Geographically Inspired Virtual Grid for Wireless Sensor Networks

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ABSTRACT
Topology management is a critical issue in the context of wireless sensor networks. There are different factors by which topology of a network may be affected. Maintaining this topology in uncontrolled mobility of nodes and make it to work efficiently is a tedious task. In this paper, we propose an efficient topology management strategy based upon geographical forwarding information. Simulation experimentation reveals that geographically inspired virtual grid [GIVG] achieves significant improvements compared to other approaches in terms of energy consumption and communication overheads.

1. INTRODUCTION
Sensor networks are a class of networks which do not have a fixed topology. It contains large number of sensor nodes which may be randomly and densely deployed. The sensor network may be considered as static if the node in the sensor network are not mobile or can be considered dynamic if nodes of the sensor network are able to move. The dynamic sensor networks could be ad hoc without having an explicit centralized node for command, control, and communication purposes [1]. There are many challenges in wireless sensor networks like location management, energy management, topology management etc. [2].

Topology management is of great importance because better management can affect network lifetime, reduce radio interference, improve routing capabilities and increases the quality of network services which overall leads to improving the network performance.

In this paper, we look into some of the topology management schemes which are widely used. These may be grid based techniques like GAF, GBDD, TTDD etc or dual radio based schemes like STEM, GAF,GBDD etc or may be clustering based algorithms like LEACH. Finally we propose an approach Geographically Inspired Virtual Grid [GIVG] which is efficient in maintaining the topology of the sensor network.

2. TOPOLOGY MANAGEMENT
Topology management is a key issue in case of wireless sensor networks. The behaviour of the nodes may change due to many reasons; the maintenance of the topology of that network becomes a tedious task. The behaviour of the sensor nodes may change due to energy depletion, battery drainage, mobility of the node from its place, link failure etc. all these reason adds to the factors of the change in the topology of a network.

To maintain topology of the network we need to focus on the patterns of how that topology is being created. There are many approaches like grid based approaches, cluster based approaches etc. Although these approaches perform well in many scenarios but may have some problems when the challenges like link failure, mobility of nodes and energy depletion are faced. In such conditions the topology of the network may be affected. To handle this topology maintenance problem, we need to design a novel topology maintenance approach which could handle the problems mentioned and could cope with the harsh limitations of the wireless sensor networks.

3. TOPOLOGY MANAGEMENT ALGORITHMS
There are many kinds of algorithms used for topology management and routing in wireless sensor networks. These algorithms could be hierarchical based, location based, virtual grid based and many more. A few of them are discussed here.

Geographic adaptive fidelity GAF [3] is an energy aware location based routing protocol for wireless sensor networks. In this protocol, the virtual grid is used and each node uses GPS based location information to associate itself to the virtual grid. The whole network is divided into a number of blocks and in each block a master is chosen. This election of master in each block could be chosen on the basis of its residual energy. In each block of the grid an election between the members of the block takes place to choose a node and remains awakened for a period of time before going to sleep. This is the node responsible for forwarding the data towards the sink on behalf of the node in that zone and can be considered as a master node. The three phases of the node used in GAF are sleep, active and discovery.

Pilot [2] in this approach wireless sensor network consists of two types of sensor nodes. The first types of nodes are w-nodes and the second one are lightweight pilot nodes. These pilot nodes are capable of moving to the desired position where they are supposed to move. All nodes know each other's location and are location aware. The status of the links in the network is checked by the acknowledgement massages flowing in the network. If the acknowledgement message if found is missing than it may be a case of link failure. If the link is found to be failed than a suitable pilot node is selected and directed to the position of the failed link. Now this pilot node acts as a bridge to the failed link.

STEM [4] deals well with the condition where the next hop in the path from source to sink is turned off as it does not detect the same event. Here each node will periodically turns on its radio to check whether any node wants to communicate. If some node wants to communicate with that node than it sends a beacon message with an ID. This node calls an initiator node and node receiving that beacon message is called as target node. This target node remains awakened a path is created. If this path is to be extended further the target node becomes the initiator node and process is repeated.

Two tier data dissemination TTDD [5] is an approach in which virtual grid is constructed. In this, the nodes are location aware and homogenous which can communicate with each other using short-range radio. Whenever a source generates a stimulus, the nearest node detects that stimulus and initiates the grid construction. a threshold is chosen to decide the size of each block of the grid is considered as dissemination node. The grid continues to be constructed till this distance exceeds the threshold. When the whole grid is constructed the sink sends the query to its immediate dissemination node which further sends it to its upstream dissemination nodes, till it reaches the source. Now the data from source to sink is sent by the same path traversed by the query in reaching to source.

Geographic and Energy Aware Routing GEAR [6], uses energy aware and geographically-informed neighbour selection heuristics to route a packet towards the destination region. In this the number of interest in directed diffusion is not considered for whole region or network rather for a small or certain region only. This makes GEAR more energy efficient. Each node in GEAR keeps estimated cost as well as learning cost to reach the destination via any other node or its neighbour. The estimated cost is a combination of residual energy and distance to destination. Learned cost estimate cost in routing around holes. A hole occurs when the node is isolated from other nodes or no other nodes are near that node. The learned cost and estimated costs are same in case of no holes.. The learned cost is propagated one hop back every time a packet reaches the destination so that route setup for next packet will be adjusted.

GBDD [7] grid based data dissemination is an approach which uses dual radio mode of sensor node to decide cell size of a grid i.e. high and low power radio ranges are used to decide the size of the square sized cell. The grid is constructed only when the sink first time appears in sensor field which remains valid for very large duration. For subsequent appearances of other sink or sinks, grid construction is triggered only if valid grid is not present in sensor field. If valid grid is present, sink discovers closest corner node (called dissemination node (DN)) of a cell of existing grid by broadcasting grid probe messages and makes it as immediate dissemination node (IDN). IDN further sets path up to last dissemination node towards event or up to DN at point of intersection of existing and new path. All nodes in a cell form a cluster with one of corner nodes acting as cluster head and communicate with it in single hop. Also, initial path setup from source nodes to sink is proactively initiated by source nodes by sending initial path setup message to their cluster head dissemination node immediately after detecting presence of an event. Path setup message follow shortest geographical route to sink by selecting at each node a one hop neighbour closest to the sink. This sets initial path between source-sink pair.

LEACH [8] uses clustering approach instead of a flat or non layered architecture. Here the network is divided into many clusters of sensors using localization coordination. Instead of sending the whole original data to the sink only a part of data is send to the sink. For this purpose the data is fused and only the meaningful data is sent to the sink. This makes routing more scalable. Each cluster head sends data directly to the sink.

4. GEOGRAPHICALLY INSPIRED VIRTUAL GRID [GIVG]

In this work, we propose a virtual grid construction similar to TTDD. However in TTDD source and sink are unaware of each other's location and hence the axis of virtual grid created is not specifically aligned to any particular direction. Here, we assume that source node knows approximate location of the sink node using GPS. Therefore, as grid construction start the initiator source node forms a grid structure by making X-axis of grid towards the approximate location of the sink. Hence unlike TTDD, GIVG has almost straight line path through dissemination nodes (i.e. corner nodes of the cell) linking source and sink.

However with the passage of time, due to the movement of source or sink, this alignment may be disturbed. GIVG tries to maintain the path by partial path modification.

Assumptions:
-Sensor field is flat and spreads in two dimensional plain of Xn * Yn.
-Sensor nodes are static and do not change location at their own.
-Communication among sensor node is symmetric.
-Whenever source appears sink knows its approximate location using GPS.

Grid construction:
-Let source location be Lsource (Xsr,Ysr) and location of sink be Lsink(Xsn,Ysn).
-Let the cell size be "*a*".

Source node Ns start constructing the grid by using geographic greedy forwarding method. This is similar to TTDD but the care is taken to align X-axis towards the sink. The complete grid construction is as follows –

First of all the source node (Ns), calculates its adjoining four corner nodes of a cell. This calculation is done by selecting one of the corner nodes aligned towards the sink, which ensures almost straight line path towards sink. Coordinates of corner nodes of a cell Lp(Xi,Yj) are calculated, where (Xi,Yj) are mathematically calculated coordinates but there is a chance that no node is present exactly at these coordinate. We use geographical greedy forwarding method to select the nearest node to this point. This node is known as dissemination node. In this manner, next selected dissemination node also calculates its four adjoining corner nodes and respective dissemination node.

1) Source location Lsr = (x,y), sink location Lsn = (x,y)
2) X-axis be the line joining sink and source Grid construction
3) Cell size of Lsr = *a*
4) Dissemination points for Lsr(x,y) = Lp(Xi,Yj) such that
 {Xi = x+I *a, Yj = y +j*a;
 I,j = ±0, ±1, ±2……}
5) Source sends data announcement message to Lp
6) Next node ← nearest Lp
7) If next node distance to Lp < *a*/2
 Then next node = dissemination node
 Else
8) Check other nodes with minimum distance
 If distance > a/2 than drop the message
 Else
 Repeat step (7)

Query and data forwarding

9) Sink sends the query to its nearest dissemination node.

10) This dissemination node forwards this query to its upstream dissemination nodes till it reaches the source.
11) The data is forwarded with the same path by which the query traversed.

4.1 Explanation

In Geographically inspired virtual grid [GIVG] we have taken two assumptions. The first assumption says that the sensor field is two dimensional means, X-axis and Y-axis. According to the second assumption the sink as well as the source knows each other's positions in that two dimensional sensor field.

Step 1) this step shows the locations of the source as well as the sink in the two dimensional sensor field (figure 1).

Step 2) As both the nodes know each other's position a straight line joining these point is supposed to be the X-axis for the construction of the grid (figure 2).

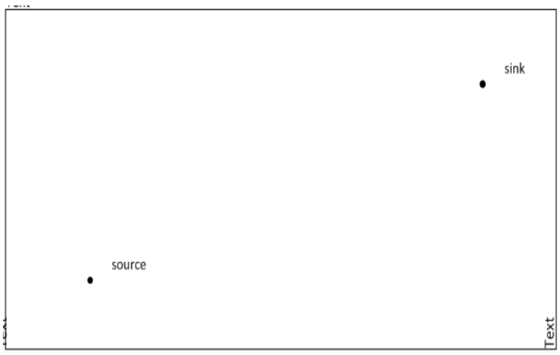

Fig 1: Shows two dimensional sensor field showing the source location as well as source location.

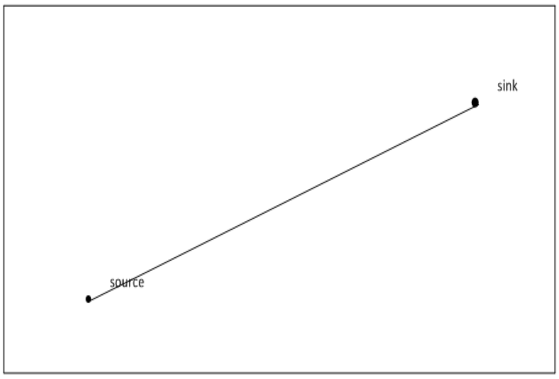

Fig 2: Shows the line between source and sink shows X-axis on which the grid is to be constructed.

Step 3) the size of cell's each row and column should be approximately "*a*" which means the distance between each dissemination node should be around *a*. this value of a depends upon a number of constraints like radio coverage, density of the network etc.

Step 4 – 8) these steps involves the method of constructing the grid with the assumed X-axis. The constructed grid looks like figure (3).

Step 9-10) Sink sends the query to its nearest dissemination node. This dissemination node forwards this query to its upstream dissemination nodes till it reaches the source (figure 4).

Step 11) the data is forwarded reverse to the path to which the query had traversed (figure 5).

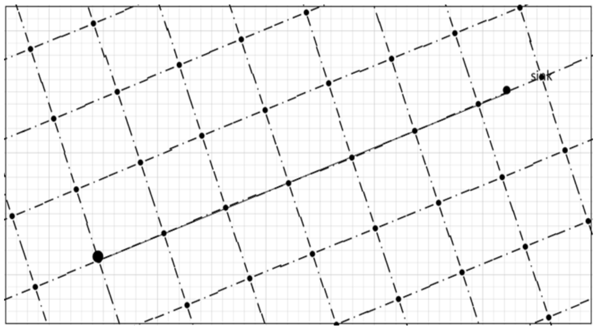

Fig 3: Shows how the grid will be constructed.

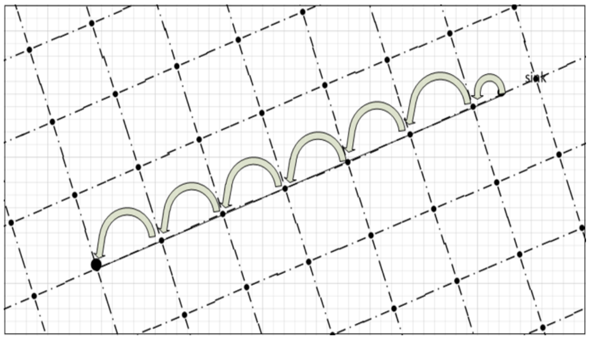

Fig 4: Shows the flow of query from sink to source.

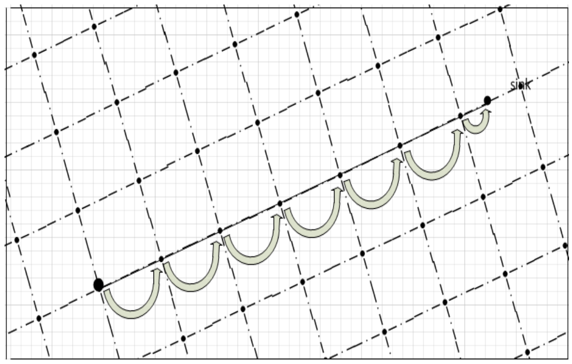

Fig 5: Shows data forwarding from source to sink.

5. OVERHEAD ANALYSIS

In this section, we analyze the efficiency of TTDD and GIVG. We measure the metric of the communication overhead for a number of sinks to retrieve a certain amount of data from a source. We study both the stationary and the mobile sink cases. We compare GIVG with TTDD, in which the path followed by the query and data in not a straight path between sink and source. Although each employs different optimization techniques, such as data aggregation and query aggregation, to reduce the number of delivered messages. Because both aggregation techniques are applicable to TTDD as well as GIVG proposed scheme, we do not consider these aggregations when performing overhead analysis. The goal is to keep the analysis simple and easy to follow while capturing the fundamental deference between TTDD and GIVG.

5.1 Models and Notation

A sensor field of area A is considered which contains N number of sensors which are distributed uniformly. Each side of sensor field have √N sensor nodes approximately. The number of sinks in the sensor field is k. The average speed of a sink is v when data packet d is received for the time period of T. The size of data packet and query packet is *l*. The number of sensor nodes present, is the key factor of communication overhead in flooding the area. They are directly proportional. And more the number of sensor nodes along the path more the communication overhead so they are also directly proportional.

Sensor field is divided into cells in TTDD, the area of each cell is a^2. n = $\frac{na^2}{A}$ is the number of nodes in each cell. A cell contains √n sensor nodes on each side. The maximum number of cell a sink can traverse is m, bounded by $1+\frac{vT}{a}$. m =1 for a stationary sink.

5.2 Communication Overhead

In this section we analyse the communication overheads of TTDD and GIVG. The overhead for the query to reach the source, without considering potential query aggregation, is: n*l* + √2(c√N)*l*.

Where n*l* is the local flooding overhead, and c√N is the average number of sensor nodes along the straight-line path from the source to the sink (0 < c ≤√2). Because a query in TTDD traverses a grid instead of straight-line path, the worst-case path length is increased by a factor of √2.

Similarly the overhead to deliver $\frac{d}{m}$ data packets from a source to a sink is √2(c√N) $\frac{d}{m}$. For k mobile sinks, the overhead to receive d packets in m cells is:

$$Km\left(nl + \sqrt{2}(c\sqrt{N})l + \sqrt{2}(c\sqrt{N})\frac{d}{m}\right) = kmnl + kc(ml+d)\sqrt{2N}$$

Plus the overhead N*l* in updating the mission of the sensor network and $\frac{4N}{\sqrt{n}}l$ in constructing the grid, the total communication overhead (CO) of TTDD becomes

$$CO_{TTDD} = Nl + \frac{4N}{\sqrt{n}}l + kmnl + kc(ml+d)\sqrt{2N} \quad (1)$$

In proposed Geographically Inspired Virtual Grid [GIVG] approach the path between source and sink is always in a straight line. So the average number of sensor node in the path between source and sink is c√N. The overhead for the query to reach the source, without considering potential query aggregation, is:

$$nl + (c\sqrt{N})\,l$$

the overhead to deliver $\frac{d}{m}$ data packets from a source to a sink is (c√N) $\frac{d}{m}$. For k mobile sinks, the overhead to receive d packets in m cells is:

$$Km.\left(nl + (c\sqrt{N})l + (c\sqrt{N})\frac{d}{m}\right)$$

Plus the overhead N*l* in updating the mission of the sensor network and $\frac{4N}{\sqrt{n}}l$ in constructing the grid, the total communication overhead (CO) of GIVG becomes

$$CO_{GIVG} = Nl + \frac{4N}{\sqrt{n}}l + kmnl + kc(ml+d)N \quad (2)$$

Figure (6) shows the comparison between TTDD and GIVG for communication overheads with different number of sinks.

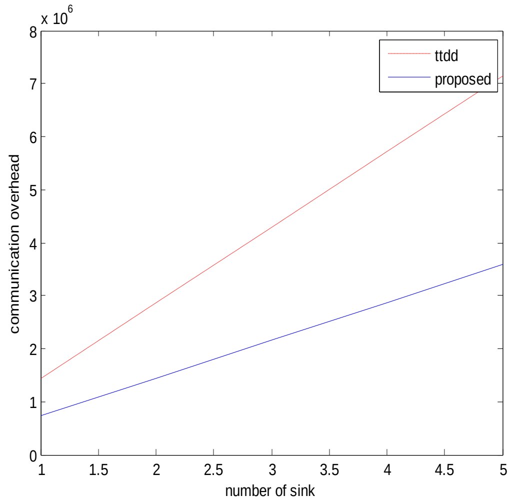

Fig 6: Shows the comparison between TTDD and proposed GIVG scheme with communication overhead on different number of sinks.

6. ENERGY CONSUMPTION

The energy consumption in TTDD as well as GIVG depends upon the number of times grid is being created, number of sensor nodes and dissemination nodes between sink and source, the energy used in sensing and forwarding the data and query. The energy consumption in a sensor network can be obtained by measuring the residual energy of a sensor network. Each sensor node in a network has energy which is used at the time of receiving, processing or transmitting the data or query. To compare TTDD with proposed Geographically Inspired Virtual Grid [GIVG] we are using the parameters with mentioned values and will see the result on 2000 number of rounds.

Table 1. Table of Parameters

S. No.	Parameters Used in Simulation		
	Parameters	**Value**	**Unit**
1	Number of nodes deployed	100	
2	Node distribution	(0,0) to (100,100)	Meters
3	Initial energy of each node	1	Joules
4	Data packet length	5000	Bits
5	E_{elec}	50	nJ/bit
6	$\epsilon_{mp}{}^{c}$	0.0013	pJ/bit/m^4
7	$\epsilon_{fs}{}^{b}$	100	pJ/bit/m^2
8	$E_{processing}$	5	nJ/bit
9	c	1.414	
10	*A*	20	

In this paper, simulations have been carried out using MATLAB taking 100 randomly deployed sensor nodes over the square field of 100m×100m .It is assumed that the transmission between sensor and sink node is reliable and sensor node can send the data once in a round.

The depleted energy of the sensor nodes to transmit l bits over a distance 'd' between sensor nodes for each round is given by the expression [9,10,11].

$$E_{Tx}(l,d) = E_{Tx\text{-}elec}(l) + E_{Tx\text{-}amp}(l,d) \quad (3)$$

$$E_{Tx}(l,d) = l\,E_{elec} + l\,\epsilon_{mp} d^4 \quad \text{for } d>d_0 \quad (4)$$

$$E_{Tx}(l,d) = l\,E_{elec} + l\,\epsilon_{fs} d^2 \quad \text{for } d\le d_0 \quad (5)$$

Where $d_0 = (\epsilon_{fs}/\epsilon_{mp})^{1/2}$ (6)

- E_{elec} represents power consumed by launching circuit or receiving circuit.
- ϵ_{mp} represents energy consumed by the circuit to launch 1-bits of information to 1 square meter.
- ϵ_{fs} represents energy consumed by the circuit to launch l-bits of information to 1 square meter in free space.
- l is the size of data packets in bits.

In case of TTDD the energy depletion will be.

Energy network TTDD (r) = Energy network (r-1) –

$$((l * (E_{Tx}(l,d) + \epsilon_{fs} * d^2)) + (\sqrt{2}*c*(\sqrt{N}-2)) * ((l * E_{Tx}(l,d) + \epsilon_{fs} + \epsilon_{Rx} * d^2)) + (l * \epsilon_{Rx})) / N \quad (7)$$

In case of proposed Geographically Inspired Virtual Grid [GIVG]

Energy network proposed (r) = Energy network (r-1) –

$$((l * (E_{Tx}(l,d) + \epsilon_{fs} * d^2)) + (c*(\sqrt{N}-2)) * ((l * E_{Tx}(l,d) + \epsilon_{fs} + \epsilon_{Rx} * d^2)) + (l * \epsilon_{Rx})) / N \quad (8)$$

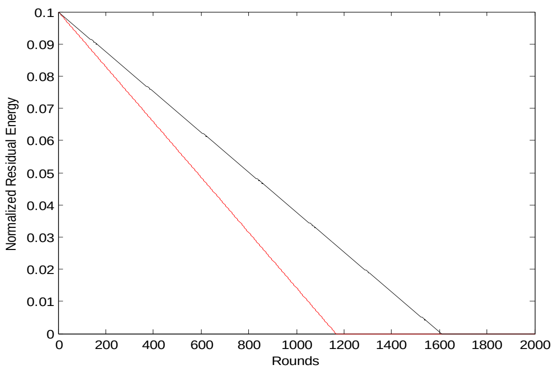

Fig 7: A the simulation of the two for 2000 rounds shows that the network runs out of energy in 1163rd round for TTDD while in case of GIVG proposed approach, it runs out at 1610th round

7. CELL SIZE

As suggested in TTDD, the cell size affects the energy consumption in the network. We need to analyze the affect of different cell sizes on our scheme too. To compare both the schemes we are simulating our approach o the same data used in the TTDD i.e. 961 sensor nodes are used in 6200 X 6200 m^2 field. The regular space between the sensor nodes is 200 m which makes it simple. There is only one source and only one sink considered in this simulation. The speed of the sink is 10 m/s constantly. The variation of cell size is 400 m to 1800 m with an incremental interval of 200 m. the focus of this simulation is kept on energy consumption.

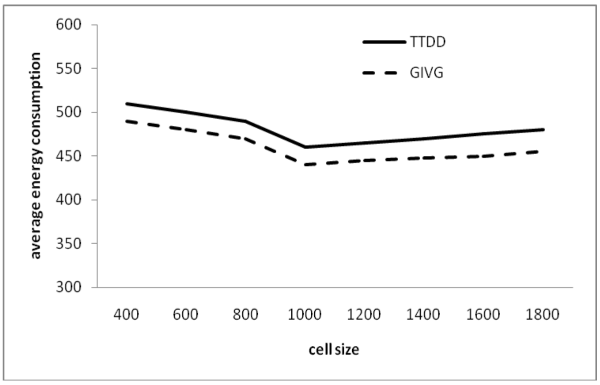

Fig 8: Shows that energy first decrease with increase in the cell size because the overhead of creating grid will be reduced and energy will be saved. But as shown in figure when the cell size reaches 1000m the energy consumption start increasing because in larger cells the local query flooding consumes more energy.

The behaviour of, GIVG as well as TTDD are similar when the cell is increased but GIVG has the advantage of having shorter path with lesser number of nodes in between sink and source. So the energy consumption in data and query forwarding will be saved in GIVG. The figure shows that energy first decrease with increase in the cell size because the overhead of creating grid will be reduced and energy will be saved. But as shown in figure when the cell size reaches 1000m the energy consumption start increasing because in larger cells the local query flooding consumes more energy. So the performance of GIVG is better than TTDD (figure 8).

8. PATH LENGTH

Path length is the number of nodes between source and the sink. As we have seen in the paper that proposed GIVG approach follows a straight line path between sources and sink it will provide a shorter path as compared to the TTDD.

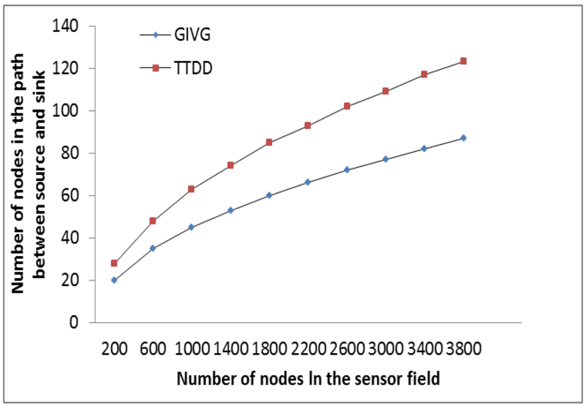

Fig 9: Shows the comparison between the length of the path between source sink. The upper red line shows the path length of TTDD and the lower blue shows the path length of GIVG on given number of sensor nodes.

9. FUTURE WORK

Wireless sensor network is a hot field now a days. Topology management being a key constraint require deep research to make wireless sensor network more dynamic and more advanced. Many algorithms designed earlier perform well in many aspects. TTDD is among one of the widely adopted approach in wireless sensor network. GIVG approach in the paper shows how the improvement over TTDD can be done.

The proposed GIVG approach leaves a room for improvement in many areas like how to exactly locate the position of each and every sensor node. The GPS locators also have some margin of error and in real world the locator should be able to locate in 3 dimensions. Moreover making each node know it's and other node's location is also an area which requires improvement in GIVG. In case of highly mobile nodes the path lengths is compromised and can be improved by reconstructing the grid which can also be an area to work upon.

10. CONCLUSION

In this paper, different topology management approaches are discussed. As topology management is a critical issue in case of wireless sensor networks, it requires a novel approach to deal with it. The simulations show that the proposed approach "Geographically Inspired Virtual Grid [GIVG]" performs better than discussed approaches.

The energy consumption in case of Geographically Inspired Virtual Grid [GIVG] is much less as compared to Two Tier Data Dissemination [TTDD]. Less the energy consumption more the network lifetime. This shows how GIVG is more durable. In case of communication overheads also GIVG gives better results when compared with TTDD. Communication overheads are source of degradation of a network and affect the energy consumptions too. GIVG has a shorter path and work better in case of different cell sizes. Due to its geographic awareness and shorter path properties GIVG could be a good option for topology management and routing in wireless sensor networks.

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