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Mobility of sink using hexagon architecture in highly data centric Wireless Sensor Networks

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Abstract— Mobility of sensor nodes brings the new challenges in wireless sensor networks. The mobility of sensor nodes in conjunction with harsh environmental conditions has influence on link reliability and energy efficiency. The energy losses are associated with the movements of the nodes and frequent updating of their coordinates which ultimately results in setting up of the final path. Here, we propose an algorithm MSDC (Mobile Sinks Data Centric), which with the help of direction agent (DA) makes the network more efficient. Direction agent (DA) and Data Dissemination Node (DDN) persistently senses the event in local grid and guides the DDNs where to disseminate the data packet. Then DDN will decide the shortest path by which the query and data is to be processed. Simulation results show how our approach can reduces the energy consumption, overhead delays, and to obtain the optimum data route.

Index Terms— Direction Agent, Data Dissemination Node, Data aggregation, Efficiency, Grid formation, Route optimization.

1 Introduction

Wireless Sensor Networks (WSNs) are emerging as an important technology. It is due to their utilizations in battlefield surveillance, home security, fire prevention, safe landing of aircrafts and crop monitoring etc. These nodes enhance the probability of determining the threats in a cost effective and efficient way [1]. WSNs are numerous miniatures which are wirelessly connected. They are low-cost and specifically designed power constrained group. Energy conservation is by and large considered as one of the important parameters because they have limited battery backup. In most of WSNs applications, nodes are normally stationary. However, there are certain applications where the nodes move and therefore position-awareness becomes the critical issue e.g. fire, traffic, habitat monitoring, and battlefield surveillance etc. In case of battlefield surveillance, in which soldiers (mobile sinks) travel in battlefield when enemy tanks (stimulus) approaches them. In such applications, data should not be lost as it is an important deciding factor. Therefore, multiple paths from source to destination are essential. When stimulus / events are triggered, node senses the data and transfers it to the sink [2, 3]. Sensed data is aggregated and then flooded to the next nodes. With node mobility the data communication suffers and leads to the following problems:-

1. Connectivity and,
2. Energy efficiency.

A few researches have been conducted where the nodes are in mobile state. Mobility of nodes introduces additional overhead, increases complexity, and failure of conventional routing algorithms [4, 5, 6]. It also degrades the performance of the system and makes the research issues more arduous.

TTDD [7] is a hierarchical routing protocol which transfers the data to different nodes by forming grid structure. Li et al [8] stated that in TTDD, all the four (corner) data dissemination nodes are active. MSDC is new routing protocol which gives a new way for dissemination of data in sensor networks. Here, the sensor field is divided into two functional nodes i.e. Direction Agent (DA) and Data Dissemination Node (DDN). DA will sense the event and guide the DDN, where to disseminate the data announcement. DA will sense the event and broadcast the data to all the six DDNs in the cell. Any query for the event may contact any of six DDNs nearest on the way. All six DDNs in particular event cell will have data and other DDNs in grid will have data announcement information. In MSDC, each node will create a grid structure of regular hexagon of edge ‘α’. Each grid of hexagon shape will have DDN at edge which will disseminate the data from the sink to source and vice-versa. In MSDC, DA will increase the efficiency of local network node by persistently sensing the event in the local grid. MSDC increases the reliability by providing the multiple paths. MSDC reduces the number of active nodes by directional agent which will remain active for path finding and data transfer. DA will keep an extra copy of the data, which can be used in the case of source failure. DA agent will transmit the data to the DDNs and the DDNs which are in the particular cell they have the data and rest will have the data announcement information.

2 Characteristics of MSDC

The characteristics of the routing protocol that lead to the better and efficient design of sensor networks are:-

1. MSDC is distributed and able to sustain the non-stop operations all the time.
2. It is adaptive to change according to the mobility of nodes.
3. It is looping independent in order to avoid deadlocks.
4. It is localized- the localized
5. It is reliable by using multiple paths.
6. It is scalable in large-scale sensor networks.

2.1 Construction of grid in MSDC

We consider a two-dimensional sensor field where a source with DA divides the field into a grid of cells and each cell is of regular hexagon shape with side α. The source itself is at one crossing point of the grid with DA at the center.

Figure 1

For creating directional point, the source sends a data-announcement message i.e. it transmits the message to the neighboring node that has the smaller distance as specified in the message. The source chooses three direction points at 120° apart, and then in the perpendicular direction to a distance of

√3α from each direction point and hence other directional point is created. The similar procedure applied in the whole area to create the directional points. Now these directional points will choose the nearest node as a direction agent.

Figure 2

Construction of grid starts with data announcement. Source sends a data-announcement message i.e. it floods the message to the neighboring node about possession of data. As shown in the Figure 2, the source chooses three direction points at 120° apart, and then in the perpendicular direction to a distance of √3α from each direction point (Figure 3). Now taking one point as a reference point, this created point will further create another direction point in exactly opposite direction to the reference one. The similar procedure is applied in the whole area to create the directional points. Now these directional points will choose the nearest node as a direction agent.

Figure 3

Taking the source as initial, the direction points will multicast the data in 360 degree so that dissemination points are created with each angle of 60 degree. Now, the node closest to the dissemination point selected as data dissemination node (DDN) for data forwarding.

The nodes that are in the center of the hexagon are termed as Directional Agent (DA) and rest nodes are termed as dissemination nodes.

Figure 4

Figure 5

Query has been forwarded from sink to source through data dissemination nodes (Figure 5), using the information about the location of the source from the data announcement message. From source to sink the path has been set, from where the data will be sent. The data will be transmitted as it is already available with DDNs nearby source only when the query is fired.

If the dissemination point falls into a void area, data propagation can continue with alternative paths as the dissemination node forwards the data announcement to all the dissemination nodes. In case any DDN crash then the other DDNs will take over and data transmission will not suffer. Direction agents and dissemination node are different for different sources, which will increase the scalability.

Lifetime of grid depends upon the expiry time set up by the source node. Expiry time of source is propagated to all nodes in the data announcement message. Lifetime of the source depends on the frequency at which events are generated by the stimuli. These are the intelligent nodes therefore the information about the life time of the particular node sent along with the data.

Expiry time for the first source may be a default time, say 10 minutes. Similarly the expiry time for the second source will be the time difference for the stimuli to reach 2nd source from 1st source. Expiry time will be set in the similar manner for 3rd, 4th so on and so forth.

2.2 Working of MSDC

MSDC forwards the query to ensure scalability and efficiency using the grid. When a sink needs data, it floods a query within a local circular area of α/2 radius about 1/3rd of a cell size large to discover nearby data dissemination node or directional agent. The sink specifies a maximum distance of α/2 in the query message, thus the propagation of query message stops at nodes that are more than the maximum distance i.e. α/2 away from the sink.

If the query reaches the directional agent, the DA will forward it to local dissemination node (local dissemination node will be in the direction of the source).

Figure 6

Once the query reaches a local dissemination node (directly or via DA, Figure 6), which is called an immediate dissemination node for the sink, it is forwarded, in the grid, to other dissemination node in the direction of source, from which this immediate dissemination node receives data announcements. The receiving node in turn forwards the query further towards the source, until finally the query reaches the source. During the above process, each dissemination node stores the location of the upstream dissemination node from which it receives the query. This state is used to direct data back to the sink later. After receiving the upstream location of sink, the source node will forwards the data using the same path. If a data dissemination node has aggregated queries then it will send a copy to all the downstream nodes. As shown in figure 7, aggregation node will cumulative the query during upstream updating and send copies to each downstream node during data forwarding. After first location update every next location update will be considered as a validation method. Each node in the path from sink to source will get a validation message in every 10 milliseconds. On reception of such validation methods, all DDN's participating in the path will store the upstream and downstream information. If validation message is not received by DDN within 10 ms then it will remove all information after 20 ms, considering that the path is no longer in use.

With the grid infrastructure in place, the query flooding can be confined within the region of around a 1/3rd cell-size. It saves energy and bandwidth compared to flooding the query across the whole cell. Within a cell, an immediate dissemination node that receives queries for the same data from different sinks accumulates these queries at the aggregation node. It only sends one copy to its upstream dissemination node, in the form of an upstream update. Similarly, if a dissemination node on the grid receives multiple upstream updates from different downstream neighbors, it forwards only one of them further using data aggregation technique.

Figure 7

Immediate data dissemination node will continue upstream updating of sink mobility to the dissemination node, depending on which dissemination node will continue sending the data. When the sink moves from one cell to another, the immediate dissemination node vanishes and again by location updating of sink a new path has been set.

MSDC forwards the data in a very simple manner. After receiving the query from the data dissemination node, the source sends the data to the same data dissemination node which subsequently forwards the data from where it receives the query. This process is continued till the data reaches the sink's immediate dissemination node. At any node if the query is aggregated then the data dissemination node will send a copy of data to each one of the downstream data dissemination node.

MSDC uses the path forwarding technique for continuous flow of data from immediate data dissemination node to mobile sink. The path forwarding approach correlated each sink with the primary and immediate agent. Sink imbibe adjacent node location as primary agent in its query. Data from immediate data dissemination node is routed to the sink through the primary agent.

In case, a mobile sink walk out from the range of immediate agent then its location is registered by another new neighbouring node as a new immediate agent and its location is updated to its primary agent as well as to the old immediate agent. User can collect data seamlessly while on constant move because of the immediate agent portray to the sink as sink's primary agent. As soon as the sink enters to the new cell, its location is updated by new formed primary agent and will discover the nearest data dissemination node by flooding locally. A timer equivalent to the sink's life in a cell is made so that the old primary agent comes to an end to avoid the duplicate data transmission. If there is no request from the sink or neighboring downstream data dissemination nodes, then the immediate data dissemination node of the sink stops forwarding update messages to its upstream data dissemination node.

3 OVERHEAD ANALYSIS

In overhead analysis, we will find the efficiency, scalability of MSDC for number of sinks to retrieve about the data and complexity for stationary or mobile sink.

We compare MSDC with TTDD. TTDD uses a square grid structure so that only sensors located at grid points on the edges of square need to acquire the forwarding information. Our analysis will focus on the worst-case communication overhead of both protocols. We aim at making the analysis simple and easy to follow while capturing the fundamental differences between MSDC and TTDD. We will add the consideration of the aggregations when we analyze the complexity in sensor state maintenance.

3.1 Model and Notations

Let N are the uniformly distributed nodes in hexagon sensor field with area A. Let k are the sinks moving with an average speed v, receiving d data packets from a source in a time period of T.

Each data packet has a unit size and both the query and data announcement messages have a comparable size l.

In MSDC, the source divides the sensor field into hexagon cells; each has an area $(3\sqrt{3}\alpha^2)/2$. There are, $n = (3\sqrt{3}\alpha^2 N)/2A$, sensor nodes in each cell and $\sqrt{n}$ sensor nodes on each side of a cell. Each sink traverses m cells, and m is upper bounded by $1 + 2vT / (2+\sqrt{3})\alpha$. For stationary sinks, $m = 1$. The relation between n and n1 can be defined as: $n = (3\sqrt{3}n1)/2$.

3.2 Communication Overhead in means of transmission

Here, we will compare the communication overhead of MSDC and TTDD. In both MSDC and TTDD a sink updates its location m times but in MSDC sink updates number of time sink in coverage of different cells and receives d/m data packets between two consecutive location updates. In MSDC, by choosing the hexagon shape of cells, the overhead for the query to reach the source is:

$$0.3nl + (2cl\sqrt{n}) / \sqrt{3}$$

Where,
$0.3nl$ = Local flooding overhead,
$c\sqrt{N}$ = Average no. of nodes,
l = Size of Packets
In MSDC, the path lengths increased by $2/\sqrt{3}$.

Now, the overhead to deliver d/m data packets in MSDC is = $2(c\sqrt{N})d / \sqrt{3}m$, where in TTDD it is $\sqrt{2}(c\sqrt{N})d/m$ and in SODD it is $(c\sqrt{N})d/m$.

In TTDD, the factor of path length increased by $\sqrt{2}$ as compare with SODD and here in MSDC, the path length factor increased by $2/\sqrt{3}$.

For k mobile sinks, the overhead to receive d packets in m cells is:

$km\,(0.3nl+2(c\sqrt{N})l / \sqrt{3}+2(c\sqrt{N})d / \sqrt{3}m)$
$=0.3kmnl+2kc(ml+d)\sqrt{(N/3)}$

The total communication overhead of MSDC is (Hexagon Cells):

$CO_{MSDC} = Nl+6Nl/\sqrt{n}+0.3kmnl+2kc(ml+d)\sqrt{(N/3)}$

where, the communication overhead of TTDD [1] is (Square Cells):

$CO_{TTDD} = Nl+4Nl/\sqrt{n1}+kmn1l+kc(ml + d)\sqrt{(2N)}$

and, the communication overhead of SODD is:

$CO_{SODD}=Nl+(c\sqrt{n})\, d/m$

where $n1=Na2/A$ and $c= (0 < c1 < \sqrt{2})$

To compare MSDC and TTDD, we have:

$CO_{MSDC} = Nl+6Nl/\sqrt{n}+0.3kmnl+2kc(ml+d)\sqrt{(N/3)}$

$CO_{TTDD} = Nl+4Nl/\sqrt{n1}+kmn1l+kc(ml + d)\sqrt{(2N)}$

In this network setup, MSDC has consistently lower overhead compared with TTDD [1] in both the stationary and mobile sink scenario.

3.3 Example of Stationary Sink(s) and Mobile Sink (s),

Let us consider N (number of sensor nodes uniformly distributed in area A) = 10,000, c = 1, L (size of the packet) = 1, d (number of data packets) = 100, m (number of cells a sink traverses) = 1, n (number of sensor nodes in a cell in MSDC), n1 (number of sensor nodes in a cell in TTDD) and k (number of Sink).

In tabular form,

For stationary sink – the calculated results are as follows:

Table 1

And For Mobile Sink, the calculated results are as follows:

Table 2

4 Performance Evaluation

In this section, we evaluate the performance of MSDC by comparing hexagonal topology over square (transmitting range "α" in both cases). Nodes are deployed on the vertices of square and hexagonal. In 6 x 7 units, the total numbers of squares are 42 while hexagonal units are 16. This implies that number of nodes in hexagonal is 45 and in square the number goes to 56; which demonstrate that less number of nodes required in hexagonal structure. The number of hopes from point A to point B by hexagonal comes out is 12 in place of 13 of square. This proves that hexagonal topology has the edge over the square as shown in figure 8.
Figure 8

5 Simulation

MATLAB software is used for simulating the results. In MSDC, we have less number of active nodes as compared to TTDD. As number of sink increases, the energy consumption also increases.
We plot a graph between number of sink and energy consumption [9-10]. As shown in graph, as the number of sink increases the energy consumption in TTDD is more as compared to MSDC.
Figure 9

In the second graph we have considered a mobile sink moving with a velocity of 20 m/s for 200s. For mobile sink, the no. of cells traversed by the sink in MSDC varies (decreases) due to the difference in cell size of TTDD and MSDC.
Figure 10

6 Conclusion

Using two-tier data dissemination model which exploit sensor nodes being stationary and location-aware and constructs & maintain a grid structure with low overhead, MSDC with hexagon grid structure increases the energy efficiency and improves the performance by decreasing the communication overhead and delay constraint. It is found that hexagonal is the only best possible structure which gives equal distance between all the vertices and between center point (DA location) to all the vertices(DNN location). This property plays an important role in WSN to keep all the nodes in same transmitting range.
However, in case of stationary sink, Directed Diffusion is better but recent trends shows for mobility of sink, MSDC is efficient.

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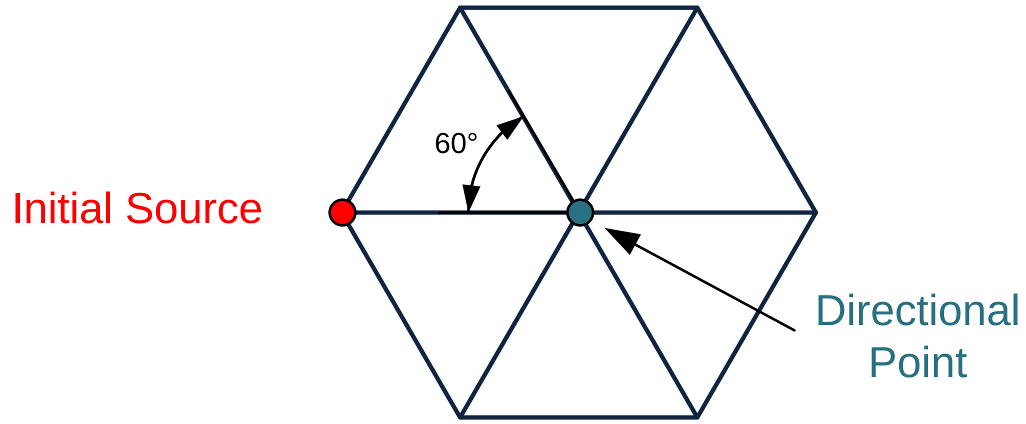

Figure1: Regular Hexagon cell with initial source

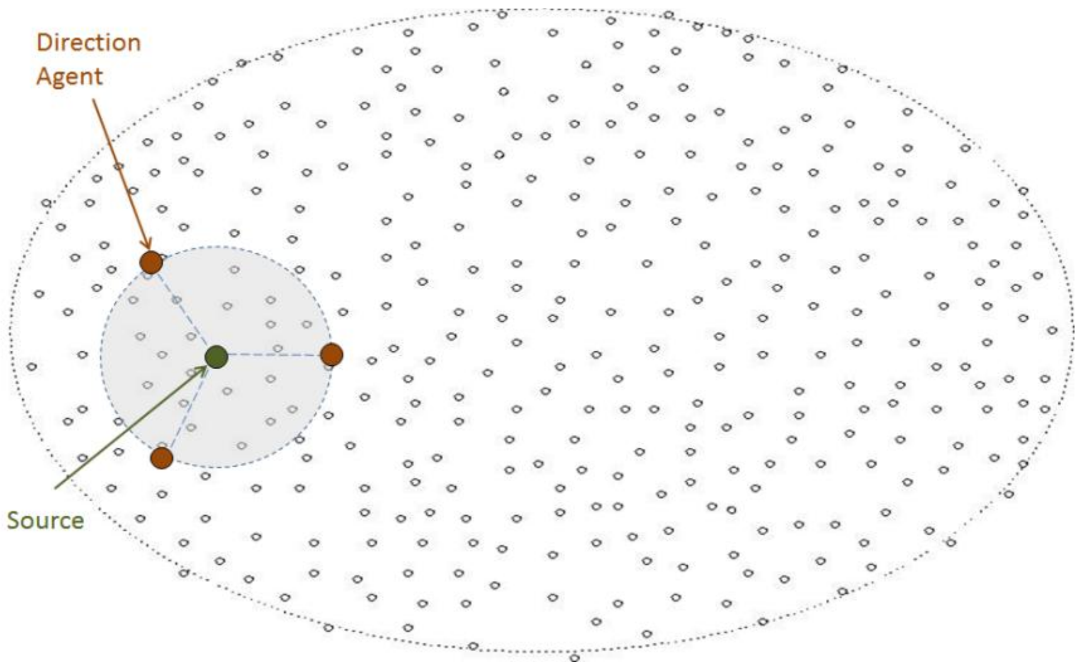

Figure 2: Grid construction created by source initially

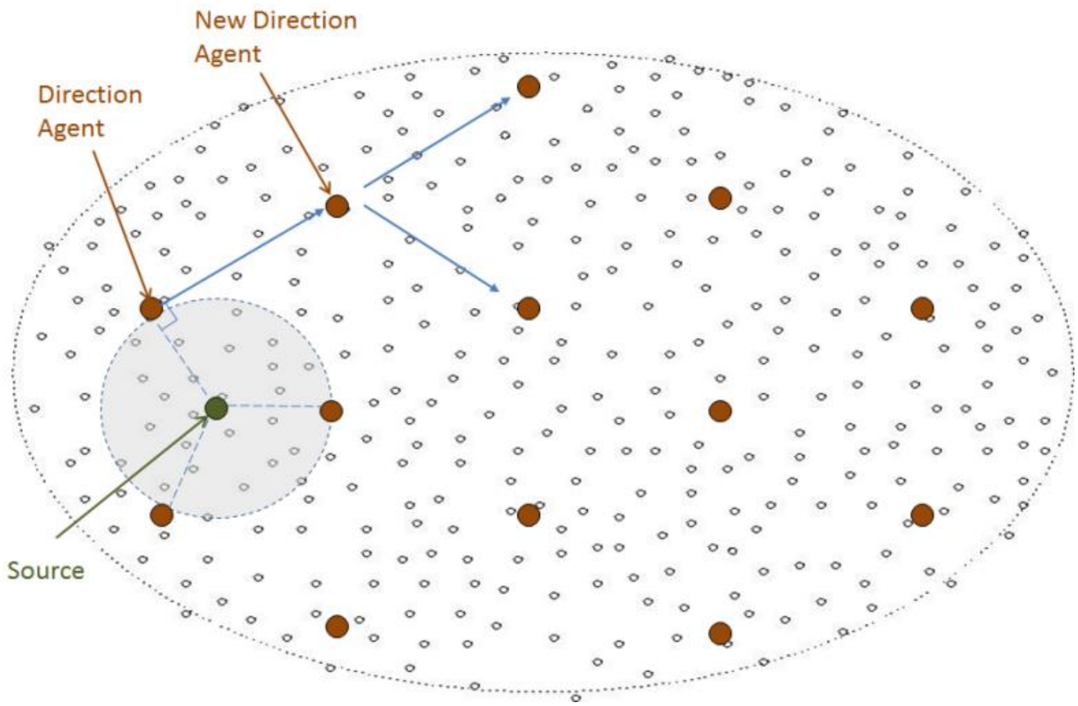

Figure 3: Formation of new direction agents

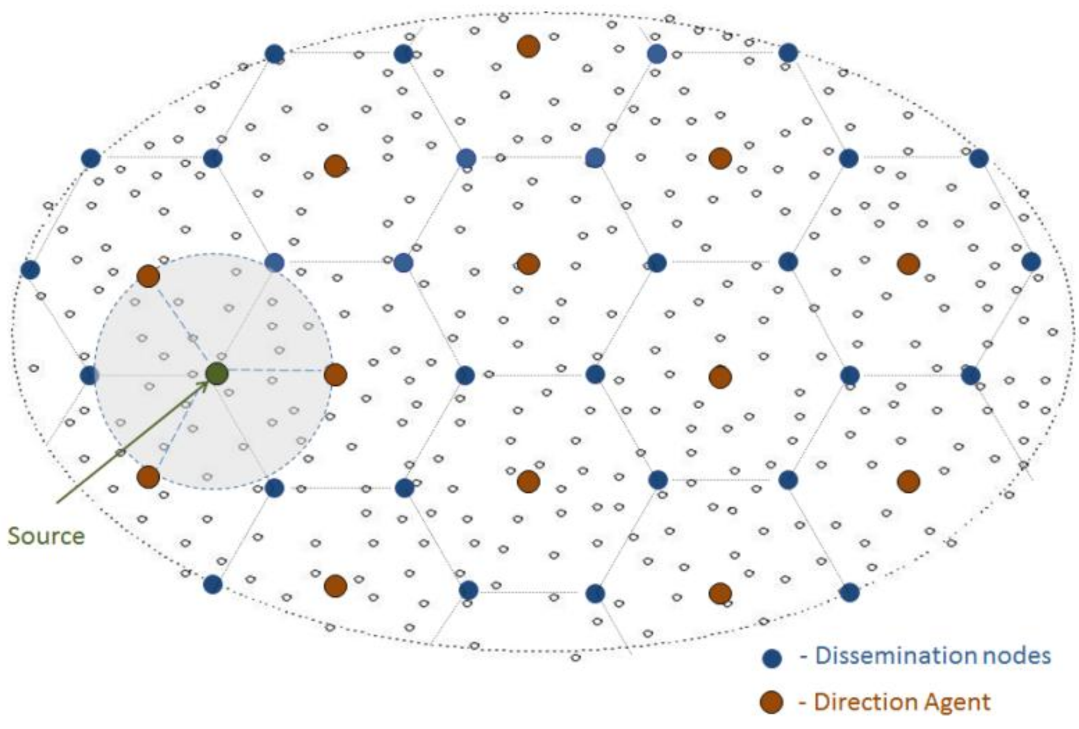

Figure 4: Formation of hexagonal grid structure having dissemination nodes at its vertices.

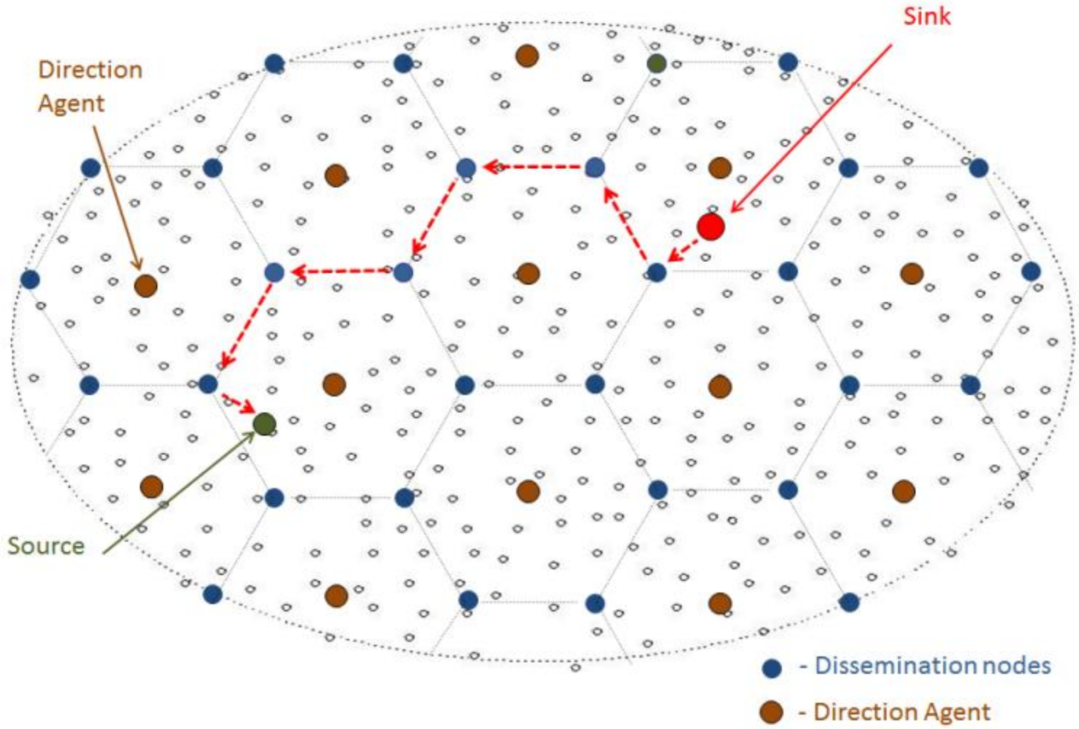

Figure 5: Shows a grid for a source and its virtual grid with directional agent.

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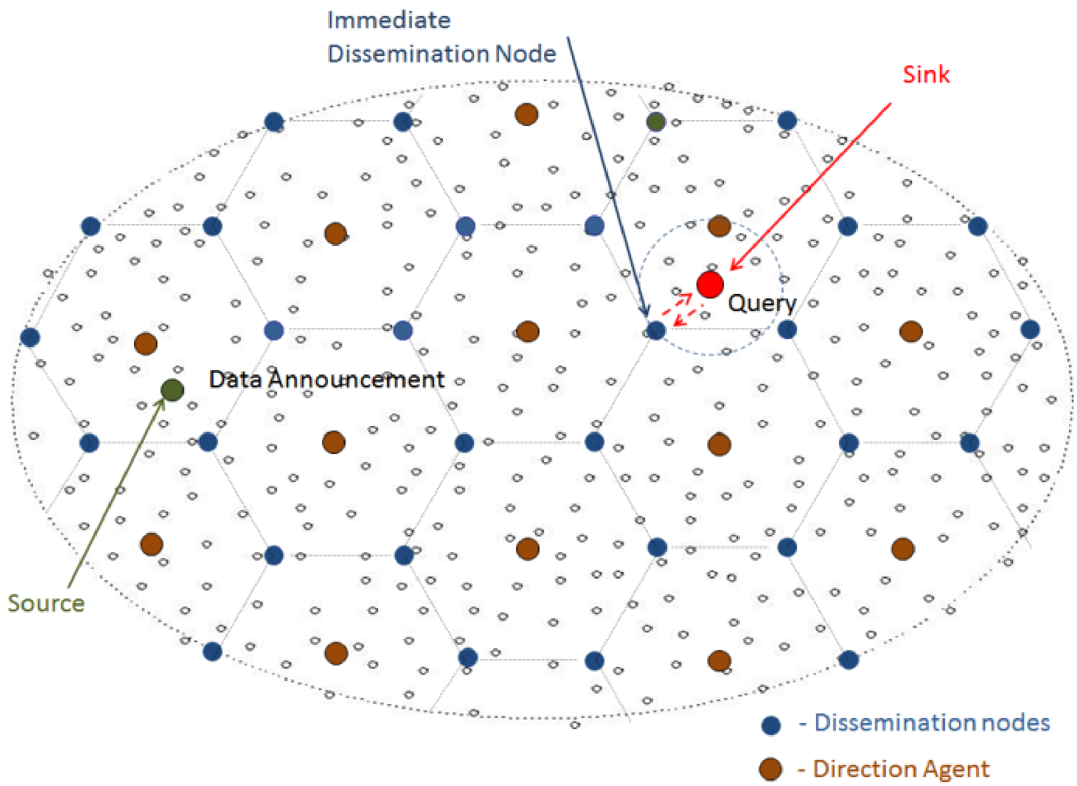

Figure 6: Immediate Dissemination Node

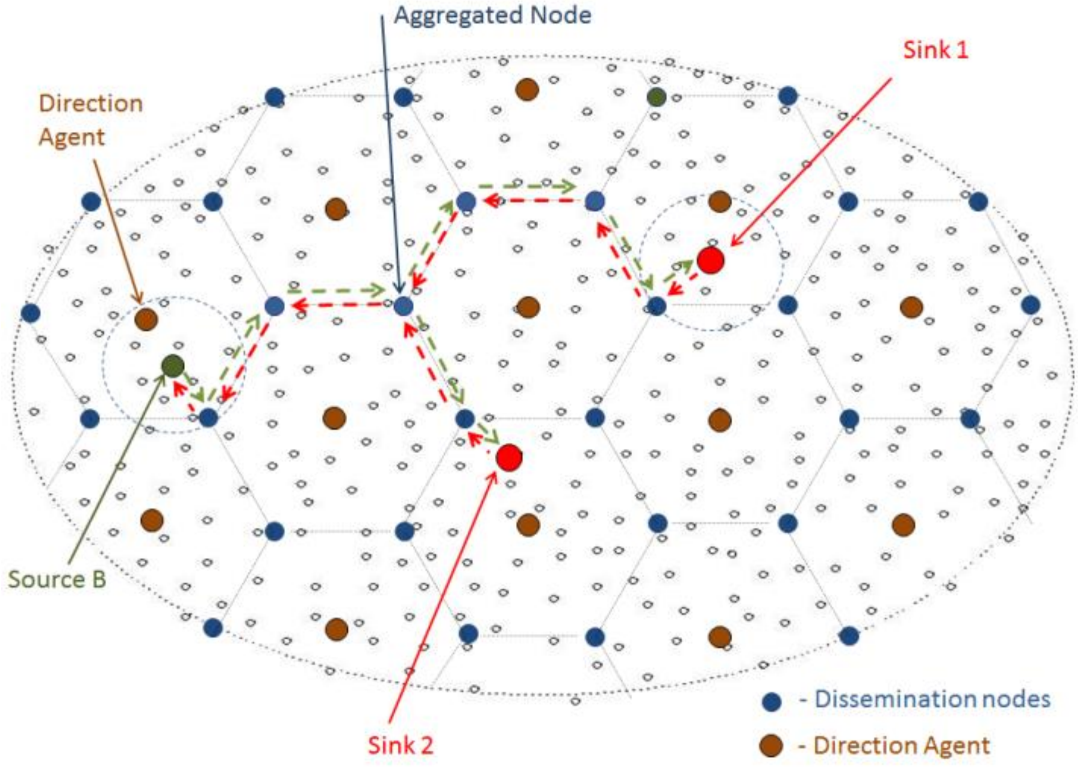

Figure 7: Source B is sending aggregated query data to sink 1 and Sink 2.

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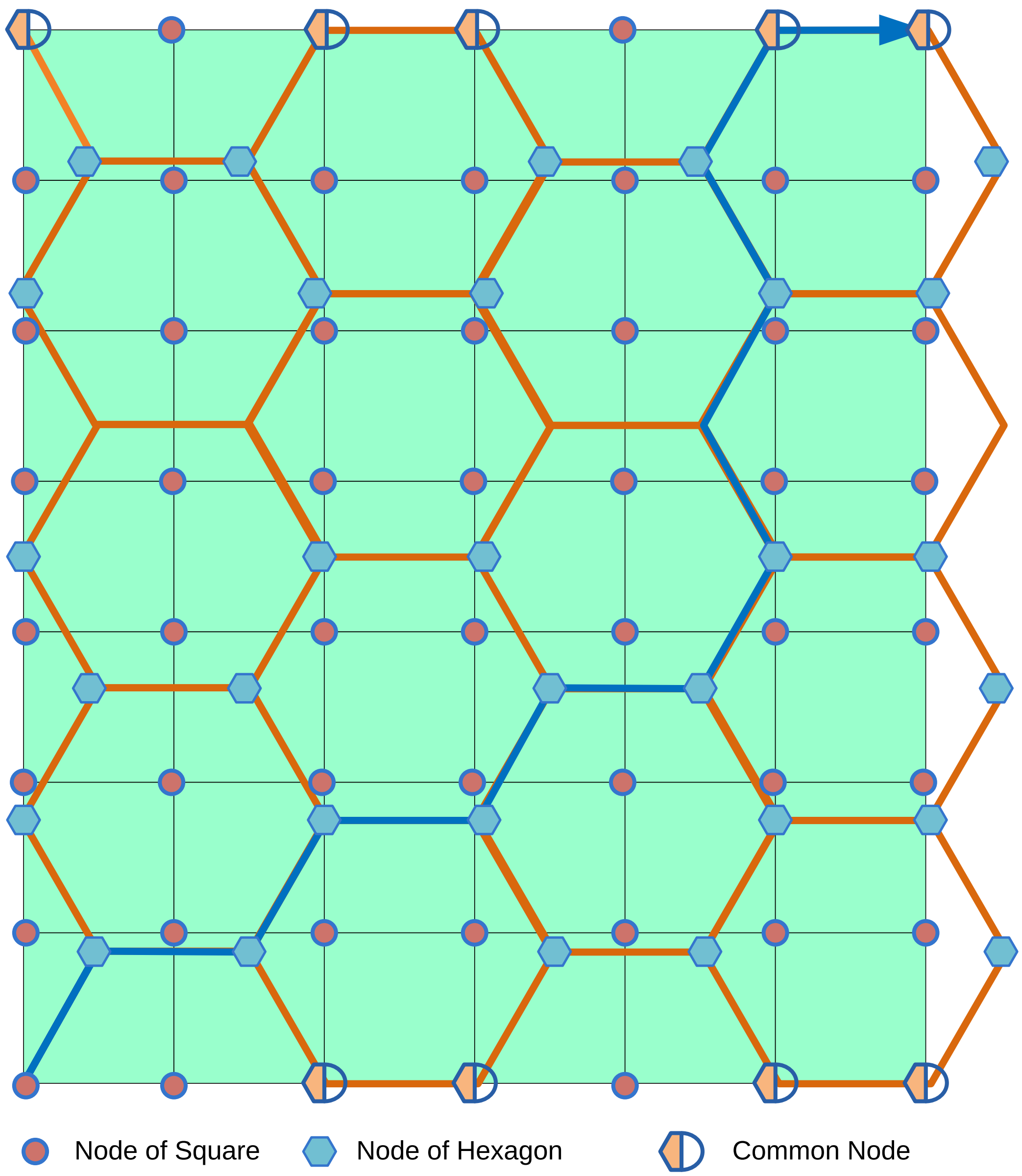

No of Hexagon:	16	No of Square:	42
No of Node used:	45	No of Node Used:	56
Optimum No Hopes:	12	Optimum No Hopes:	13

Figure 8 Comparison in hexagon and square topology

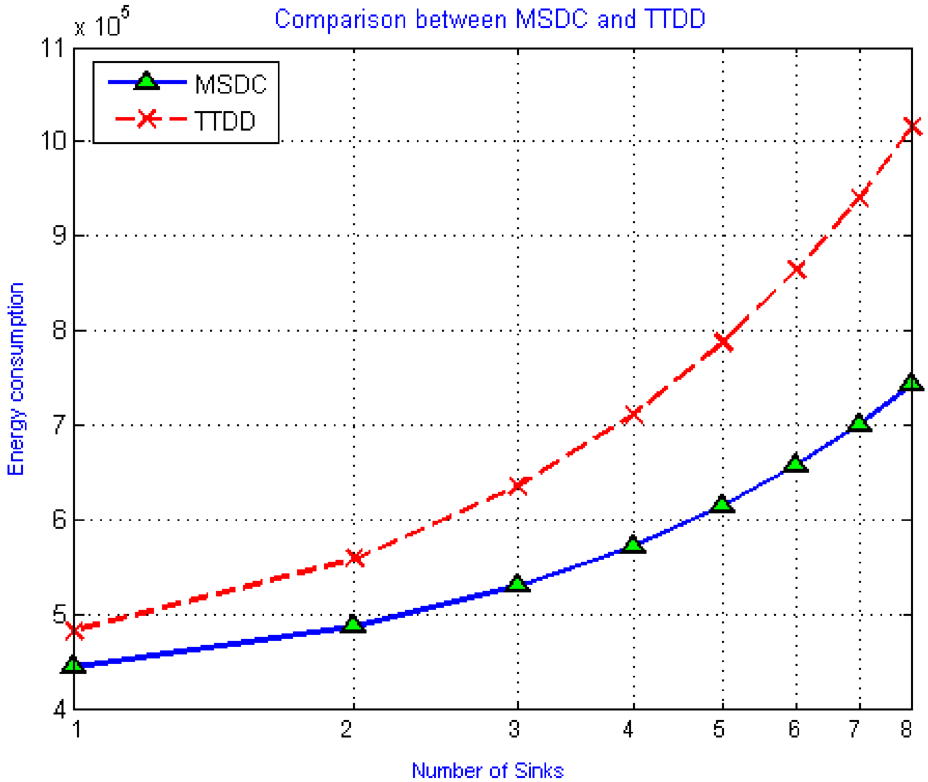

Figure 9: Comparison Graph between MSDC and TTDD plotted with a single Source.

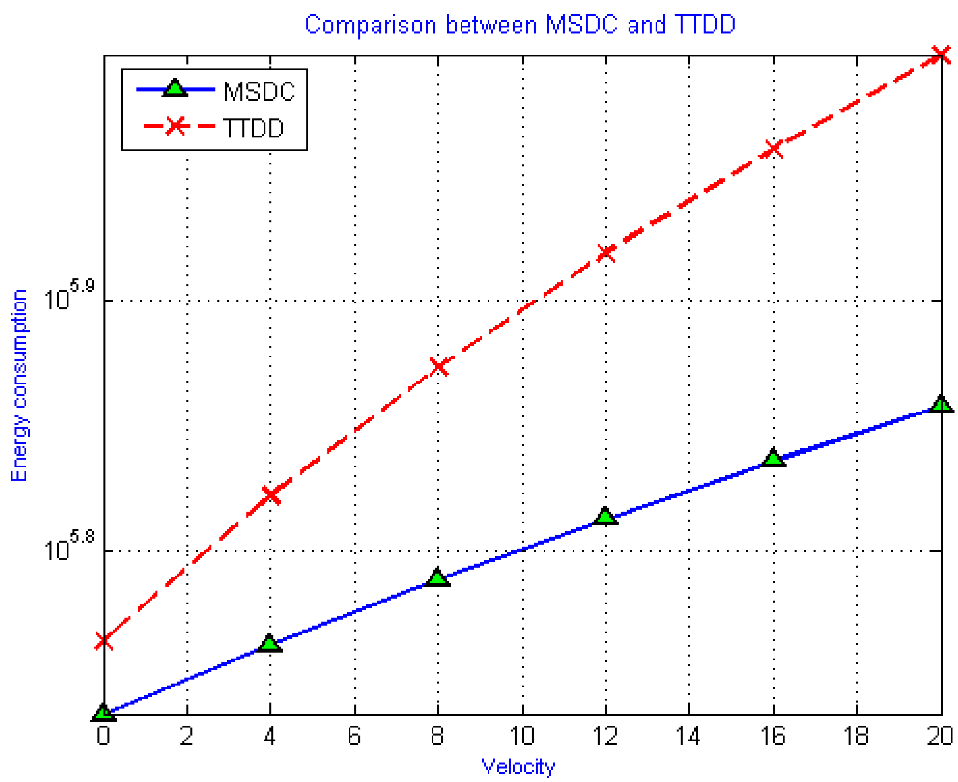

Figure 10: Comparison for mobile sink, velocity vs. energy consumption

Stationary Sink				
	n=200, n1=77		n=400, n1=154	
	k=1	k=4	k=1	k=4
MSDC	25965.1	61132.54	24782.4	60129.9
TTDD	28918.9	72000.6	27660.8	70973.5
Ratio CO_{MSDC} / CO_{TTDD}	0.8978	0 .8490	0.8959	0 .8472

Table 1

Mobile Sink					
		n=200, n1=77		n=400, n1=154	
		k=1	k=4	k=1	k=4
MSDC	m=5	26205.1	*62092.5*	25262.4	*62049.9*
TTDD	m=8	29457.9	*75495.3*	28738.8	*75285.5*
Ratio CO_{MSDC} / CO_{TTDD}		0.8895	0 .8224	0.879	0.8241

Table 2