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Efficient Method for Identifying Shortest Path in Duty Cycled Wireless Sensor Networks

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Abstract: *A Wireless Sensor Network contains a large amount of Sensor Nodes that are mainly data-centric. The sensor nodes operate on battery they cooperate among themselves and transfer data to the sink which processes the sensed information. The end user can access the information collected by these sensor nodes through the Internet. The proposed algorithm deals to find the optimistic path between the sensor nodes and also between the sink and the sensor nodes. The minimum spanning tree algorithm is used in finding the shortest path and a comparison is performed between the enhanced Kruskal's and Prim's algorithm.*

Key Words: Wireless Sensor Networks, Duty Cycled, Routing Protocols, Shortest Path

I. INTRODUCTION

Wireless Sensor Networks consists of battery powered small nodes which are distributed across the sensing areas. The sensor nodes are usually scattered in a sensor field as shown in Fig 1.1 Each of these scattered sensor nodes has the capabilities to collect data and route data back to the sink. Data are routed back to the sink by multi-hop infra structureless architecture through the sink. The sink may communicate with the task manager node via Internet and satellite.

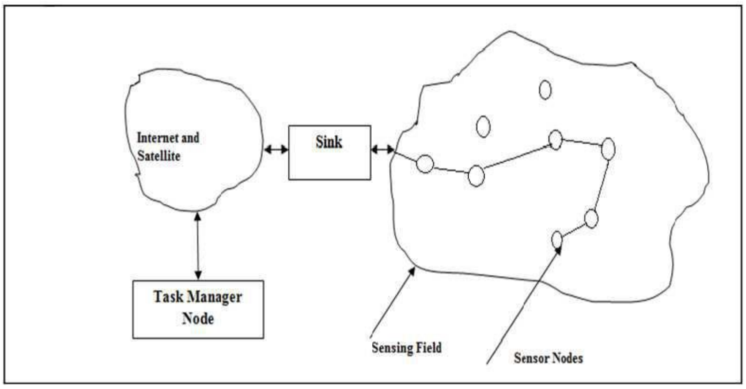

Fig 1.1 Sensor nodes scattered in a sensor field

Routing is the mechanism to find the optimistic path between source to destination. There may be multiple paths from the source to the destination. Therefore, message routing is an important technology. The main performance measures affected by the routing scheme are throughput (quantity of service) and average packet delay (quality of service). Routing schemes should also avoid deadlock. Routing methods can be fixed (i.e. pre-planned), adaptive, centralized, distributed, broadcast.

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Fixed Routing scheme uses Routing Tables that dictate the next node to be routed to, given the current message location and the destination node. Routing tables can be very large for large networks, and cannot take into account real-time effects such as failed links, nodes with backed up queues, or congested links. There is another method called Adaptive Routing scheme which depends on the current network status and can take into account various performance measures, including cost of transmission over a given link, congestion of a given link, reliability of a path, and time of transmission. They can also account for link or node failures. Some of the routing challenges and design issues are

- Data routing methods
- Fault tolerance
- Transmission media
- Coverage
- Data aggregation
- Quality of Service

Also many energy aware routing protocol are proposed to reduce the energy consumption. This protocol maintains set of path instead of maintains or reinforce one optimal path. Maintenance and selection depends on a certain probability which relays on how low energy consumption of each path can be achieved. The possible goal of energy aware routing are

- Shortest-hop (fewest nodes involved)
- Lowest energy route
- Route via highest available energy
- Distribute energy burden evenly
- Lowest routing overhead

This is very much needed in Wireless Sensor Networks since sensor nodes are battery powered and energy consumption is absolutely necessary. Energy consumption can be reduced by following least latency routing in Time Dependent Duty Cycled Wireless Sensor Networks.Least Latency can be achieved by following a shortest path in order to transfer the messages efficiently from the source to the destination.

II. LITERATURE SURVEY

Low Power Listening(LPL) was proposed by Shouwen Lai,Binoy Ravindran. In LPL the Node only wakes up and listens the channel state for a short time period. B-MAC is a Carrier Sense Media Access(CSMA) protocol for Wireless Sensor Networks.It provides Flexible interface to obtain ultralow power operation,Effective collision avoidance and High channel utilization.The disadvantages of B-MAC are it is difficult to reconfigure the protocols after deployment, thus lacking in flexibility.They do not explicitly support adaptive duty cycling, where nodes choose their duty cycle depending on their residual energy.Showen Lai ,Binoy Ravindran also proposed the Adaptive Low Power Listening (ALPL).In ALPL, since nodes have heterogenous duty cycle setting, it is more difficult for neighbor discovery since a node cannot differentiate whether a neighbor is sleeping or failing when it does not receive feedback from the neighbor.Delay-efficient routing over adaptively duty-cycled Wireless Sensor Networks stated by Shouwen Lai and Binoy Ravindran Routing becomes more difficult due to two reasons:

i. Intermittent connection between two neighbour nodes
ii. Changes in the transmission latency at different times.

Two methods to solve routing over intermittently connected Wireless Sensor Networks due to duty cycling are On-Demand Approach which uses probe messages to determine the least-latency route and Proactive Method where all least-latency routes at different departure times are computed at the beginning. The Limitations of On-Demand Approach are that the method does not work well for frequent data deliveries. The Proactive Approach is Centralized approach and is not flexible for distributed construction.Thus both of these approaches suffer from limitations.Routing must be done with least latency inorder to transmit data efficiently. Hence we first model the Wireless Sensor Networks as Time Dependent which can operate for any particular time interval. The sensor nodes are either in a wake mode or sleep state.Solutions for this problem using a centralized approach and has been studied by Time Dependent Graphs .Limitations are it cannot be applied to WSNs where the global network topology is not known by a centralized node. If the whole time period has M discrete intervals we have to execute the algorithm M times, which is inefficient.Multiple executions suffers from high message cost, which is undesirable for resource-limited Wireless Sensor Networks.It computes all pair shortest path which includes node insertions and deletions.It is an efficient incremental solution. Some of the limitations are it needs O(n) space at each node which is impractical for sensor nodes with limited memory capacity.In the Fast Time Dependent Shortest Path(FTSP)algorithm proposed by Binoy Ravindran Initial Route Construction from the source to destination is computed by this algorithm.It exchanges vectors among sensor nodes rather than single values of static link cost and distance.FTSP computes the shortest path for N discrete Time intervals in one execution rather than N different executions.In first Iteration FTSP computes the shortest path for nodes in layers nearest to sink .In next Iteration it goes beyond every layer until last layer is reached.FTSP-M is used for distributed route maintenance with node insertion, updating,and deletion of sensor nodes in a sensing Network. In Dynamic route maintenance each node stores the route information only to sink and it is memory efficient in sensor node with limited memory.Single sink exists in the sensing areas. Limitations include Active Neighbour Discovery and Synchronization . In Active Neighbour Discovery sensor nodes needs to probe the schedule of the neighbours actively to

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find out it's state.Synchronization must be ensured at all neighbouring nodes so that they wake up at the same time when an activity is detected.

A distributed algorithm was proposed for efficient routing in duty cycled Wireless Sensor Networks Shouwen Lai and Binoy Ravindran.It uses a synchronizer which provides synchronization among the Sensor Nodes in asynchronous Duty Cycled Wireless Sensor Networks.The nodes are modeled as FIFO(First In First Out.) where first arriving nodes are served first.The main disadvantage is that the algorithm is based on the observation that the time-varying link cost function is periodic, and hence by derivation, the time-varying distance function for each node is also periodic.

A technique for Power Efficient Routing was proposed by Raja Jurdak, Pierre Baldi, and Cristina Videira Lopes which contains a framework for local optimizations in sensor networks that reduces overall power consumption and provides Load Balancing across sensor nodes.Thus the duties of a sensor node are equally shared among the available nodes. The performance decreases drastically when presented with data sets exhibiting higher variability, spending significant portions of time with an either empty or full battery.

A. Woo, T. Tong, and D. Culler provided a method for Reliable Multihop Routing . In this methodology Link status and routing information are maintained in a neighbourhood table with constant space and reliable routing protocols are also discussed. This method stores more space since every node maintains the routing information of its neighbor. When conjestion occurs it results in unstable network performance due to inteference from collisions and estimations over the same pair of nodes behave differently under different channel utilization The Clustered nodes Routing methodology was initiated by

C. Schurgers and M.B. Srivastava which contains implementation of Bitmap-Assisted (BMA)B-MAC routing protocol for large-scale cluster-based Wireless Sensor Networks. Performance decreases when there is high traffic loads and the number of nodes per cluster increases.An adaptive bidirectional interface for wireless sensor network applications uses this B-MAC protocol. It provides an interface allowing middleware services to reconfigure the MAC protocol based on the present workload of the system.A node's lifetime can be extended by changing the configuration of the B-MAC protocol. A set of benchmark standards are used to assess the performance of Wireless Sensor Networks. Clustered nodes routing using B-MAC protocol extends the lifetime of the system by 50%. Data Routing in Extremely Low DutyCycle Wireless Sensor Network was proposed by Y. Gu and T. He where end-to-end routing does not offer to maintain an always-awake communication backbone. Low duty-cycle always causes unreliable nature of wireless communication. It forces to develop a new routing strategy for such networks, so as to achieve network energy efficiency, reliability. The concept of Dynamic Switch-based Forwarding (DSF) that optimizes the expected data delivery ratio, improves energy consumption and reduces the communication latency DSF is designed for networks with already determined node communication schedules.

H. Chon, D. Agrawa, and A. Abbadi developed a Route Planning based on Time dependency. There are certain methods for speeding up the routing process in Time Dependent Networks called Contraction Hierarchy algorithm which is an modified version of Dijkstra shortest path algorithm is discussed in this paper.It is suitable for time dependent Wireless Sensor Networks.A query is sent to all nodes and based on the response a route plan is proposed. In the algorithm for Initial Route Construction the distances from all nodes to the sink node are initially infinite. The time axis is infinite, the time-varying link costs and distance are implemented by vectors. The algorithm is similar to the distributed Bellman-Ford algorithm. The main difference is that algorithm is exchanges vectors for time-varying link costs and distances, rather than single values of static link cost and distance.However, due to the diagram of Time Dependent Wireless Sensor Networks. Routing in Duty Cycled limited resource in WSNs, it is more important to avoid the exponential message complexity of the traditional Bellman-Ford algorithm. This algorithm is equipped with the vector implementation, this algorithm computes the shortest path in infinite time intervals.The adaptively duty cycled Wireless Sensor networks are modeled as time dependent networks which satisfy the FIFO condition.Then a distributed algorithm is computed which can be executed for a single execution across the entire timeperiod.Then the shortest path found is maintained so that it can be used with suboptimal implementation.The FIFO condition referes to the fact that packet which was delivered earlier will always arrive at a direct neighbor earlier.There are two steps in construction of
shortest path.

i.)A shortest path is created by Minimum Spanning Tree Algorithm.
ii.)A shortest path is calculated and an acknowledgement message is sent to the sink

When comparing to static networks, link changes and node changes are more frequent in duty-cycled WSNs. If a node changes its duty-cycle configuration, or dynamically joins or leaves the network, the links connecting with all its neighbors will be changed at different time intervals. During such conditions occurring a single node update usually causes multiple link updates.Some previous works in static networks have proposed solutions that efficiently deal with single link updates. They are inefficient for multiple link updates caused by a single node update. The algorithms in are also memory-inefficient, since each node stores the route entries for all other nodes, increasing the space complexity. In dynamic Route Maintenance algorithm a node only stores the route to the sink, which is more efficient in WSNs due to their memory constraints.The updates of the shortest path are updated only from the sink to the destination and not on the entire collection of nodes.The node which is to be monitored is first identified . The updating involves creation of initial route and sending an acknowledgement to the sink.The algorithm runs on multiple node when there are multiple node updates.

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III. SYSTEM DESIGN

A collection of Sensor nodes in a Sensing area can communicate among themselves and the shortest path is found out by the minimum spanning tree algorithm.The diagram shown below in Fig 3.1 gives a high level block diagram of Time Dependent Wireless Sensor Networks.

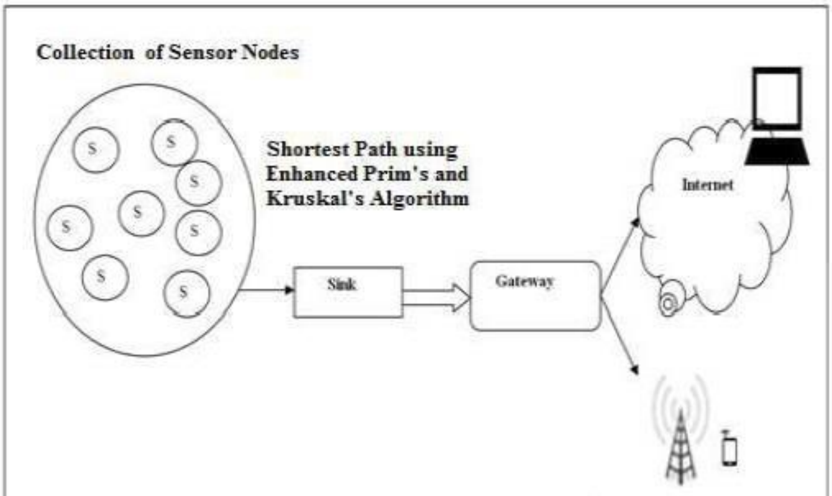

Fig 3.1 Overview of Fast Distributed Routing in WSN

Every node maintains the shortest path to the sink node and does not contain the routing information of other nodes. The sink node interacts through a gateway by which it can be connected with the Internet or transmit information through the Base Station which can be received by the mobile.The Dynamic addition and deletion of Nodes can be easily maintained by changing the initial route maintained.The sensor nodes can represent any of the states as shown in Fig 3.2

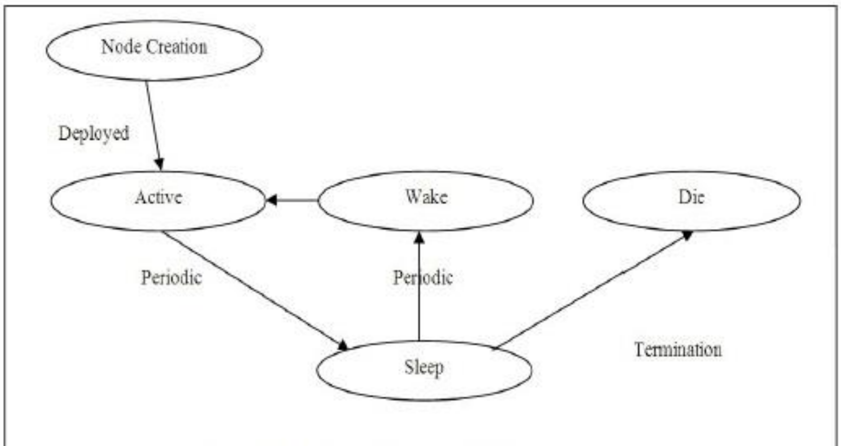

Fig 3.2 States of Sensor Node

The node is initially introduced in to the sensing system which begins to operate in datacentric manner depending on the application. It is active when a particular condition is to be sensed. Then all the nodes either enter in to sleep state or wake up state based on S-MAC protocol. The S-MAC protocol uniformly awakes all the nodes for a certain time period and also the nodes sleeps uniformly for a certain time period. The awake time can be chosen as 120 ms and sleep time can be taken as 2ms as shown in Fig 3.3.The sleep and wake up time period can be changed as per the type of application environment where the sensor node is deployed.A timer is set by the sleeping node and wakes up when it expires.It requires periodic synchronization among nodes to take care of clock drift

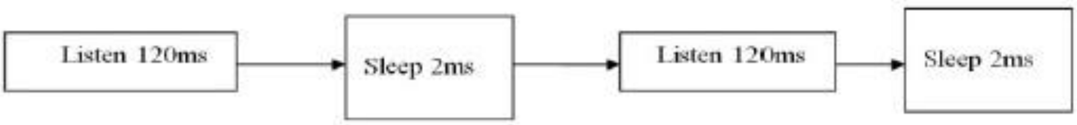

Fig 3.3 S-MAC Protocol

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The sending of message can be by the S-MAC protocol can be represented by maintaining a vector Xi(t).When the value of Xi(t)=1 then the sensor node is active and message can be sent. When the sensor node enters in to sleep state it sets the vector as Xi(t)=0.So when a node wants to send a message to another node in a sensing area then it checks whether Xi(t) is One or Zero and sends message only when it is in awake state ie.) Xi(t)=1.If Xi(t)=0 then it waits for a time period say 120 ms as described in the above S-MAC protocol .Then using the Intial shortest path construction it sends the message. The below flowchart in Fig 3.4 explains the procedure more elaborately

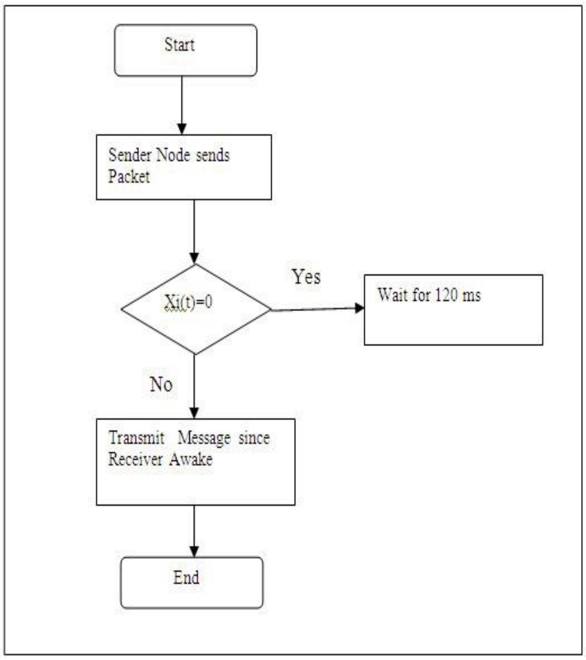
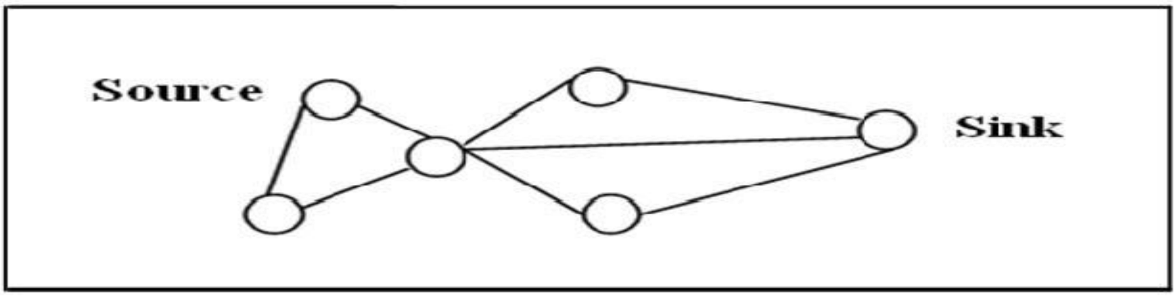


Fig 3.4 Flowchart for Transmitting Messages

The Sensor nodes duty cycle refers the ratio of the active period of the nodes to the full active or dormant period of the sensor node over a predefined time interval.The sensor nodes in a Sensing System can be modeled as directed graph and message can be transferred over the time dependent duty cycled sensor networks.When the message is transferred over the shortest path calculated there is least latency since the optimal path is used to transfer message across the nodes and also from nodes to the sink.Thus the optimal performance is achieved in a sensing system under consideration.The estimation of shortest path for routing in the architecture mentioned above leads to the refinement of Minimum Spanning Tree algorithm namely Prim’s Algorithm ,Kruskal’s Algorithm.Both of the modules are implemented and a comparison is made.Collision avoidance among the sensor nodes is also implemented.The type of routing followed in the above mentioned architecture is multicast routing.

3.1 Enhanced Prim’s Algorithm:

Prim’s algorithm is used for finding the shortest path as the sensor nodes are added to the sensing area. In this algorithm the the array holds the node that have been added.Instead of manipulating the traditional Prim’s Algorithm with weights in each edge the enhanced Prim’s Algorithm works only by the addition of only the active nodes in a sensing area.The distance of every node from the sink is calculated by means of hopcount.During every iteration all of the sensor nodes that are part of the sensing area are checked is selected and then added to the array. It is quite clear that after each round the number of sensor nodes to be checked increases and since each node has a number of edges, we have a loop within a loop.For the last iteration the function must go through almost the entire sensing area.



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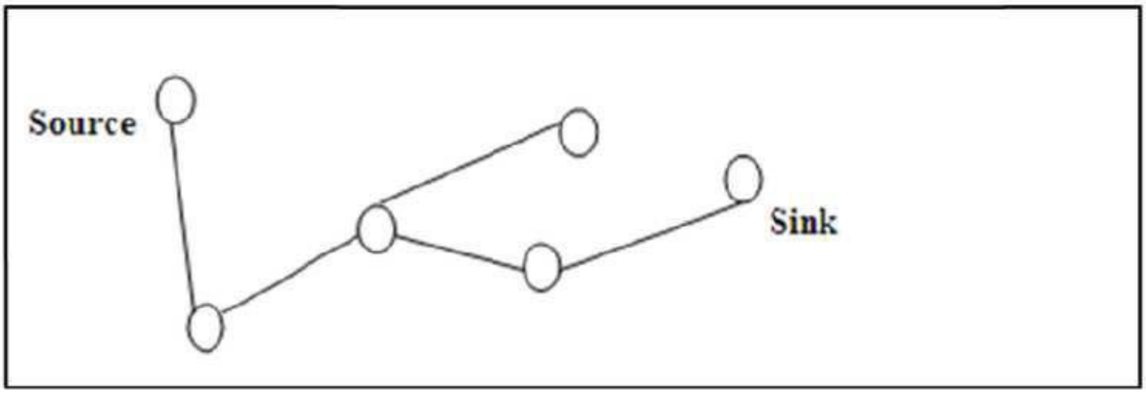
The algorithm repeats until a minimum spanning tree is formed without loop and this gives the shortest path from the source node to the sink.The Fig 3.1.2 gives the structure of minimum spanning tree formed by enhanced Prim's algorithm



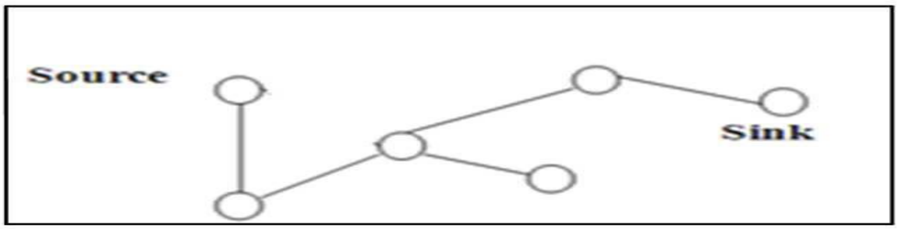
Prim's Algorithm

The time complexity for enhanced Prim's algorithm is O(E +N logN) depending on network structure.The number of edges(Communication Links)are represented by E and Sensor Nodes are represented by N.

A.Algorithm for Source Node in Enhanced Prim's Algorithm:
Initialization:
For any ni which belongs to Nsrc
Curr_Src=ni
ACK_SINK_SRC(i)=0;
Data_Value (i)=0
Data Transfer
If(Data_Value (i) = Sensing_Threshold)
{
then send MSG(src,dest,Hopcount,data) to sink along shortest path by Enhanced Prim Set_Timer(25);
}
If ACK_SINK not received after 25ms
then resend the MSG;
End Data Transfer

B.Algorithm for Sink Node in Enhanced Prim's
Algorithm: Initialization:
For every Nsink which belongs to a Sensing area of N nodes
ACK_SINK=0;
Response Message
If (Data_value(i) = valid_data)
Then send ACK_SINK =1;
Else
Send "Error_Message"

3.2 Enhanced Kruskal's Algorithm:
In this algorithm the the nodes may be in a active state or sleep state.Instead of considering the weights among the edges and sorting them only the active edges along two sensor nodes are identified.Then the number of hops needed to reach the sink is taken as the weight among the edges.The active link among the nodes and the edge with the minimum hop count to the sink is considered first and added to the sensor nodes.The edges are added among the sensor nodes until a minimum spanning tree is formed without a cycle.



Kruskal's Algorithm

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The Fig 3.2.1 gives the Minimum Spanning Tree by
Enhanced Kruskal's algorithm for the sample WSN in Fig
3.1.1. The Time complexity of Kruskal's Algorithm is O(E+log N)
A.Algorithm for Source Node in Enhanced Kruskal's
Algorithm:
Initialization:
For all link Lis which belongs to Nsrc and Nneighbor along the shortest path
Lis=active;
ACK_SINK_SRC(i)=0;
Data_Value (i)=0
Data Transfer
If(Data_Value (i) = Sensing_Threshold and Lis=active)
{
then send MSG(src,dest,Hopcount,data)to sink along
shortest path by Enhanced Kruskal;
Set_Timer(25);
}
If ACK_SINK not received after 25ms
then resend the MSG;
End Data Transfer
B.Algorithm for Sink Node in Enhanced
Kruskal's Algorithm:
Initialization:
For every Nsink which belongs to a Sensing area of N nodes
ACK_SINK=0;
Response Message
If (Data_value(i) = valid_data)
Then send ACK_SINK =1;
Else
Send "Error_Message"

3.3 Collision Avoidance:

When more than one node tries to transfer data at the same time through the same channel then there is a possibility of collision and this leads to corruption of packets. It also leads to energy wastage among sensor nodes.This can be avoided by RTS/CTS mechanism.When a sensor node wants to transfer message the RTS message is sent to the Sink .When a RTS message is sent by a node it is overheard by all the nodes along the shortest path identified.So the overhearing nodes along the shortest path constructed will not send RTS message since there is some node already waiting to transfer the message.The Sink on receiving the RTS message transfer to the sink at the time of RTS being sent then the sink replies with CTS.Then the Source node transfers the message.After the entire message is transferred the next node sends the CTS message

A.Algorithm for Collision Avoidance in Source Node
: Initialization:
For every Ni in N nodes of sensing area
Send Request_To_Send_MSG(src,dest,hopcount,data) to
Sink
RTS[i]=1
Data Transfer
Multicast RTS[i]=1 from Source node to nodes along the
Shortest Path
Algorithm for Collision Avoidance in Sink Node :
Initialization:
For all i=1 toN in Sensing Area
{
CTS[i]=0
RTS[i]=0
}
Response Message
For all i=1 to N in Sensing Area
For all j=i+1 to N in Sensing Area
If(RTS[i] = 1 and Time_of_RTS[i] !=Time_of_RTS[j])

Then send CTS[i]=1
Else
Send “PKT_COLLSION_MSG”

IV. IMPLEMENTATION

The Prim’s and Kruskal’s Algorithm were implemented in NS-2 .The sensor nodes always function according to S-MAC protocol and the time taken to route according to the shortest path is noted.The number of sensor nodes taken in to consideration is 12. The algorithm is simulated using random placement of sensor nodes since the topology of sensor network always vary according to the need of the user.The distance between every sensor node is calculated by the Euclidean’s distance formula|(x1-x2)2-(y1-y2)2|.The distance between every sensor node and the sink is displayed along with the vizualization of packet transmission along the shortest path.A distance of 150 meters is taken as the simulation area for Wireless Sensor Network.When the distance calculated between the sensor nodes exceeds 150 meters then an error message is displayed.This criteria is achieved by setting the threshold value as 150 meters.Destination Sequence Distance Vector Routing (DSDV) algorithm is used .The files for implementing DSDV is correspondingly modified in the simulation tool. The shortest path for a specific discrete time interval is simulated and the trace file values are gathered.

V. EVALUATION

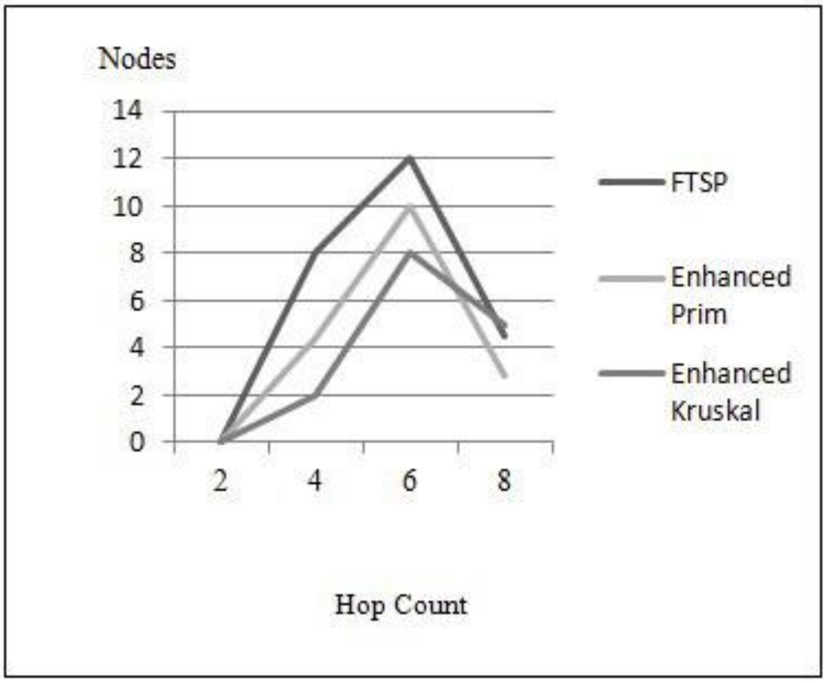
A comparison is made between the Enhanced Prim’s,Enhanced Kruskal’s and Fast Time Dependent Shortest Path(FTSP)Algorithm.The time taken by enhanced Prim algorithm to transfer a message is the least since it works well when the number of nodes are added dynamically to a Wireless Sensor Network.In the enhanced Kruskal algorithm the efficiency increases as the number of links between the sensor nodes increases.This algorithm is best examines if it can receive the message.If there are no data suited when all the messages are broadcasted among themselves.FTSP takes more time to route compared with the Prim and Kruskal’s algorithm.The metrics used in evaluation are as follows

A. Hop Value corresponds the routing distance of nodes throughout the network which considers the end to end latency among the sensor nodes and the energy consumption among them.

B. Data Reliability measures the link quality along the shortest path discovered from each node in the network.It accounts for the end to end message transfer in a Wireless Sensor Network without retransmission.

C. Transmission Rate refers to the ratio of number of packets received at the sink for a particular node to the number of packets actually originated at that node.A value of one indicates that the network is highly reliable since all the messages are received at the processing unit without any loss.

5.1 Analysis of Network by Graph The Wireless Sensor Network of 12 nodes organized as a grid of 100x100 with a random placement of nodes is analysed by means of Graph.The Hop count value is tabulated for the three algorithms as shown in the Fig 5.1.1 which conveys the information that enhanced Kruskal’s algorithm is 50 % more efficient compared to FTSP .The enhanced Prim’s algorithm is 75% more efficient compared to the existing FTSP as the number of nodes increases



The next metric taken for analysis is Data Reliability.The values of data transferred from the source to the sink can be tabulated in a graph as shown in the Fig 5.1.2 .It can be concluded from the graph that enhaced Prim's and Kruskal's algorithm are 50% more reliable than the existing FTSP algorithm.

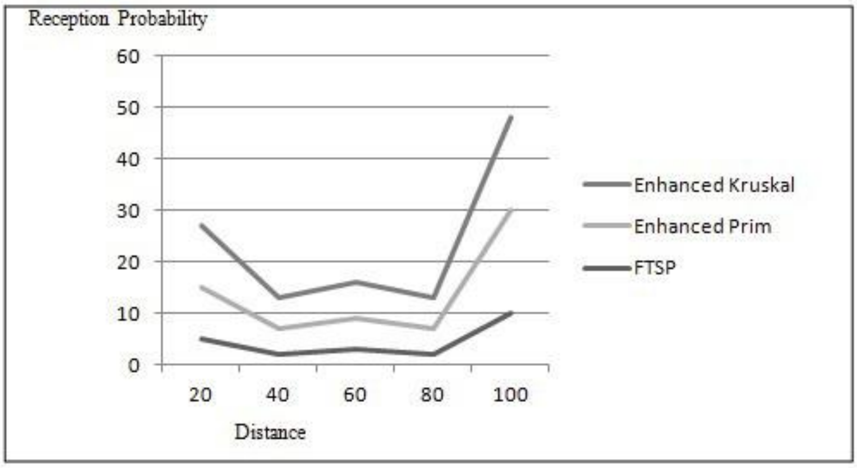
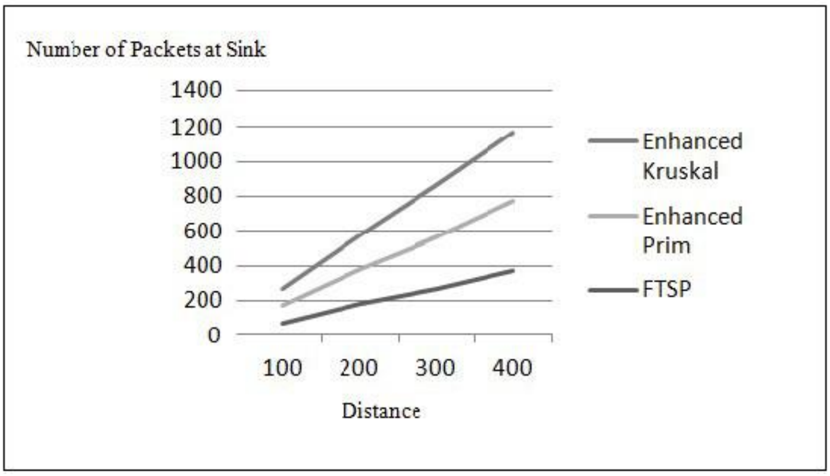


Fig 5.1.2 Data Reliability Analysis

The Transmission Rate can be tabulated in a graph by measuring the total number of packets received at the sink.



It depends on the congestion of the packets in a network and the time period of transfer.Based on the analysis from the Fig 5.1.3 it can be concluded that the Transmission Rate is maximum for Kruskal followed by Prim and finally the FTSP algorithm.Therefore the enhanced Prim's and Kruskal's algorithm are almost 75% more efficient than the existing FTSP algorithm.

VI. CONCLUSION AND FUTURE WORK :

In this paper we addressed the various types of routing in Duty Cycled Wireless Sensor Networks.The strengths and limitations of various methods are surveyed.The best method to achieve least latency is to construct the shortest path using minimum spanning tree algorithm.The enhanced Prim's and Kruskal's algorithm can be used and a comparison can be done based on time and number of sensor nodes in the sensing area.The security of data transferred by multicast routing can be a problem and it is to be addressed in future.The failure of sink posses a threat since the data cannot be processed and some alternate solution needs to be proposed.

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