Energy Aware Path Establishment and Maintenance for Sensor Network with Parameters as used in Agricultural Field

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ABSTRACT
Enhancing the network life, transmitting and receiving the data periodically are essential for any application. In this paper we are trying to enhance the network life by working on various layers. To enhance the network life hexagonal topology is chosen. Simulation parameters are chosen for agricultural application. Reducing the control signal in the network and also providing maintenance of enhances the network life.

General Terms
Routing, Algorithm

Keywords
Agriculture, path establishment, energy aware, wireless sensor network.

1. INTRODUCTION
Sensors are responsible for capturing, analyzing and transmitting information using radio signals. Sensor networks contain a base station usually called a sink and enormous number of other sensors which carry out the task of sensing and transmitting, along with relaying information of other nodes. Sink is a high computation device used to gather information of the whole network and is normally connected to the Internet or other data processing equipment. Sensors are highly resource constrained, major being battery power, transmission range, data and program memory. Sensors are application specific and can be used to continuously sample physical data like humidity, temperature, soil moisture etc. They are statically or dynamically deployed based on the application and are battery, solar or grid power driven. Sensors are self-organizing, detecting their neighbors, communicating with each other and exchanging information.

Scarcity of water is the major issue faced by the world. An awareness of water consumption is very much essential to avoid depletion of water in the water bed. Knowledge of water usage if provided to the farmers could help them in significantly improving the way water is managed [1-3].

Sensors placed in the soil could help in detecting the soil moisture, and this data collected by the network could help in regulating the water flow to the fields [2]. Analysis of data collected could help in predicting the yield and any new strategies can be adopted to overcome any associated problems. In order to enhance the lifetime of the network, to avoid replacement of battery, efficient path has to be established. This paper is based on AODV and some changes are incorporated so as to enhance the lifetime of the network

2. RELATED WORK
Sensors play an important role when it comes to sensing environment parameters like water pressure, humidity and temperature in the agricultural field. Ref. [4] deals with the deployment of sensors to measure water content. In Ref. [5], the usage of wireless sensor network in agriculture and cattle breeding is examined using solar. In the agricultural field, it may not be right choice to use solar if the leaves of the crop cover the solar panel or there is a likely hood of any theft. In the current paper we are looking into an instance where we are using battery power. Ref. [6] deals with a scenario where sensor nodes are deployed in the form of a grid and readings are measured using this topology. Ref. [7], explains that a route has to be selected so that there is maximum available power, minimum energy consumption along the route. Ref. [8], discusses many routing protocols where design trade-offs between energy and communication overhead is dealt with. COMMON Sense Network is a project associated with monitoring the regulation of water supply to the field. The sensors used here are placed at a depth of 15cm to 30cm and the moisture content is sensed. Based on this on- going project the path finding and path establishment algorithm, NEWAODV is devised to overcome node failure using ns2.34. Part 3 deals with the best way to deploy sensors to enhance the network life. Part 4 deals with the criteria for simulation parameter selection. Part 5 deals with the choice to routing table and packets. Part 6 deals with routing algorithm, part 7 with route maintenance

In this paper we try to enhance the lifetime of the network by working on different layers of the network. The deployment chosen is hexagonal which provides connectivity and coverage with minimum number of nodes and also has a longer shelf life. The choice of mote provides long distance transmission and has high sensitivity which avoids the need for large quantity of motes. Path is chosen so that it follows the known minimum hop count. During path breakage, new path is established from the location of node failure up to the destination.

3. DEPLOYMENT
Sensors can be deployed in the field in random order. In order to find a network which is cost effective various topologies have been studied [9]. Of the triangular, square (grid) and hexagonal, hexagonal topology is found to be cost effective and has a relatively longer life shelf when compared with the other two. Figure 1 shows the grid, triangular and hexagonal topology with a slight shift in their location of deployment. The topology is so chosen that they are placed in the hearing range of each other, and at the maximum only three sensors are able to listen to each other in hexagonal and only four are

in the hearing range in the case of grid topology. Diagonally they are not able to hear each other. In this paper square topology is used.

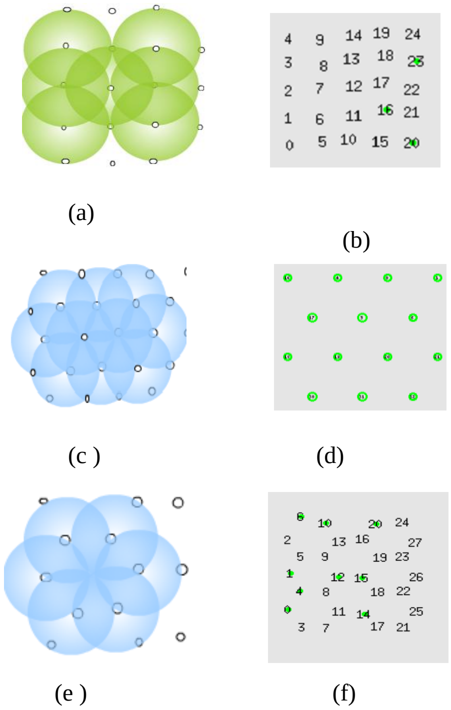


Figure 1. Various deployment topologies

4. SIMULATION PARAMETERS

The parameters for the simulation are as per the on-going COMMON Sense project. The design is based on the simulation environment for ZigBee [10]. In Ref. [11], the design of simulation environment for the agricultural application is explained in detail. The sensor mote chosen is Tinynode from manufacturers of Shockfish. This mote has the larger transmission range as compared to Mica motes. Briefly the design steps for simulation parameter are specified below.

4.1 Receiver Threshold

Ref. [12] gives the Tiny node data sheet. Based on this, the transmit power is chosen to be 5dBm. The receiver sensitivity is -104dBm @ 76.8dBm for 5dBm transmit power and range of transmission as 200m for the antenna height of 1m.

4.2 Capture and Carrier Sense

The least carrier sensing threshold should be at least equal to the receiver threshold value. Capture threshold is maintained at 10. This captures only the signal which is higher than other signal by 10dBm when both of them reach the same node at same time.

4.3 Range of communication

According to the Two-Ray Ground Propagation model, the received power at a distance of d from the transmitter is given by,

$$Pr(d) = PtGrGt\ hr^2\ ht^2 / d^4 L$$

where ht: transmitter antenna height, hr: receiver antenna height, Pr: power required to receive the signal at distance d, Pt: transmitted signal power, Gt: transmitter gain, Gr: receiver gain, d: distance from the transmitter, L: path loss.

With Pr = −104dBm =3.98e-014 W, Pt==5dBm =0.0032W,

Gt = 1.0, Gr = 1.0, L = 1.0, ht = 1.0, hr = 1.0m we have $3.98e\text{-}014\ W = (0.0032*1.0*1.0*(1.0)^{2*}(1.0)^{2)} / (d4 *1.0)$

d=531m.

Therefore using a carrier sensitivity of -104dBm is equivalent to using a sensing range of around 531m around the node. As per the data specification provided in the Tinynode data sheet transmission is possible for at least 200m.

4.4 Power and energy parameters for Tiny node

Ref. [13] shows the discharge characteristic of battery. Two alkaline batteries of 1.5V are used in the Tiny node.

The power to transmit is 33mA * 3V =99mW.

Power to receive is 14mA * 3V= 42mW

Idle power is 1uA * 3V= 3uW

With an average transmit and receive current of 23.5 mA, the number of hours of operation is 80hours as obtained from the battery characteristics [13].

5. ROUTING TABLE AND PACKETS

The nodes (motes) in the agricultural field are placed statically. We carry out searching and establishing path dynamically, whenever there is a need for the path establishment between the source and the destination (sink). The failure in the node could occur either because of the drained battery, malfunctioning of the electronic circuitry etc. This leads to broken link, and delinking of neighboring nodes. Dynamic path establishment necessitates the presence of routing table in each of the nodes. The routing information can be obtained from the routing table. Packets are used to transfer information between various nodes. Control packets help in establishing the path and data packet to transmit the data from the source to the base station (sink). The working principle of AODV is explained in the reference [14-17]. The power consumption increases as the packet size increases. Hence the packet size is kept to a minimum during transmission of control and data.

5.1 Routing Table

The routing table has the following information as shown in Table 1. The total space occupied in each node is 29 bytes. Each node also has a pointer to a linked list containing information of all the neighbors along with the hop count from both the source and the destination. Each time a new route has to be discovered the sequence number depicting the new route is incremented. The routing table is dynamically updated with new route discovery and maintenance phase. Route establish flag is used to check if a route is established up to the destination from the current node. Before the path is established it is set to 0 and once a path is established from the current node up to the destination at the time of receiving a path establishment message this flag is set to 1. The neighbors of the current nodes are added to the routing table in the form of linked list. Each neighbor has information of its distance from the source, destination and other neighbors.

Table 1. Routing table

Information stored	Size occupied	Functionality
Node id	4 bytes	Current nodes address
Previous node address	4 bytes	Previous neighbors address
Next hop address	4 bytes	Next neighbors address
Source node address	4 bytes	The node from where data is sent
Destination node address	4 bytes	The base station (sink) address
Address of neighbors*	4 bytes	Address of the linked list containing the information of its neighbors
Time stamp	2 bytes	Time when the signal reached the node
Sequence number	1 bytes	The number of times path search was carried out
Hop count	1 bytes	Hop count from the source
Route establish flag	1 byte	Detects if path is establishment up to the destination from current node

5.2 Packet format to search path from source to sink

Packets are transmitted between the source and the sink during the path search, establish and data transfer. Figure 2 shows the NEWAODV_BEACON broadcast packet format required to search for a path between source and sink. This packet is broadcast from the source to the sink. The field packet type (NEWAODV_PATH) specifies the packet is for path search. Destination address is sink address. The size of the packet is 32 bytes at the routing layer.

```
0                   1                   2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Packet type    |   Reserved    |  Hop Count    |   Reserved    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Destination node  Address                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Source node Address                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Time stamp                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 2. NEWAODV_BEACON packet format

5.3 Packet format to establish path from sink to source

Figure 3 shows the NEWAODV_PATH packet format is same as the NEWAODV_BEACON. But here the hop count is from the sink to destination. Packet type is NEWAODV_PATH.

Destination address is the source address, and source address is the sink address during path establishment.

```
0                   1                   2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Packet type    |   Reserved    |  Hop Count    |   Reserved    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Destination node  Address                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Source node Address                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Time stamp                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 3. NEWAODV_PATH packet format

Sequence of operation involves the broadcast packets to find a path to the sink from the source during the path discovery process. The path with minimum hop is initially used to establish a path between the sink and the source. A reverse path (path establish) is established between the sink and source using unicast. Data transfer involves sending data packet along the established path.

5.4 Data packet

Establishment of path from source to sink will allow data packet to be sent for transmission. Currently data packet of size 4 bytes at the application layer is sent from the source to the sink using Constant Bit Rate with interval of 300 seconds(once in every 5 minutes). This data only has information about the moisture content. This along with the common and IP header amounts to 24 bytes of data.

5.5 Neighbors table

The sixth entry* in the routing table (Table 1) has the address of the linked list. Every node has a pointer to a linked list containing the neighbor's information. For each neighbor, 4 fields of information is stored as shown in the Table 2. Total size is 10 bytes for each neighbor. Each of the neighbor's information is connected to the other in the form of linked list. Information regarding a new neighbor is added to the front of the linked list. Hop count from source gets filled during path discovery and hop count from destination only for valid routes from the destination.

Table 2. Neighbor's node information table

Information stored in each neighbor	Size occupied
Neighbor node address	4 bytes
Hop count from source	1 byte
Hop count from destination	1 byte
Link to next neighbor of the current indexed node	4 byte

Figure 4 shows the linked representation of neighbor's information.

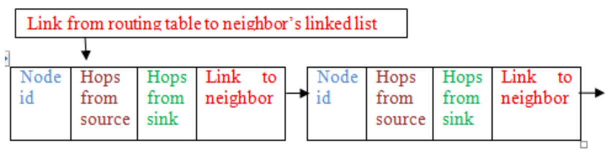


Figure 4. Linked representation of neighboring nodes in a routing table.

In the Figure 6, the data transmit path is shown in Figure 6c. At node 20, Figure 5 shows the routing table with its neighbor's information after the path is established and data is being transferred. Nodes 7 has -1 as a distance from destination as it is not in the path from destination to source during path establish. Node 12 and 23 are along the path established. During link break, the available hop count up to destination helps in establishing the path. The path has to be established only up to the node already having the information of destination.

Routing table	
Information	**Data**
Node id	20
Previous node address	23
Next hop address	12
Source node address	23
Destination node address	24
Address of neighbors	
Time Stamp	xxx
Sequence number	1
Hop count	1
Route establish flag	1

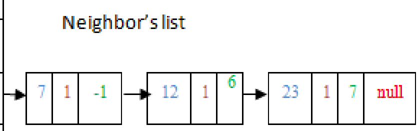


Figure 5. An example of routing table and neighbors list

6. ROUTING ALGORITHM

AODV is reactive protocol for mobile nodes. The neighbors they are associated will keep changing with mobility. During the process of path discovery, multiple RREP (Route Reply) packets, in response to a single RREQ (Route Request) packet lead to heavy control overhead. The periodic beaconing leads to unnecessary bandwidth consumption. There is high overhead when data packets gets delivered to too many nodes which are not destined to receive them. In this application as the nodes are static, we have not incorporated the hello, neighbor, route cache, broadcast purge. This saves considerable amount of energy [18].

6.1 Path discovery

The following pseudo code shows the algorithm used to discover the path.

1. As the path search begins, path-established flag, from the current node is set to 0. Packet (fig.2) is broadcast with the path search sequence number set to 1, which gets incremented with each new path search.

2. If the node has energy less than that required to transmit and receive prevent it from broadcasting and start a new search path from the previous node, incrementing the sequence count by 1. Low energy node is switched-off.

3. If the node which received a message is having the same node id as the sending source node then it has formed a loop prevent message from broadcasting.

4. If a node is receiving the control message for the first time (or routing table is not created), create the routing table with entries as specified in the Table 1. If this node is the destination node prevent it from further propagating the broadcast control signal.

4.1 If it has reached the destination with minimum hop count then start the path establish process.

4.2 If it is some intermittent node with hop count greater than the minimum known hop count, stop broadcasting the packet.

Else forward the packet

5. If node entry exists and new packet has higher or same hop count as in the routing table hop count entry, or greater than known minimum hop count prevent packet broadcasting.

6. If routing table entry exists and new hop count is lower than that existing in the routing table, update the routing table with the new information and forward the packet.

Else forward the packet

For all path searches other than the first sequence the routing table is updated for all entries based on the current values of hop count and sequence number.

In each step the neighbor node information with its hop count from the source is updated. The previous node from where the packet was obtained is updated. The hop count from destination is set to -1 during path search and which gets updated during path establish.

6.2 Path establish

Reverse route is established from the destination to the source using unicast packet (fig.3) based on the previous nodes information. The next hop entry in the routing table is entered based on the node id from where the message is obtained.

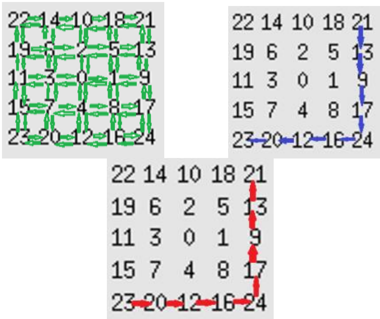
The hop count from destination is incremented and is updated in the destination hop count field only for the nodes which are neighbors and are in the path of establishment. The hop count from destination is useful during path break. The new path is established only up to the node which has a hop count up to the destination.

The destination flag is set to 1 when the path is able to establish up to the location where path search started.

Figure 5 shows destination hop count entry for node 7 as -1. This is because node 7 is not along the path for path establishment.

6.3 Data dispatch

Data is sent continuously using a constant bit rate. The interval to send the data is 300 secs. This rate is sufficient to check if the field is irrigated, once every 5 minutes. The path for sending data is unicast and is based on the next hop value entered in the routing table during path establishment. Figure 6a shows the broadcast path search, 6b path establish and 6c the data send paths.



(a) (b) (c)

Figure 6. Stages of path discovery, establishment and data transfer with source 23 and sink 21

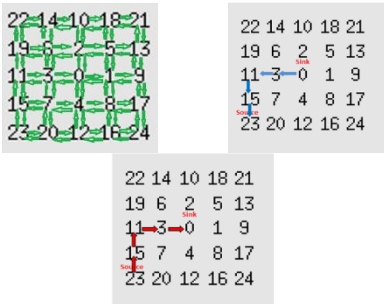


Figure 7. Stages of path discovery, establishment and data transfer with source 23 and sink 0

Considering another scenario with node 23 the source and 0 as the destination Figure 7 shows the three stages of path discovery, establishment and data transfer. During the path discovery when broadcast signals are sent from node 23, Table 3 shows the routing table contents in the nodes 23, 15 and 20. Figure 8 shows the neighbors details at that instance of time.

Table 3. Routing table for node 23, 15, 20

Information stored	Node 23	Node 15	Node 20
Node id	23	15	20
Previous node address	23	23	23
Next hop address	-1	-1	-1
Source node address	23	23	23
Destination node address	0	0	0
Address of neighbors	null	Address of linked list *	Address of linked list #
Time stamp	0.000	xxx	xxx
Sequence number	1	1	1
Hop count	0	1	1
Route establish flag	0	0	0

Figure 8 Neighbor's information

Of the many path that can be established between the source and destination one of the possible path that has been established with a hop count of 4 could be from 23→15→11→3→0. Another path established after some delay could be 23→20→7→4→0. Table 4 shows the status of the routing table for nodes 0 and 3. For node 3 the forwarding and reversing path status is displayed. We have assumed that the packet to the sink is obtained from 3 much before node 4 sends the packet for path establish to node 0. Broadcast packet is also obtained from node 2 to the node 0 but with a longer hop count. Initially in the node 0 the path is established through 2, but as soon as the signal is obtained from node 3, the routing table which specifies the previous hop information is updated in the routing table. Figure 9 shows the neighbor's information for the node 0.

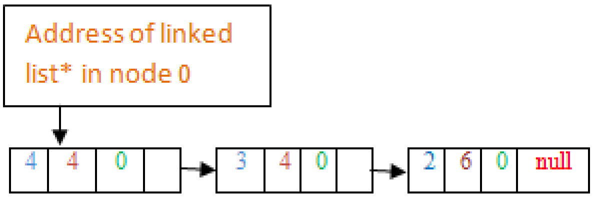


Figure 9. Neighbor's information for node 0

Table 4. Routing table for node 0, 3

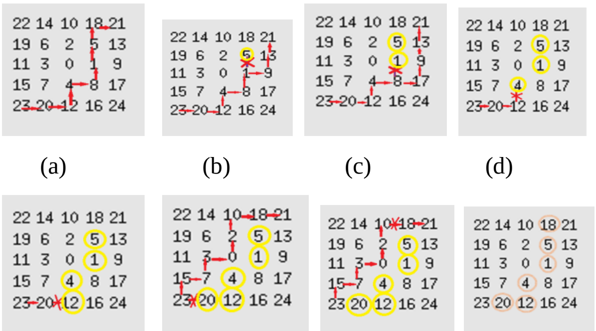
Information stored	Node 0 after receiving broadcast from node 3 and path is established	Node 3 during path establish	Node 3 during reverse path
Node id	0	3	3
Previous node address	3	11	11
Next hop address	0	**-1**	**0**
Source node address	23	23	23
Destination node address	0	0	0
Address of neighbors	Address of linked list *	Address of linked list +	Address of linked list #
Time stamp	xxx	xxx	xxx
Sequence number	1	1	1
Hop count	4	3	3
Route establish flag	1	0	1

7. ROUTE MAINTENANCE

The data gets transmitted for the stipulated period of 15897600 seconds which is the equivalent to 6 months. The link between nodes could break if radio signal do not reach the neighboring nodes. Some nodes lose considerable amount of energy due to continuous transmission of data, especially the ones which are close to the source and the sink. The nodes which are not involved in the transmission or reception also lose energy when it is idle for a long interval of time. During battery depletion new route are generated based on the available energy in the neighbors.

A new path beacon control signal (NEWAODV_BEACON) is started from the node where the node failure occurred. The route establish flag is again set to 0 during this process. It is set to 1 when the path is established up to this node. Path discovery and path establishment process is repeated as before. New route is discovered only up to the node which has lost its energy.

If new path discovery from current node is not possible after two discovery cycles, then any length path (less than maximal path) is used for establishing the path. Figure 10 shows the different stages of path establish with link /node failure. Figure 10h shows the case when there is no path from the source 23 to sink 21.



(a) (b) (c) (d)

(d) (f) (g) (h)

Figure 10 Path re-establishment process

Figure 11a shows another scenario with route established. Figure 11b shows node 10 is faulty. Transmission is not possible to node 10. Figure 11c shows broadcast from 14 to its neighbors. But the new hop count 6 is higher than the existing hop count of 4 in node 6 and it stops broadcast. Broadcast from previous nodes 22 is carried out. If no path is possible during the next search, new path is established from the source to destination. No path search is carried from 19, 11, and 15. Hence as shown in figure 11d a new path with higher residual energy is started.

In order to avoid repeated new path search from just the previous nodes as shown in Figure 10h, the route establish flag helps detect that the path is not established, for the past two path search process. This flag is not set if the path is not established. In the Figure 11 during path fetch from node 14, the flag is set to 0 and it would have been set to 1 if there was a path established from 14 up to 21. During the next data transmission it finds that it is not able to send the data. After two such trials, a new path search is initiated from the source up to the destination.

(a) (b) (c) (d)

Figure 11 Path re-establishment with high available energy.

8. SIMULATION RESULTS

Table 5 shows the various initialization parameters to carry out the experiment. The simulation is carried out for time period of 15897600seconds (6 months).

Figure 12 shows the topology used to carry out the simulations. The nodes are deployed in hexagonal manner with source as node 0 and destination as node 216.

Table 6 shows the amount of energy consumed by the network of size 448.In this experiment the initial energy of the nodes is 20304J. On an average 6J of energy was drained from the node. Most of the energy drained is due to the idle state of the nodes. In order to explain the behavior of the path re-establishment algorithm, simulation was carried out for a node size of 25. To implement a situation with path failure the initial energy of each of the nodes is set to 0.7J. This leads to draining of the battery and path break.

Table 7 shows the simulation results which show the average consumption of energy. With the NEWAODV protocol the network is alive for a longer period and average percentage energy consumption is also reduced in the energy aware path. The number of packets which are delivered to the destination during the stipulated period is also improved. The number of packets dropped is also less. With AODV the path is searched from the previous node each time. But as the previous node also has their energies drained, and there is no advantage of finding new path from previous nodes in consecutive iteration, with no path being established. An absolutely new path without taking a previously consumed path could make a better choice and making the network live longer.

Table 7 shows the advantages of NEWAODV against AODV. The number of path searches is reduced from 3 to 2. The network is also alive for long. The residual energy is also high. The number of packets transmitted is also higher than AODV protocol. The number of packets which are dropped is also reduced.

Table 5. Initialization parameters

Radio parameters	
Radio frequency	915 MHz
Antenna Height	1m (min. reqd. height 0.0819m)
Antenna Type	Omnidirectional –Quarter wave
Transmit Power	*3.16 mW =5dBm*
Receive Power	*−104dBm@ 5dBm=3.98e-14W*
Carrier Sense Threshold	*−104dBm@ 5dBm*
Capture Threshold	10 dBm
Gain of transmitting/Receiving antenna	1
Path loss	1
Transmitting distance	200m. as given in manual. 531m as calculated
Sensor parameters (Tiny Node)	
Transmit Power	0.099W=19.95dBm
Idle Power	0.006W=7.78dBm
Receive Power	0.042W=16.23dBm
Sleep Power	0.000003W=-25.2dBm
Battery (Alkaline battery of 1.5V)	
Battery supply	3V with 2 AA sized battery
Power consumption	0.0705W for 23.5mA discharge current
Energy consumption	20304J for 80 hrs. of operation
Simulation parameter	
Simulation period	15897600seconds i.e. 6 months.
Simulation interval	300secs.
Topology	Hexagonal.
Network size	448
Consumption of energy	2000mW/ 5J
MAC	802.11
Queue	Drop Tail
Queue size	150
Routing protocol	NEWAODV

Table 6. Simulation result for 448 node topology

Information	Average Values
Energy used by the network	6.044053J
Idle energy used	4.577538J
Transmit energy	0.798670J
Receive energy	0.667846J

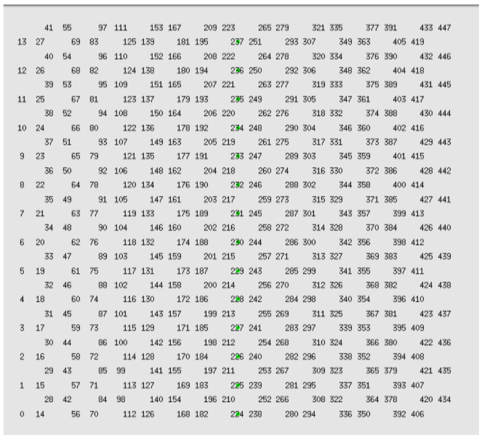


Figure 12. Topology of 448 nodes using hexagonal topology

Table 7. Simulation result with 25 nodes in grid topology

Average values	Energy aware path (NEWAODV)	AODV
Transmit energy	0.037299J	0.037594J
Receive energy	0.045528J	0.042627J
Idle energy	0.467145J	0.491576J
Percentage energy used by the network	99.999261	99.999369
Period for which the network was alive	190523 secs.	190502 secs.
No of successful transmission	633 transmissions	631 transmissions
Number of packets dropped	2 packets	4 packets
New path search count	2 times	3 times

9. CONCLUSIONS

Agricultural application requires that the network be alive for a cropping season. In order to achieve this efficient path is required to be maintained between the source and the destination. Routing tables are present in every node which directs the path to be followed to transmit data. In this paper on establishing a new path, based on minimum hop count, data starts transmitting from the source to the destination. Once a node is drained of its energy, new path has to be established. The new path will be from the previous node where the path is broken, to the destination. Destination flag helps in detecting if a new path is established between the current previous node and the destination. If on consecutive two new path search, path is not established, between the previous node and the destination, a new path is established between the original source and the destination. This avoids usage of the path which is already drained of energy. The new path established could result in transmission for a longer interval of time. This process also avoids new path searches very often. Large amount of energy is consumed during path search and just one or two transmissions for every path search results in unnecessary drainage of energy. New path established helps in network to be alive for longer interval of time. It is also observed that large amount of energy is consumed during idle state. Steps to put the node to sleep during this idle state could result in considerable reduction in consumption of energy.

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