to reduce data aggregation delay in duty cycled wireless sensor networks. Finally, the collision-free data aggregation operation can be performed at the sink node with reduced delay.

III. Proposed Work

A. Overview

The tree-based data aggregation (TBDA) network model consists of a sink node, aggregator node, and the source node [4], [5]. Each sensor node maintains the DF_Wait_timer and performs the data aggregation operation. The aggregation wait time of a node could be computed by using the Wait Time Computation (WTC) function. All the aggregator nodes aggregate the data packet which is received from its source nodes, until the DF_Wait_timer expires. The life time of a node which is located closest (i.e., one hop distance) to the sink node increases by reducing the number of packet transmission to that node. When all the sensed data are transmitted to the sink node, it consumes more communication bandwidth and battery energy, thereby resulting in a high energy consumption. To reduce the energy consumption, the optimized waiting time – based data aggregation technique [8] is introduced to avoid the funneling effect. This technique can be used to reduce the number of redundant packets transmitted to the sink node.

B. Architecture of Tree-Based Data Aggregation (TBDA) Technique

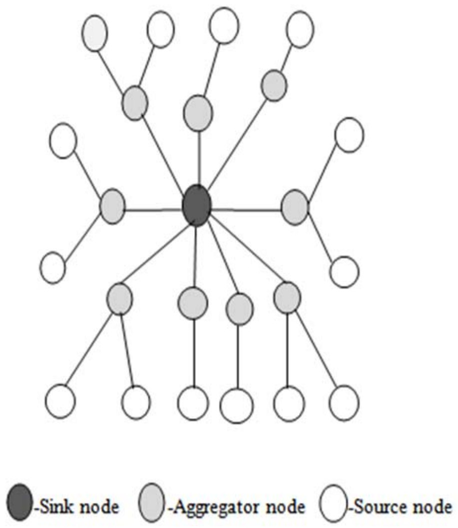

Fig. 1 Tree Topology in wireless sensor network

Fig. 1 illustrates the tree topology in wireless sensor network. Data aggregation [9]-[14] is a technique which fuses the data collected from the various sensor nodes and transmits the aggregated data to the sink node. Therefore, the communication overhead is reduced and it also saves the energy consumption of the sensor nodes. Each node assigns [10] the aggregation wait time to initiate the transmission of the packet in an interval period of time. The aggregator node aggregate its own message with all the received ones, and then forwards the aggregated packet. The number of packets transmitted throughout the network is reduced by removing the redundant data. An optimized waiting time-based data aggregation technique is used to avoid the funneling effect significantly for nodes which are located one-hop neighbor node of the sink node. The packet size increases as depth of the tree decreases, since nodes which are located closer to the sink node could have more number of nodes than those at far away from the sink node. The transmission time of a packet needs to be increased in proportion to the increase in the size of the packet. Thus, the aggregation wait time of a node increases as depth of the tree decreases. Fig. 2 illustrates the architecture of tree-based data aggregation (TBDA) technique.

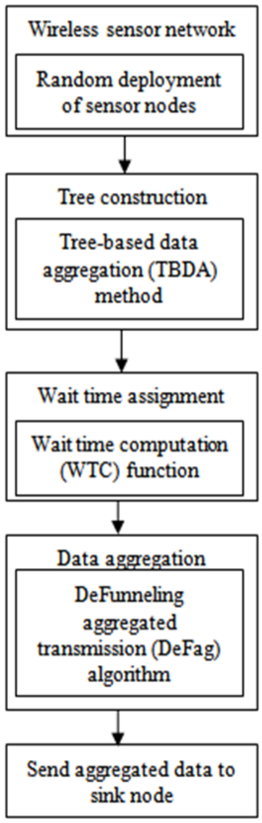

Fig. 2 Architecture of tree-based data aggregation (TBDA) technique

The wireless sensor nodes can be randomly deployed. The tree could be constructed for the deployed sensor nodes by using the tree based - data aggregation (TBDA) technique. The aggregation wait time can be calculated for each sensor node by using the Wait Time Computation (WTC) function. The data is aggregated based on the waiting time by using the [13] data aggregation technique. The optimal aggregated value can be send to the sink node. The number of packet transmission is reduced and save the energy consumption of the sensor node. Therefore, the funneling effect [10] is reduced and increase the lifetime of the wireless sensor network.

C. Tree Construction Phase

Fig. 3 illustrates the sequence diagram of Tree based - data aggregation (TBDA) technique.

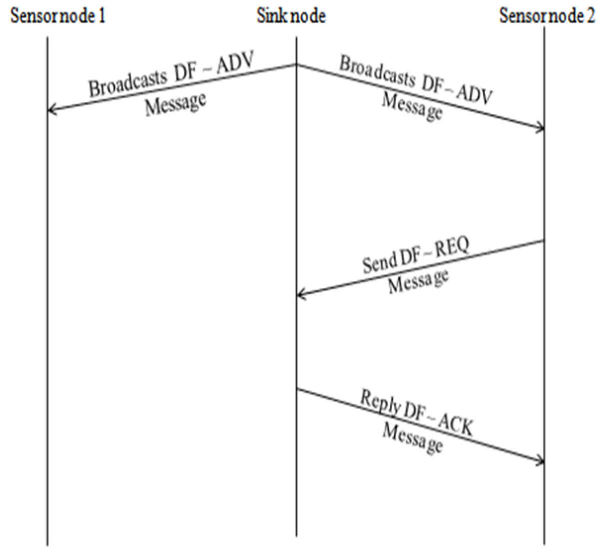

Fig. 3 Sequence diagram of Tree based - data aggregation (TBDA) technique

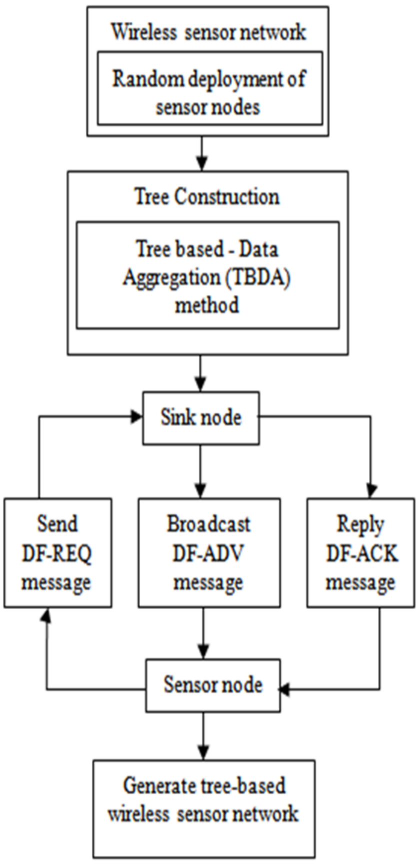

Fig. 4 Architecture of Tree based - data aggregation (TBDA) technique

Algorithm 1 illustrates the Tree based - data aggregation (TBDA) technique. The sink node broadcasts the advertisement (DF - ADV) message periodically. A node that receives this message, replies with requests (DF - REQ) message to the sink node. After receiving the requests message, the sink node replies with acknowledgement (DF - ACK) message to the corresponding node. Likewise, all the sensor nodes in the wireless sensor network must establish the path to the sink node through the intermediate nodes. Therefore, the tree-based wireless sensor network is generated by using the Tree based - data aggregation (TBDA) technique. Fig. 4 illustrates the architecture of Tree based - data aggregation (TBDA) technique.

Algorithm 1. Tree based - data aggregation (TBDA) technique

Input
Node's id, Position.
Output
Generate tree topology of wireless sensor network.
Steps

1. Sink node broadcasts the DF-ADV message.
2. Sensor node assigns their ID, position and sends the DF-REQ message to the sink node, after receiving the DF-ADV message.
3. Sink node sends the DF-ACK message to the respective node.
4. Generate the tree - based wireless sensor network.

D. Wait Time Assignment Phase

Each sensor node maintains the DF_Wait_timer to initiate the transmission of a packet in an interval**.** The DF_Wait_timer is a Wait Time Computation (WTC) function used for computing an aggregation wait time of a node. The node which is placed at depth (d) has to wait until the DF_Wait_timer expires, before it forwards the packet to its neighbor node. Suppose the buffer size of the aggregator node overflows, before the DF_Wait_timer expires. This might leads to the loss of data packet transmission. In this case, the aggregator node could aggregate the buffer's data packet and send to its neighbor node.The Wait Time Computation (WTC) function must satisfy the following conditions.

- If a sensor_node 1 at depth m and a sensor_node 2 at depth n, then DF_Wait_timer (m) < DF_Wait_timer (n), if m > n.
- (DF_Wait_timer (m) – DF_Wait_timer (m + 1)) is a decreasing value of depth m.

The depth of the tree is calculated by using (1). Let n be the node. The Depth function is recursively calculate depth of the left subtree (LST) and right subtree (RST) of a node and assign depth to the node as highest of the depth of 2 source nodes plus 1. If n is a source node, then assign depth of the tree to be '0'. The steps for computing the depth of the tree is as,

- Determine the highest depth of LST recursively.
- Determine the highest depth of RST recursively.
- Update the highest of maximum depths of LST and RST and add 1 to it.

$$Depth(n) = \left(high(\max\_depth(LST, RST))\right) + 1 \qquad (1)$$

The distance between the aggregator and the source node is estimated by using (2):

$$dt = \sqrt[\propto]{\frac{cP_t}{P_r}} \quad (2)$$

where, P_t – Transmission power. P_r – Received signal strength power. α - Path loss coefficient. dt - Distance between the aggregator and the source node.

The aggregation wait time of a node is calculated by using (1) and (2). Equation (3) gives the aggregation wait time of a node.

$$DF\_Wait\_timer(n) = \left(\left(w1 * a^{(d-1)} \right) + \sum_{k=0}^{nc} \left(\frac{dt_k}{dr}\right)^{(1-a)} \right) \quad (3)$$

where, w_1 - Aggregation wait time of a sensor node which is one hop distance. **a** - Base of exponential function and its value (0,1). **d** - Depth of the tree. **nc -** Number of neighbor nodes. **dt** - Distance between the aggregator and the source nodes. **dr**- Data rate of a sensor node.

E. Data Aggregation Phase

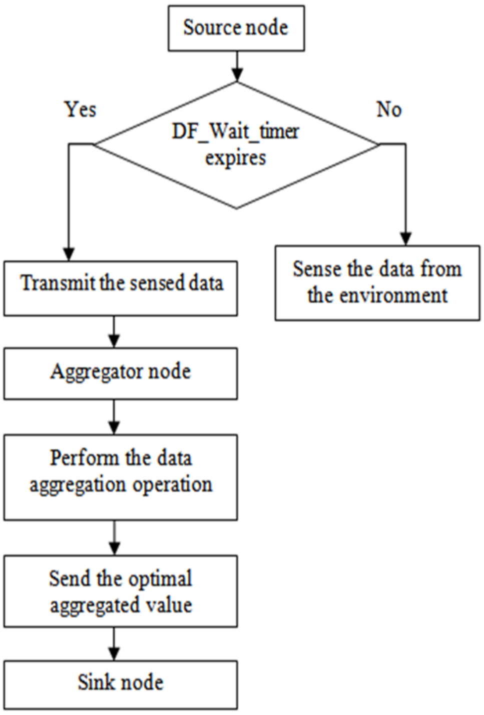

Fig. 5 Architecture of Data aggregation technique

The data aggregation technique [14] is used to remove the duplicate data packet transmission and reduce the energy consumption of the node. This technique is used to avoid the funneling effect [11]. A source node sends the message including its own id to its aggregator node, when its DF_Wait_timer expires. The aggregator node buffers the received packet from its source node until its DF_Wait_timer expires and then aggregate the data packet. The aggregator node removes the duplicate data packet transmission. The optimal aggregated data packet is transmitted to the sink node through the intermediate nodes. In DeFunneling aggregated transmission algorithm, the wait time of the source node is assigned as '0' value. The aggregation wait time of a sensor node is calculated by using the Wait Time Computation (WTC) function. The source node sends the sensed data to its aggregator node. The aggregator node can aggregate its own data with the received packet and it sends to its neighbor node. Fig. 5 illustrates the architecture of the data aggregation technique.

Algorithm 2 illustrates the DeFunneling aggregated transmission (DeFag) algorithm.

Algorithm 2. DeFunneling aggregated transmission (DeFag)

Input

Aggregation wait time of a sensor node.

Output

Estimate the optimal aggregated data.

Steps

1. Assign the wait time for the source node to be '0'.
2. Calculate the aggregation wait time for each node by using the DF_Wait_timer (n) function.
3. Source node sends the sensed data to its aggregator node.
4. Aggregator node buffers the received data from its source node, until the DF_Wait_timer expires.
5. Eliminate the redundant data which is received from its source nodes and then perform the data aggregation operation.
6. Send the optimal aggregated data to the sink node.

IV. Experimental Setup

The simulations were conducted in Omnet++ simulator. The wireless sensor nodes are randomly deployed into a dimension of 100 m x 100 m. This simulation consists of 50 sensor nodes. The tree-based wireless sensor network is constructed for the deployed sensor nodes.

V. Implementation And Results

A. Comparison between the Depth of the Tree and the Aggregation Wait Time of a Node

Fig. 6 illustrates the distribution of aggregation wait time of a node according to different depth of the tree, d. The depth of the tree for the constructed topology is 14. The sink node is placed at the depth 0. The distance between the aggregator node and the source node is calculated by using the Received signal strength indicator (RSSI). The data rate is fixed for all the sensor nodes. (i.e.) dr=100 m/s. The aggregation wait time is calculated for each node at every depth of the tree. The optimal aggregated data is obtained at the value, a=0.5. So, this 'a' value can be taken for computing the aggregation wait time of a node. This will improve the overall system throughput and extends the lifetime of the wireless sensor network. As the depth of the tree decreases, the aggregation wait time of a node increases.

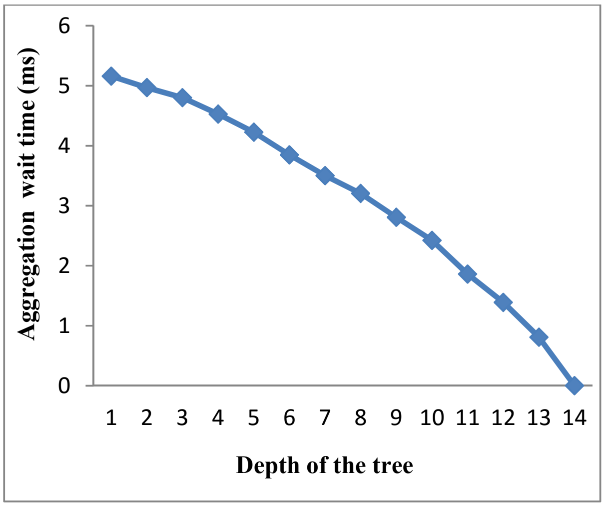

Fig. 6 Comparison of the aggregation wait time of a node according to the different depth of the tree using TBDA technique

B. Comparison between the Scalability of Nodes and the Tree Complexity

The tree could be constructed for the deployed sensor nodes. The time complexity of the tree construction depends upon the number of nodes in the network. As the number of nodes increases, the complexity of the tree also increases. The average case time complexity for inserting the node in the tree is O(n log n) and for the worst case time complexity is $O(n^2)$. Fig. 7 illustrates the tree complexity according to the number of nodes in the network using TBDA technique.

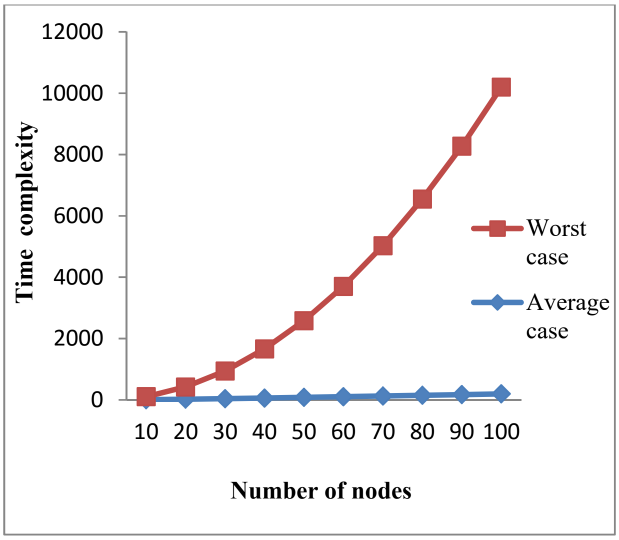

Fig. 7 Comparison of the tree complexity according to the number of nodes in the network using TBDA technique

C. Comparison between the Distance and the Aggregation Wait Time of a Node

Fig. 8 illustrates the distribution of the aggregation wait time of a node and the distance between the nodes. The aggregation wait time of a node is calculated based on the wait time of its source node, base of the exponential function (a=0.5), the depth of the tree, the distance between the aggregator and the source nodes and the data rate of a node. The wait time of a node may be vary depends on the distance between the nodes. The wait time of a node is directly proportional to the distance between the nodes. (i.e) As the distance between the nodes increases, the aggregation wait time of a node also increases. The time taken to transmit the data packet from the source node to its aggregator node is directly depends on the distance between the nodes.

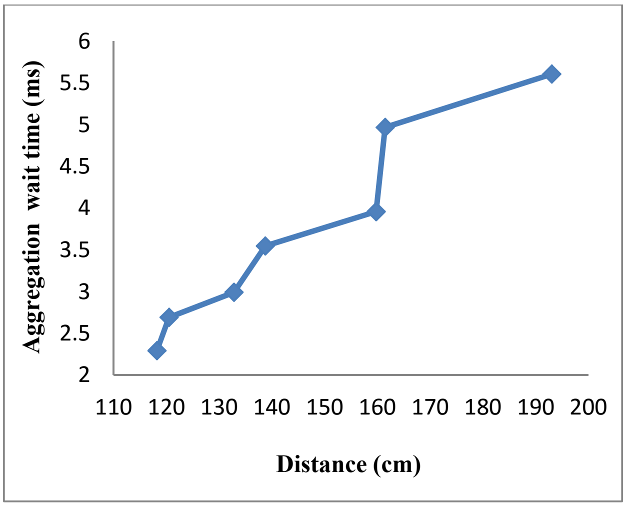

Fig. 8 Comparison of the distance and the aggregation wait time of a node by using TBDA technique

D. Comparison Between the Neighbors and the Aggregation wait Time of a Node

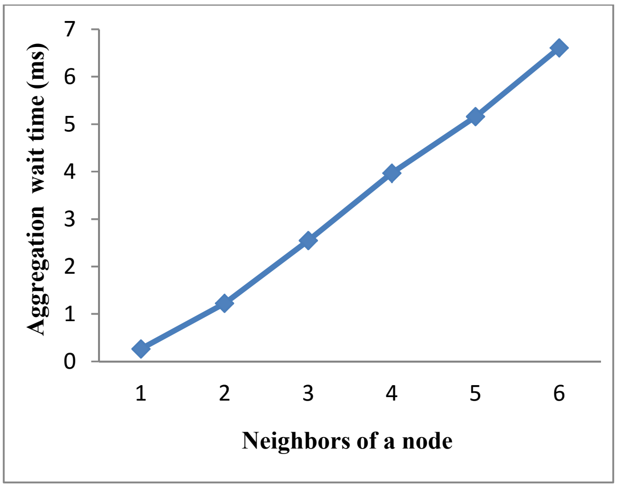

Fig. 9 Comparison of the neighbors and the aggregation wait time of a node by using TBDA technique

Fig. 9 illustrates the distribution of the neighbors and the aggregation wait time of a node. The neighbors of the node is estimated by computing the number of nodes connected with respect to that node. The queue (buffer) status is maintained at each aggregator node in the network. The aggregator node performs the dequeue mechanism and the source node performs the enqueue mechanism. The aggregator node is continuously receives the data packet from its source nodes and it buffers the data packet till the DF_Wait_timer expires. In case, if the buffer overflows before the DF_Wait_timer expires, then the aggregator node aggregates the data packet and sends to the intermediate node. If the number of neighbor nodes increases, then the aggregation wait time of a node also increases. The aggregation wait time of a node is directly proportional to the number of nodes in the network.

VI. Conclusion and Future Work

Data sensed by nodes are transmitted to the sink node periodically, which consumes more communication bandwidth and battery energy, thereby resulting in a high energy consumption of the sensor nodes. The tree-based data aggregation (TBDA) technique is used to avoid the funneling effect and thus increase the lifetime of the wireless sensor network. This work could be extended to balance the workload among the sensor nodes in the network inorder to reduce the tree complexity.

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