Chapter 3

Initializations of the Sensor Network

3.1 Introduction

This chapter addresses the setting up of environmental parameters for the project based on CSN. Based on this foundation, various topologies are studied. The effect of the size of the network, transmission range on packet delivery ratio is deliberated upon. The energy model with minimum required threshold energy is addressed. The simulation parameters needed for the computation is visualized. The methodology presented here is for the agricultural application, but can be applied to other applications as well with minor changes.

3.2 Physical Parameters for the Simulator

The WSN uses the cross layer approach along the Application, Transport, Network, Data Link and the Physical layer. Along the physical layer is the setting up of the radio parameters, the sensor energy consumption parameters, the battery specification, transmission range etc. The agricultural application that is considered in the current work uses ns2 with the sub sections illustrating the steps based on the work by (Marandin 2006).

3.2.1 Radio Model

The project CSN specifies that the transmission range between the sensors be as large as possible. This could possibly be to avoid the expense incurred in unwanted additional sensors and also their maintenance. A comparison of Mica motes from
crossbow and Tinynode from Shockfish is studied in Table 2.1 and 2.2. A proposal for choosing Tinynode is suggested. The fact sheet of Tinynode is shown in Table 3.1. Following are the steps carried out in order to design the network using network simulator ns2.34.

**Antenna Height**

Tinynode uses quarter wave monopole antenna with frequency of operation 868 MHz and 915 MHz as per the Table 3.1 (Tinynode 2011). The antenna height is computed as follows:

\[
\text{Speed}_\text{Of}_\text{Light} \text{in meter per second}(c) = \text{Frequency}_\text{Of}_\text{Operation} \text{in cycle per second}(f) \times \text{Wavelength in meters}(\lambda) \tag{3.1}
\]

Substituting the values in eq. (3.1), \(\lambda\) value can be computed as,

\[
3 \times 10^8 = (868 \times 10^6) \times \lambda
\]

\[
\lambda = 0.345622 \text{ meters}
\]

With *quarter wave* monopole antenna the *minimal* height obtained is,

Antenna Height = \(\lambda/4 = 0.345622/4\) meters

= 0.0864 meters for frequency of 868 MHz

= 0.0819 meters for a frequency of 915 MHz

The antenna height of 0.0864 meters | 0.0819 meters is the absolute height of the antenna. This is the minimum height which is essential for the proper functioning of the network. On comparing with the fact sheet of Tinynode from Table 3.1 the height of the antenna is suggested as 1 meter. \(\tag{3.2}\)

Using a square ground plane with edge length equal to one quarter of the carrier wavelength \((\lambda/4)\) and transmit power of +5 dBm, one may deploy sensors up to a transmission range of about 200 meters as illustrated in the fact sheet. The transmission range increases with the height of the antenna. If the antenna is raised higher, it will greatly reduce the likelihood of interference, which decreases at the inverse square of the distance.
**Transmit Power (Pt)**

It is the power with which the signal is transmitted. With a transmit power (Pt) of 5 dBm as per the fact sheet, we are calculating the other parameters. With higher transmit power longer distance of transmission is achieved.

dBm (sometimes dBmW) is an abbreviation for the power ratio in decibels (dB) of the measured power referenced to one milli watt (mW).

The power conversion of dBm to watts is given by the formula:

\[
P(W) = 10^{(P(dBm)/10)} / 1000 \quad (dBm = log10 (mW)x10 and mW=10 (dBm/10))
\]

With Pt = 5dBm, the transmit power in watts is given by,

\[
Pt (W) = 10^{(5/10)} / 1000 = 10^{(0.5)} / 1000 = 0.0032W
\]  (3.3)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Frequency</td>
<td>868-870 MHz</td>
</tr>
<tr>
<td>915 MHz version</td>
<td>902-928 MHz</td>
</tr>
<tr>
<td>RF Output Power</td>
<td>0 to + 12 dBm</td>
</tr>
<tr>
<td>Data Rate</td>
<td>1.2 – 152.3 kbps</td>
</tr>
<tr>
<td>Receiver Sensitivity</td>
<td>-121 dBm</td>
</tr>
<tr>
<td>@ 1.2 kbps</td>
<td>-104 dBm</td>
</tr>
<tr>
<td>@ 76.8 kbps</td>
<td>-101 dBm</td>
</tr>
<tr>
<td>@ 152.3 kbps</td>
<td></td>
</tr>
<tr>
<td>Range @ 76.8 kbps</td>
<td>200 m (+5 dBm)</td>
</tr>
<tr>
<td>Outdoor elevation</td>
<td>40 m (+5 dBm)</td>
</tr>
<tr>
<td>Indoor</td>
<td></td>
</tr>
<tr>
<td>Current Consumption</td>
<td>33 mA</td>
</tr>
<tr>
<td>Transmit @ +5 dBm</td>
<td>14 mA</td>
</tr>
<tr>
<td>Receive</td>
<td>&lt; 1 uA</td>
</tr>
<tr>
<td>Sleep</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.1: Fact Sheet for Tinynode 584

Courtesy: [http://www.tinynode.com](http://www.tinynode.com)

**Receiver Sensitivity**

Receiver systems are normally required to process very small signals. The weak signals cannot be processed if the noise magnitude added by the receiver system is larger than that of the received signal. The minimum level, at a receiving antenna,
of a radio signal at which the useful information contained in the signal may be reproduced with the required quality is the receiver sensitivity. With greater receiver sensitivity, the device is able to receive weaker signals, which means greater transmission distances can be supported. *Receiver power should be greater than the receiver threshold for it to receive the packet.* In the current scenario, Receiver Sensitivity is \(-104\ \text{dBm} = 10^{(-104 / 10)} / 1000 = 3.98e-014\ \text{W}\) for 5dBm transmit power @ 76.8 Kbps. \(3.4\)

**Carrier Sense Threshold (CSThresh)**

The Carrier sense threshold is the required power to sense the signal. If the received signal strength is more than this threshold, the transmission can be sensed. To detect the signal, its power level should be *at least equal* to the Receive Threshold Value. If the carrier sense threshold value is higher than receive threshold, all unintended neighbors can hear. If it is less than receiver threshold, then it is not able to sense. The least carrier sensing threshold is the Receiver threshold value. Equating the value of CSThesh to Receiver Sensitivity the Carrier Sensor Threshold is obtained as 3.98e-014 W \(3.5\)

**Capture Threshold (CPThresh)**

Capture threshold limit defines the power ratio between the desired packets (packet at higher power level) with that of the other. If two packets reach a node, then if one packet has a power level higher than the capture threshold value, then the node can sense that packet value, else it drops the packet. Hence if the ratio is greater than or equal to the capture threshold limit, the packet is chosen else both the packets are dropped. Collision scenario is successfully detected if the difference between the power levels of two signals is at least 10 dBm.

With \(P_a\) and \(P_b\) being the two power levels,

\[10\log_{10}(P_a) - 10\log_{10}(P_b) \geq 10\quad \text{i.e.} \quad 10\log_{10}\left(\frac{P_a}{P_b}\right) \geq 10 \quad \text{or} \quad \frac{P_a}{P_b} \geq 10\]

\(\text{CPTresh} \geq 10\ \text{dB}\) \(3.6\)
**Two Ray Ground Propagation model**

Direct path without atmospheric attenuation or multipath component exists between transmitter and receiver in the propagation model. This first model cannot be used for two reason; such terrain is not possible and also the direct transmission range is too less in free space.

Taking the values of ht = hr =1.0 meter, from eq. (3.2) where ht: Height of the transmitter antenna, hr: Height of receiver antenna, and using the eq. (3.1),

\[
\lambda = \frac{c}{f} = \frac{3 \times 10^8}{915 \times 10^6} = 0.327 \text{ meters,}
\]

Or \( \lambda = 0.345 \) meters for \( f=868 \) MHz

Cross over distance is given by, \( 4 \times \pi \times ht \times hr \) / \( \lambda \)  

Substituting in eq. (3.8) the values from eq. (3.7) the cross over distance is obtained as 38.4 meters.

If the distance of transmission (d) >cross over distance, two ray propagation model is used else it is free space. With a distance of 38.4 meters as computed in eq. (3.9) large number of sensors are required in the agricultural field. In the agricultural field the sensors are sparsely deployed, with the distance between the nodes running above 200 meters. Here with transmission range of 38.4 meters, free space model is not the right choice.

The shadowing model is not taken into account as there are no tall buildings or huge trees in between the field. There is a possibly of reflection from the ground. Hence two ray propagation model is proposed.

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

\[
Pr (d) = \frac{PtGrGt \ hr^2 \ ht^2}{d^4L}
\]

Where \( Pr \): Power required to receive packet at distance d, \( Pt \): Transmitted Signal Power, \( Gt \): Transmitter Gain, \( Gr \): Receiver Gain, \( d \): Distance between transmitter and receiver, \( L \): Path loss.

Substituting the values with \( Pr = -104 \) dBm =3.8e-014 W, \( Pt = 0.0032 \) W
Gain of the amplifier = 10 log (Pout/Pin) where Pout and Pin are input and output power of the transceiver.

With input and output at same power level Gain = 10 log 1 =1 dB.

Hence substituting the values of Gt = Gr = 1.0 dB, L = 1.0 dB (without any path loss), ht = 1.0 meter, hr = 1.0 meter in eq. (3.10) the distance of transmission is obtained as,

\[ 3.98 \times 10^{-14} W = \left(0.0032 \times 1.0 \times 1.0 \times (1.0)^2 \times (1.0)^2 / (d^4 \times 1.0)\right) \]

\[ d = \left(\left(0.0032 \times 1.0 \times 1.0 \times (1.0)^2 \times (1.0)^2 / (3.98 \times 10^{-14} W)\right)^{0.25}\right) \]

\[ d = 532 \text{ meters} \quad (3.11) \]

Therefore using a carrier sensitivity of -104 dBm is equivalent to using a sensing range of around 532 meters around the node. The value obtained by the theory is matching with the ns2 simulation transmission range. But this distance is not a practical one. Hence in order to have a transmission range of 200 meters as per the Tinynode data sheet the height of the antenna is reduced from the value of 1 meter to value 0.375 meters. The actual deployment as suggested by Panchard involves a distance of 250 meters.

### 3.2.2 Sensor Node Specifications

Tinynode584 is the chosen sensor node candidate, as it provides a large transmission range as compared to Mica nodes. Table 3.1 shows the current consumption as 33 mA to transmit, 14 mA to receive and < 1 μA for sleep at 5 dBm transmit power. Two 1.5 V alkaline batteries with cumulative voltage of 3 V are used to drive the circuitry of the sensor nodes.

**Transmit Power**

The transmit power is the power consumed by the transceiver to transmit a data packet. The transmit power given here is for the transmission of an average sized packet. The transmit power is supplied to be 33 mA at 3 V.
Therefore the transmit power is calculated to be,

$$33\text{mA} \times 3\text{V} = 33 \times 10^{-3} \times 3 = 0.099 \text{ W}$$

or $txPower = 0.099 \text{ W}$ \hfill (3.12)

**Receive Power**

It is the power consumed to receive a data packet. The power consumed for a discharge current of 14 mA at 3 V is.

$$rxPower = 14 \text{ mA} \times 3 \text{ V} = 14 \times 10^{-3} \times 3 = 0.042 \text{ W}$$

or $rxPower = 0.042 \text{ W}$ \hfill (3.13)

**Sleep Power**

It is the power consumed by the node during sleep mode of operation. The sleep mode power can be calculated with current consumption of 1μA @ 3V

$$sleepPower = 1 \mu\text{A} \times 3 \text{ V} = 1 \times 10^{-6} \times 3 = 0.000003 \text{ W}.$$  

or $sleepPower = 0.000003 \text{ W}$ \hfill (3.14)

**Idle Power**

It is the power consumed by the node during idle mode of operation. The idle mode power consumption with current consumption at 2mA @ 3V is,

$$idlePower = 2 \text{ mA} \times 3 \text{ V} = 2 \times 10^{-3} \times 3 = 0.006 \text{ W}.$$  

or $idlePower = 0.006 \text{ W}$ \hfill (3.15)

### 3.2.3 Battery Specifications

With advances in power techniques, more energy–efficient, environmental friendly alternative energy sources are raising research interest, familiarly called as green power- solar technologies. Because of variable nature of solar energy and the lack of cost-effective electricity storage techniques, solar power has been unable to become the sole power supply. Solar power is not a choice for the current application as grain leaves can cover the solar panel, and also there is a possibility of it being stolen. However, it can be used with the base station, where it is under vigilance. Sensor circuitry needs a voltage supply of 2.4 V to 2.7 V. To calculate the energy in joules supplied by the batteries the following steps are invoked.
**Power and Energy Computation**

Two 1.5 V AA type battery (from Eveready, commercial name Energizer), are used for the computation. Once a path is established between the sink and the source there will be a single reception for every transmission. Hence taking the values from eq. (3.12) and eq. (3.13), the average current consumption is approximately \( (33 \, \text{mA} + 14 \, \text{mA}) / 2 = 23.5 \, \text{mA} \) \( \)  
(3.16)

Figure 3.1 shows the milliamps capacity of the battery. Figure 3.2 shows the discharge characteristics for the alkaline and lithium battery. With the current consumption of around 24 mA, the operating service period for the battery is around 80 hours in the case of alkaline battery as shown in the Figure 3.2a.

![Graph](image)

**Fig. 3.1: Milliamps- Hours Discharge Capacity of the Battery**

Lithium batteries have a longer shelf life as compared to alkaline batteries. Here the service hour for the same current consumption is around 140 hours as shown in Figure 3.2b.

The power consumption for alkaline battery with a current consumption of 23.5mA using eq. (3.16) is,

\[
\text{Power (in W)} = \text{Voltage (in V)} \times \text{Current (in A)}
\]

\[= (1.5 \times 2) \times 23.5 \, \text{mA} = 70.5 \, \text{mW} = 0.0705 \, \text{W} \]  
(3.17)

Energy available for an operation of 80 hours with constant current discharge is,

\[
\text{Energy (in J)} = \text{Power (in W)} \times \text{time (in seconds)} = 0.0705 \, \text{W} \times (80 \times 60 \times 60)
\]

\[= 20304 \, \text{Joules or 20304 Ws.} \]  
(3.18)
Each node in the simulation setup has this amount of initial energy.

![Graph showing Constant Current Performance](image)

Fig. 3.2: Constant Current Performance (a) Alkaline Battery (b) Lithium Battery
[http://data.energizer.com/PDFs/ea91.PDF](http://data.energizer.com/PDFs/ea91.PDF)

**Simulation Period**

Using an operating period of 80 hours as depicted in the Figure 3.2, the simulation period is \(80 \times 60 \times 60 = 288000\) seconds in the active mode. \(\text{(3.19)}\)

The network can live longer if the network is put to sleep whenever the node has nothing to transmit or receive. The rate of data acquisition is once in every 5 minutes when it rains or once per day during dry days. So the network is in sleep or idle state rest of the time. The network designed should be alive for a cropping period of around six months.

### 3.3 Sequence of Operation

The proposed project is carried out using ns2. Sensor node reads the sensor moisture contents at the physical channel and sends it directly to the application layer. This data is sent to the transport layer where the rate of accessing the data is varied according to the environmental conditions like the rainfall, irrigation or the existing soil moisture condition. The data is sent down to the routing layer and on following the routing direction sent to the MAC layer. Here, the collision handling is
taken care of and sent down the channel to be sent to the neighboring nodes. This neighbor could be the destination base station or the forwarding node. In the new node, the data is moved up the channel to the MAC layer and the routing layer to check if it is the destination. If so, the data is delivered up to the application layer, else it attains the next node information and forwards it. CSN project uses the AODV (Ad hoc On-Demand Distance Vector) protocol as proposed by (Perkins et al. 2003) for its application. AODV works on the principle of minimum hop count to reach the destination.

The current project improves upon the existing AODV protocol along the routing layer incorporating better routing techniques and aggregation concepts in
order to conserve energy in the nodes. Figure 3.3 shows the schematic diagram of the CBR (Constant Bit Rate) application over UDP (User Datagram Protocol) with message passing from the source application layer through intermediate nodes to the destination application layer with changes carried out to the existing ns2.

The proposed system has added new functions to CBR called the sensorApp. It regulates the interval as to when data has to be obtained. sensorUDP is the extended version of UDP with added features to handle new type of application specific data packets. The base station receives data packet and is addressed as sensorAppSink. At the routing layer many new protocols are implemented.

3.4 Analysis of Energy Model

During transmission and reception of control or data signal collision is likely to occur. In sensor networks, in order to avoid the hidden terminal problem, Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA) is made use of.

3.4.1 RTS-CTS-DATA-ACK Mechanism

CSMA-CA introduces the three way handshake between the transmitter and receiver to solve the hidden terminal problem. Each node transmits a Request-To-Send (RTS) message whenever it has a packet to send. If the receiving node receives the RTS message and the channel is free, it responds with a Clear-To-Send (CTS) packet indicating that it is ready for reception. The source then sends the DATA packet to the destination once the CTS are received. All users that overhear the RTS or CTS packets remain silent for a duration corresponding to the length of the DATA packet. Acknowledge (ACK) message in response to DATA packet is sent. CSMA serves the basis of Distribution Coordination Function (DCF) in the contention period of IEEE 802.11 standard, and also the Contention Access Period (CAP) in the IEEE 802.15.4 standard. Figure 3.4 shows the RTS-CTS-DATA-ACK
mechanism. In the case of the current simulation the Address Resolution Protocol is disabled. With RTS-CTS disabled the ACK is available only for path establishment and sending of data but not available during path discovery.

3.4.2 Energy Model and Computation of Energy Consumption

Continuous energy consumptions is the minimum energy needed to sustain the network during its lifetime without data collection including the battery leakage and the energy consumed in sleeping, sensing and signal processing.

Reporting energy consumption is the energy consumed in transmission, reception and channel acquisition.
In the current work the sleep, idle, transmit and receive energy consumption is addressed. Basic rate and data rate have effect on the amount of current consumed during transmission and reception. AODV protocol uses two control packet formats. Figure 3.5 is for path discovery and Figure 3.6 for path establishment.

Fig: 3.5: Path Discovery Control Packet

Fig. 3.6: Path Establishment Control Packet

Courtesy: [http://www.ietf.org/rfc/rfc3561.txt](http://www.ietf.org/rfc/rfc3561.txt) [Fig. 3.5 and Fig. 3.6]
Energy Consumption for Packet used during the Path Discovery and Establishment Process

Computation of energy consumption is carried out using eq. (2.1), eq. (2.2) and eq. (2.3) where energy for data sampling is not considered.

Packet format for path discovery includes the common header (20 bytes) up to the routing layer, routing layer packet to send ($p_{send}$ bytes), and the MAC header (58 bytes).

In the current work, the size of the routing packet varies according to various algorithms used.

Packet size sent from MAC layer to the next node = (78 + $p_{send}$) bytes

(3.20)

Time $t$ in seconds (s), to transmit/ receive a packet is given by,

Time = Packet Size in bytes x 8 / Packet rate in bytes per second

(3.21)

This packet is sent to the neighboring node and the time required to transmit this packet is computed.

Given, $t_{brate}$ the basic rate of the control signal, in Mbps, the time $t_{pd}$, in seconds required to transmit the path discovery packet to nearby node is obtained by substituting eq. (3.20) into eq. (3.21).

$t_{pd} = (78 + p_{send}) x 8 / t_{brate}$

(3.22)

Energy in Watt second (Ws) or Joules (J), consumed to transmit or receive a packet is given by,

Energy = Power x Time

(3.23)

Using the values of transmit power as 0.099W from eq. (3.12) and substituting the values of time $t_{pd}$, from eq. (3.22) into the eq. (3.23),

Energy for transmission of path discovery control signal to discover the path is,

$E_{pd} = 0.099 x t_{pd}$

(3.24)

Similarly to receive a path discovery message, the energy that is obtained using eq. (3.13) and eq. (3.22) in eq. (3.23),

$E_{pd_r} = 0.042 x t_{pd}$

(3.25)
A route is established from the sink to the source and the path establish control packet, \( p_{\text{receive}} \) at the routing layer is sent to the source.

Adding upper layer above network layer and lower layer packet size (MAC) the packet that is sent to next node has a size of \((78 + p_{\text{receive}})\) bytes.  \[(3.26)\]

Substitute the values of packet size from eq. \((3.26)\) in the eq. \((3.21)\) to obtain time. Using this value of time substitute in the eq. \((3.23)\) with value of transmit power from eq. \((3.12)\) to obtain, energy to \textbf{transmit} the \textbf{path establish} control \( E_{\text{pet}} \) as,

\[
E_{\text{pet}} = 0.099 \times (78+p_{\text{receive}}) \times 8 / t_{\text{brate}} \quad (3.27)
\]

The energy to \textbf{receive} the \textbf{path establish} control \( E_{\text{per}} \) as from eq. \((3.13)\) in eq. \((3.23)\) gives,

\[
E_{\text{per}} = 0.042 \times (78+p_{\text{receive}}) \times 8 / t_{\text{brate}} \quad (3.28)
\]

**Energy Requirement for Control Packets (RTS, CTS, ACK)**

These packets are generated in the MAC layer, so no control overhead is added from the upper layer.

The packet size for RTS is 44 bytes, for CTS 38 bytes and for ACK 21 bytes. \[(3.29)\]

Given, \( t_{\text{brate}} \) the \textbf{basic rate} of the control signal, the energy \( E_{t\text{RTS}}, E_{t\text{CTS}}, E_{t\text{ACK}} \) to \textbf{transmit} RTS, CTS and ACK are computed using the eq. \((3.29)\) and eq. \((3.12)\) in the eq. \((3.23)\)

\[
E_{t\text{RTS}} = 0.099 \times 44 \times 8 / t_{\text{brate}} \quad (3.30)
\]
\[
E_{t\text{CTS}} = 0.099 \times 38 \times 8 / t_{\text{brate}} \quad (3.31)
\]
\[
E_{t\text{ACK}} = 0.099 \times 38 \times 8 / t_{\text{brate}} \quad (3.32)
\]

The energy \( E_{r\text{RTS}}, E_{r\text{CTS}}, E_{r\text{ACK}} \) to \textbf{receive} RTS, CTS and ACK are computed using the eq. \((3.29)\) and eq. \((3.13)\) in eq. \((3.23)\)

\[
E_{r\text{RTS}} = 0.042 \times 44 \times 8 / t_{\text{brate}} \quad (3.33)
\]
\[
E_{r\text{CTS}} = 0.042 \times 38 \times 8 / t_{\text{brate}} \quad (3.34)
\]
\[
E_{r\text{ACK}} = 0.042 \times 38 \times 8 / t_{\text{brate}} \quad (3.35)
\]
**Energy Requirement for Data Packet**

Considering the data packet size as $p_{\text{data}}$ bytes, the total packet size is $p_{\text{data}} + 58$ bytes from MAC layer + 20 bytes up to the routing layer \hspace{1cm} (3.36)

Given the data rate to transmit data as $t_{\text{drate}}$.

The energy to **transmit data packet** $E_{\text{tdata}}$ is given using eq. (3.12) and eq. (3.36) in eq. (3.23),

$$E_{\text{tdata}} = 0.099 \times (p_{\text{data}} + 58+20) \times 8 / t_{\text{drate}} \hspace{1cm} (3.37)$$

Similarly, the energy to **receive data packet** $E_{\text{rdata}}$ is given using eq. (3.13) and eq. (3.36) in eq. (3.23),

$$E_{\text{rdata}} = 0.042 \times (p_{\text{data}} + 58+20) \times 8 / t_{\text{drate}} \hspace{1cm} (3.38)$$

Using the value of basic rate, $t_{\text{brate}}$ and data rate, $t_{\text{drate}}$ as 1 Mbps, the size of the control packet for path discovery, $p_{\text{send}}$ (at routing layer 28 bytes) at the MAC layer is 106 bytes, size of control packet for path establish, $p_{\text{receive}}$ (at routing layer 24 bytes) at MAC layer 102 bytes, the data size, $p_{\text{data}}$ (22 bytes at routing layer) at MAC layer 100 bytes, the various energy consumed are as follows.

$E_{\text{pdt}} = 0.000084 \text{ Ws}, \; E_{\text{pdr}} = 0.000036 \text{ Ws}, \; E_{\text{pet}} = 0.000081 \text{ Ws}, \; E_{\text{per}} = 0.000034 \text{ Ws}, \; E_{\text{tRTS}}= 0.000035 \text{ Ws}, \; E_{\text{tCTS}}=0.000030 \text{ Ws}, \; E_{\text{tACK}} =0.000030 \text{ Ws}, \; E_{\text{rRTS}} =0.000015 \text{ Ws}, \; E_{\text{rCTS}} =0.000013 \text{ Ws}, \; E_{\text{rACK}} =0.000013 \text{ Ws}, \; E_{\text{tdata}} = 0.000079 \text{ Ws}, \; E_{\text{rdata}}=0.000034 \text{ Ws}. \hspace{1cm} (3.39)$

Data acquisition interval = 300 seconds \hspace{1cm} (3.40)

The idle period is obtained by deducting the transmission and reception energy from the total idle energy.

The energy consumed by a node if it is assumed to be idle throughout the data acquisition interval is given by using eq. (3.40) and eq. (3.15) in eq. (3.23),

$$\text{Idle energy} = \text{Idle period} \times \text{Idle energy} = 300 \times 0.006 = 1.8 \text{ Ws} \hspace{1cm} (3.41)$$

The source transmitting node should have energy to send RTS, receive CTS, send DATA and receive ACK to and from next node. Using values from eq. (3.39),

$$E_{\text{tRTS}}+E_{\text{rCTS}}+E_{\text{tdata}}+E_{\text{rACK}} = 0.000035 + 0.000013 + 0.000079 + 0.000013=0.00014\text{Ws} \hspace{1cm} (3.42)$$
The idle energy computed at the source node is, total energy required to be idle for the specified interval – energy to transmit and receive. 

\[
E_{\text{idle}} = 1.8 - 0.00014 = 1.799 \text{Ws} \tag{3.44}
\]

The destination receiving node should have energy to receive RTS, send CTS, receive DATA and send ACK from and to the previous node. Using eq. (3.39),

\[
E_{r\text{RTS}} + E_{t\text{CTS}} + E_{r\text{data}} + E_{t\text{ACK}} = 0.000015 + 0.000030 + 0.000034 + 0.000030 = 0.000109 \text{Ws} \tag{3.45}
\]

The idle energy at the destination node is obtained using eq. (3.45) and eq. (3.41) in eq. (3.43),

\[
E_{\text{idle}} = (300 \times 0.006) - 0.000109 = 1.799 \text{Ws} \tag{3.46}
\]

Intermediate forwarding nodes should have energy to receive RTS, send CTS, receive DATA and send ACK to previous node. It should also have energy to send to next node RTS, receive CTS, send DATA and receive ACK. Using values from eq. (3.39),

\[
E_{r\text{RTS}} + E_{t\text{CTS}} + E_{r\text{data}} + E_{t\text{ACK}} + E_{r\text{RTS}} + E_{t\text{CTS}} + E_{r\text{data}} + E_{t\text{ACK}} = 0.000249 \text{Ws} \tag{3.47}
\]

The minimum energy required to transmit and receive data at intermediate node is 0.000249 Ws.

The idle energy required at the intermediate node is obtained using eq. (3.47) and eq. (3.41) in eq. (3.43),

\[
E_{\text{idle}} = 1.8 - 0.000249 = 1.799 \text{Ws} \tag{3.48}
\]

During path discovery and path establishment the amount of energy consumed at the intermediate node using values from eq. (3.39),

\[
( E_{r\text{RTS}} + E_{t\text{CTS}} + E_{pdr} + E_{t\text{ACK}} ) + ( E_{r\text{RTS}} + E_{r\text{CTS}} + E_{pdt} + E_{r\text{ACK}} ) + ( E_{r\text{RTS}} + E_{t\text{CTS}} + E_{per} + E_{t\text{ACK}} ) + ( E_{r\text{RTS}} + E_{r\text{CTS}} + E_{pet} + E_{r\text{ACK}} ) = 0.000035 + 0.000013 + 0.000084 + 0.000013 + 0.000030 + 0.000013 + 0.000034 + 0.000030 = 0.000228 \text{Ws} \tag{3.49}
\]
Minimum energy required to be available in a node to discover and establish a path is obtained using the eq. (3.49), energy to transmit and receive data is obtained using eq. (3.47) and energy consumed during idle period is obtained using eq. (3.48). Minimum energy required at intermediate node=Energy to discover and establish path + energy required to receive and transfer data during the next interval + idle energy = 0.000228 + 0.000249 + 1.799 = 1.8 Ws. (3.50)

The values obtained from the simulation are the same as obtained with the theoretical evaluation.

In reality, the data rate as suggested in the data sheet of Tinynode is 76.8 kbps for the receiver sensitivity of -104dBm. IEEE 802.15.4 in ns2 is not supporting this data rate. The maximum rate that is possible without packet loss was 50 bps for the transmission range of 200 meters which is sufficient for the current application. With IEEE 802.15.4 heavy flooding of broadcast control packet is not possible. (Zheng and Lee 2006) suggested that the data rate of 250 kbps as specified for Zigbee is possible only after the initial path is established. In this chapter, to appreciate the routing concepts, IEEE 802.11 is used (RTS-CTS and ARP disabled) for network size containing more than 25 nodes.

3.5 Geographical Model for Topology Selection

Three models of wireless network exists using n nodes and transmission range r as proposed by (Swami et al. 2007):

1. **Collocated Networks.** Every node transmission reaches every other node in one hop. Spatial reuse is not carried out here.

2. **Random or Arbitrary Multi-hop Wireless Networks.** A random graph that is formed by including a link between any two nodes which are at a distance of not larger than the transmission range.

3. **Grid network.** A network where in there are n nodes located at coordinates (i, j) with 1≤ i, j≤√n. It is a connected network with bounded neighborhood.
Each node can communicate with its eight neighbors through one-hop communication. Single sensor could gain information of a limited area. But if the area of assessment is large as in agricultural fields we need a large number of sensor nodes. Sensor networks form a collaborative network and are responsible for self-organizing often with multihop connections between sensor nodes to send data to the base station. In situation as in agricultural fields, it is not possible to use wired connection between sensors as planting long wires in the field is not feasible. Given an area there are various ways the sensors can be statically deployed. In order to avoid duplication of data the next sensor should occupy region other than that sensed by the current sensor. It should at the same time be in the hearing range of other sensor node. Having many sensors listening to same information and forwarding it, could result in multiple transmission of same redundant information. Each unnecessary transmission results in unwanted energy consumption. The other problem will be contention of the network and possible retransmissions. Optimal number of nodes covering the entire region saves energy.

Theoretically the transmission region of a sensor is assumed to be spherical. Placing other sensors along the spherical borders of the current transmitting node provides maximum range of coverage of the area of interest with maximum possible distance between nodes. Minimal of six points (triangular), four points (square) or three points (hexagonal) along the circumference of the circular region is chosen. Figure 3.7a, 3.7b and 3.7c show the way sensors can be deployed occupying the whole area of study.

Given a choice of six neighboring nodes, each of the neighbors is placed along the circumference of maximum transmission range of the current node under consideration. The distance of $2\pi r/6$ with respect to each other, where $r$ represents the transmission range is maintained as shown in Figure 3.7a. If data has to be transmitted to nearby four sensors then they can be placed in the gird or square topology as shown in Figure 3.7b. The nodes are placed at a distance of $2\pi r/4$ along
the circumference of the maximum transmission range. In Figure 3.7c three locations on the circumference of the circle at a distance of $2\pi r/3$ along the circumference is identified. The distance of transmission $r$, is 532 meters from eq. (3.11). But according to the data sheet of Tinynode a distance of 200 meters is chosen for the three topologies. Figure 3.8 shows the transmission range for all the three topologies.

![Various Topologies for Deployment](image)

**Fig. 3.7:** Various Topologies for Deployment (a) Triangular topology (b) Square topology (c) Hexagonal topology

![Transmission Range for the Sensors](image)

**Fig. 3.8:** Transmission Range for the Sensors of the three Topologies

During path discovery with hexagonal topology the number of nodes in the hearing range are six, where as with grid it is four and hexagonal it is three. With increase in the number of neighboring nodes, during flooding of path discovery message more energy is consumed among these nodes which does not contribute positively to the path establishment process.
3.6 Simulation Parameters and Discussions

The experiments are conducted using ns2 simulator. Ns2 uses C++ at the back end for carrying out routing. The UDP layer, Application layer and MAC layer (when used with 802.11) are modified in order to suit the current application. Tcl scripts are used in the front end to initialize all the parameters required for computation. Execution of ns2 generates two file. The nam file is for the network animation, a visual animation of the simulated network. The trace file has all the information of each packet moving along the layers from the Application to the Physical. Useful and relevant information from the trace file is obtained by invoking the awk script on the trace file.

3.6.1 Performance metrics

The discussion of the simulation results is carried out for the following parameters:

Network Throughput

It is a measure of the amount of data transmitted from the source to the destination in a unit period of time (second).

The throughput of a node = Total Data Bits Received / Simulation time

The throughput of the network is finally defined as the average of the throughput of all nodes involved in data transmission.

Network Throughput =

   Sum of Throughput of Nodes Involved in Data Transmission / Number of Nodes

End-to-End Delay

The end-to-end delay is the time taken for a data packet to reach the destination node. The average delay is calculated by taking the average of delays for every data packet transmitted. The parameter comes into play only when the data transmission has been successful.

Packet Delay = Receive Time at Destination − Transmit Time at Source
Average Delay = Sum of all Packet Delays / Total Number of Received Packets
It includes all possible delays caused by buffering during route discovery latency, queuing at the interface queue, retransmission delays at the MAC and propagation and transfer times of data packets.

**Packet Delivery Ratio**
It indicates the percentage of the transmitted data packets that are successfully received. The packet delivery ratio is calculated as the percentage of packets received to the packets transmitted.
Packet Delivery Ratio =

\[
\frac{\text{Received Packets at destination}}{\text{Transmitted Packets at source}} \times 100
\]

**Energy Consumption**
The metric is measured as the percentage of energy consumed by a node with respect to its initial energy. The percentage energy consumed by all the nodes in a scenario is calculated as the average of their individual energy consumption of the nodes.
Percentage Energy Consumed = (Initial Energy – Final Energy)/Initial Energy x100
Average Percentage Energy Consumed

\[
= \text{Sum of Percentage Energy Consumed by All the nodes / Number of Nodes}
\]

Average Energy Consumed =

\[
\frac{\text{Sum of Energy Consumed by All the Nodes}}{\text{Number of Nodes}}
\]

**Routing Load**
The number of routing packets transmitted per data packet delivered at the destination. Each hop-wise transmission of a routing packet is counted as one transmission. The routing load metric evaluates the efficiency of the routing protocol.
Normalized Routing Load = 
Number of Routing Packets sent / Number of Packets received at the destination

### 3.6.2 Simulation Results

Table 3.2 shows the generalized values used for all the experiments carried out in the current proposed work. The setting up of values is carried out as per the application.

**Table 3.2: Simulation Parameters.**

<table>
<thead>
<tr>
<th>Radio Parameters</th>
<th>Simulation parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Radio frequency</strong></td>
<td>868 MHz</td>
</tr>
<tr>
<td><strong>Antenna Height</strong></td>
<td>0.375 meter</td>
</tr>
<tr>
<td><strong>Antenna Type</strong></td>
<td>Omnidirectional – Quarter wave</td>
</tr>
<tr>
<td><strong>Transmit Power</strong></td>
<td>3.16 mW = 5dBm</td>
</tr>
<tr>
<td><strong>Receive Power</strong></td>
<td>-104 dBm @ 5 dBm = 3.98e-14 W</td>
</tr>
<tr>
<td><strong>Carrier Sense Threshold</strong></td>
<td>-104 dBm @ 5 dBm</td>
</tr>
<tr>
<td><strong>Capture Threshold</strong></td>
<td>10 dB</td>
</tr>
<tr>
<td><strong>Gain of transmitting / receiving antenna</strong></td>
<td>1 dB</td>
</tr>
<tr>
<td><strong>Sensor parameters (Tinynode)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Transmit Power</strong></td>
<td>0.099 W = 19.95 dBm</td>
</tr>
<tr>
<td><strong>Receive Power</strong></td>
<td>0.042 W = 16.23 dBm</td>
</tr>
<tr>
<td><strong>Sleep Power</strong></td>
<td>0.000003 W= -25.2 dBm</td>
</tr>
<tr>
<td><strong>Idle Power</strong></td>
<td>0.006 W = 7.78 dBm</td>
</tr>
<tr>
<td><strong>Battery (Alkaline battery of 1.5 V )</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Battery supply</strong></td>
<td>3 V with 2 AA sized alkaline battery of 1.5 V each</td>
</tr>
<tr>
<td><strong>Power consumption</strong></td>
<td>0.0705 W for 23.5 mA discharge current</td>
</tr>
<tr>
<td><strong>Energy consumption</strong></td>
<td>20304 J for 80 hours of active operation</td>
</tr>
<tr>
<td><strong>Transport protocol</strong></td>
<td>UDP</td>
</tr>
<tr>
<td><strong>Topology</strong></td>
<td>Square</td>
</tr>
<tr>
<td><strong>Bandwidth</strong></td>
<td>1 Mbps</td>
</tr>
<tr>
<td><strong>Application Traffic</strong></td>
<td>CBR</td>
</tr>
<tr>
<td><strong>Data acquisition time period in seconds</strong></td>
<td>150</td>
</tr>
<tr>
<td><strong>Network size in numbers</strong></td>
<td>9</td>
</tr>
<tr>
<td><strong>Network size in numbers</strong></td>
<td>532</td>
</tr>
<tr>
<td><strong>Transmission Range</strong></td>
<td>532</td>
</tr>
<tr>
<td><strong>Sampling Interval</strong></td>
<td>150</td>
</tr>
</tbody>
</table>
Table 3.3: Comparison of Energy based on Topology

Number of nodes used in the network area of size 1300 x 1300 meters: 63 nodes for triangular, 49 for square and 45 for hexagonal, Initial Energy 20304 J in each of the nodes. Distance between nodes 200 meters. Every node sends data to the base station at a time interval of 300 seconds.

<table>
<thead>
<tr>
<th>Topology</th>
<th>Triangular</th>
<th>Square</th>
<th>Hexagonal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Simulation period : 300 seconds</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Energy consumed in Joules</td>
<td>0.0232</td>
<td>0.0196</td>
<td>0.0189</td>
</tr>
<tr>
<td>Average Percentage Energy consumed (%)</td>
<td>0.00014</td>
<td>0.00096</td>
<td>0.00093</td>
</tr>
<tr>
<td>Number of Routing Packets used in the network</td>
<td>6093</td>
<td>3618</td>
<td>2687</td>
</tr>
<tr>
<td>Routing Load</td>
<td>98.2741</td>
<td>75.375</td>
<td>61.0681</td>
</tr>
<tr>
<td>Average Delay in seconds</td>
<td>0.0129</td>
<td>0.0126</td>
<td>0.0088</td>
</tr>
<tr>
<td>Network Throughput in bits per second</td>
<td>291.8739</td>
<td>283.028</td>
<td>280.5262</td>
</tr>
<tr>
<td>Packet Delivery Ratio (%)</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Number of Data Packets sent</td>
<td>62</td>
<td>48</td>
<td>44</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Topology</th>
<th>Triangular</th>
<th>Square</th>
<th>Hexagonal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Simulation period : 600 seconds</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Energy consumed in Joules</td>
<td>1.8251</td>
<td>1.8206</td>
<td>1.8199</td>
</tr>
<tr>
<td>Average Percentage Energy consumed (%)</td>
<td>0.00898</td>
<td>0.00896</td>
<td>0.00896</td>
</tr>
<tr>
<td>Number of Routing Packets used in the network</td>
<td>8995</td>
<td>5298</td>
<td>4263</td>
</tr>
<tr>
<td>Routing Load</td>
<td>72.5403</td>
<td>55.1875</td>
<td>48.4431</td>
</tr>
<tr>
<td>Average Delay in seconds</td>
<td>0.0116</td>
<td>0.0097</td>
<td>0.0079</td>
</tr>
<tr>
<td>Network Throughput in bits per second</td>
<td>3.2867</td>
<td>2.5484</td>
<td>2.3368</td>
</tr>
<tr>
<td>Packet Delivery Ratio (%)</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Number of Data Packets sent</td>
<td>124</td>
<td>96</td>
<td>88</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Topology</th>
<th>Triangular</th>
<th>Square</th>
<th>Hexagonal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Simulation period : 900 seconds</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Energy consumed in Joules</td>
<td>3.6276</td>
<td>3.6218</td>
<td>3.6209</td>
</tr>
<tr>
<td>Average Percentage Energy consumed (%)</td>
<td>0.01786</td>
<td>0.01783</td>
<td>0.01783</td>
</tr>
<tr>
<td>Number of Routing Packets used in the network</td>
<td>11897</td>
<td>6978</td>
<td>5839</td>
</tr>
<tr>
<td>Routing Load</td>
<td>63.9623</td>
<td>48.4583</td>
<td>44.2348</td>
</tr>
<tr>
<td>Average Delay in seconds</td>
<td>0.01058</td>
<td>0.0087</td>
<td>0.0076</td>
</tr>
<tr>
<td>Network Throughput in bits per second</td>
<td>2.4725</td>
<td>1.915</td>
<td>1.7563</td>
</tr>
<tr>
<td>Packet Delivery Ratio (%)</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Number of Data Packets sent</td>
<td>186</td>
<td>144</td>
<td>132</td>
</tr>
</tbody>
</table>
The first step is to analyze the topology that is to be used so that minimum number of nodes (for cost efficiency and maintenance issues) are deployed and at the same time consuming minimum amount of energy. In order to achieve this, a comparison of various ways to deploy sensor nodes is studied. The results of the various topologies are as shown in the Table 3.3. The area of the field is chosen to be 1300 meters x 1300 meters. This size is chosen so that the number of nodes placed using the three topologies hexagonal, triangular and square can almost fit in the desired area properly. Sampling rate is once in 300 seconds as per the requirement of the application. Data packets are sent from all the nodes to the base station which is positioned at the center of the area of interest. Initial energy at all the nodes is 20304 J. Transmission range is 200 meters.

During the first 300 seconds period, new path is fetched, which involves broadcasting of the path discovery messages, path establishment and data transfer. With simulation period set to 600 seconds each node sends two data packet at the interval of 300 seconds. The data sent during the second interval follows the path set during the first interval. The process is repeated for subsequent data packets.

Inference from the Table 3.3:

(a) Number of nodes required: With hexagonal topology the number of nodes required to occupy the area (in this example 1300 x 1300 meters) is less (45 nodes) as compared to square (49 nodes) and triangular topology (63 nodes). When the number of nodes has to be optimized, the best option is the hexagonal topology.

(b) Energy consumption: With large number of nodes (63 nodes compared to 49 or 45 nodes), the number of transmission and reception increases, resulting in higher consumption of energy. (0.0232 J for 63 nodes as compared to 0.0196 J for 49 nodes and 0.0189 J for 45 nodes in the first sampling period of 300 seconds. Similarly for every row.). The average percentage energy consumption also shows that the amount of energy consumed for the network
increases with number of nodes (0.00014% for triangular, 0.000096% for square and 0.000093% for hexagonal topology.

(c) Routing Packets: The number of routing packets that is used increases with large number of nodes (6093 routing packets are used for triangular, 3618 with square and 2687 for hexagonal). This is because each node has to flood in the first 300 seconds and then find a path. During successive interval the routing packets required is equal to number of hops required for the data packet to reach destination along with its acknowledgement message.

(d) Routing Load: Routing load and number of routing packets used is dependent on the retransmission, collision, packet drop and other factors too. The routing load is more with larger number of nodes (98.2741 for triangular, 75.375 for square and 61.0681 for hexagonal)

(e) Delay: This is also associated with other features like retransmission, buffered queue etc. The delay also increases with more number of routing packets in the network. (0.0129 seconds delay is observed in triangular on sending 63 data packets, 0.0126 seconds for square with 48 packets being sent and 0.0088 seconds in hexagonal when 44 packets is sent)

The throughput is of less significance in this low data rate application. The current work is associated with finding a minimum energy path. During the first 300 seconds the routing as well as data dispatch is carried out. Hence, the period of interest is during the first 300 seconds. In the next 300 seconds the energy consumption only for sending the data is analyzed. From the Table 3.3 it is observed that using less number of nodes energy can be saved. Hence in the current project work, nodes are arranged in the square or hexagonal structure. Sensors with a transmission range r, if allocated on a WSN of size \((r^{\sqrt{2}})/2 \times (r^{\sqrt{2}})/2\) i.e. \(0.71r \times 0.71r\), then single-hop communication is ensured among any of the sensor node with largest distance between any sensors as r.
If the maximum transmission ranges \( r \) is 532 meters. If nodes are placed at a distance of \((0.71 \times 532) = 372.4\) meters the eight neighbors in the square topology can listen. If we want only the nearby four nodes to listen to each other, then the distance between the neighboring nodes should be greater than 373 meters. The simulation is also carried out for a field area of 8648 meters width wise and 9768 meters breadth wise. To cover this area, 496 nodes are placed using hexagonal topology. Similarly in grid (square) fashion it is 598 nodes and triangular 728 nodes with a transmission range of 376 meters. Experiment is also carried out with these values for the three topologies to achieve similar results as shown in Table 3.3 and Table 3.4. Table 3.4 shows the effect of network density on the consumption of energy.

In large sized network the flooding of the routing packet is not practical using IEEE 802.15.4 standard. On carrying out various experiments it is found that it is possible to send broadcast signals in the network of size 25 nodes with minimal packet loss (less than 10%). The next step is to find the density of the nodes so that the consumption of energy is at its minimum. In order to achieve this, 25 nodes are placed in an area of 800 meters x 800 meters with nodes placed at a distance of 200 meters from each other. 81 nodes occupying the same area with distance of 100 meters between them is created using the square topology. This experiment is also conducted using 18 nodes for the hexagonal topology occupying the same area at a distance of 200 meters with respect to each other. The same area is occupied by 61 nodes using hexagonal topology with distance of 100 meters between them. All the nodes send the data with an initial energy of 20304 J in each node at an interval of 300 seconds.

**Inference from the Table 3.4:**

(a) Energy consumption: **Energy consumption increases with the higher density of the network.** (In the current example with the 200 meters distance between the nodes the amount of energy consumed is 0.0163 J for square and 0.0158 J for hexagonal topology. With the distance between nodes as 100
meters the amount of energy consumed is 0.0275 J and 0.0261 J respectively for square and hexagonal topology. The average percentage consumption of energy is 0.00008% and 0.000077% with 200 meter range in square and hexagonal topology and 0.000135% and 0.000128% with 100 meters range in square and hexagonal topology respectively. The number of neighboring nodes to which a node can broadcast is increased from four in the case of 200 meters to twelve in the case of 100 meters square topology. Increase in the number of neighbors explains for the higher consumption of energy.

Table 3.4: Effect of Network Density on the Energy Consumption

| Network Area 800 meters x 800 meters. Square Topology. 25 nodes placed at a distance of 200 meters and 81 nodes at a distance of 100 meters. Initial energy 20304 J in each of the nodes. All nodes sending the data. |
|---|---|---|---|---|---|---|
| Sampling interval | 300 seconds | 600 seconds | 900 seconds |
| Distance between nodes in meters | 200 | 100 | 200 | 100 | 200 | 100 |
| Average Energy (Joules) | 0.0163 | 0.0275 | 1.8169 | 1.8293 | 3.6176 | 3.6323 |
| Average Percent Energy (%) | 0.00008 | 0.000135 | 0.0089 | 0.009 | 0.01781 | 0.01788 |
| Routing Packets | 1329 | 11500 | 1869 | 13832 | 2409 | 16164 |
| Routing Load | 55.375 | 143.75 | 38.9375 | 86.45 | 33.458 | 67.35 |
| Average Delay (seconds) | 0.0067 | 0.0112 | 0.0054 | 0.0084 | 0.0050 | 0.0074 |
| Packet Delivery Ratio (%) | 100 | 100 | 100 | 100 | 100 | 100 |
| Data Packets sent | 24 | 80 | 48 | 160 | 72 | 240 |

| Network Area 800 meters x 800 meters. Hexagonal Topology. 18 nodes placed at distance of 200 meter and 61 nodes at a distance of 100 meters. Initial energy 20304 J in each of the nodes. All nodes sending the data. |
|---|---|---|---|---|---|---|
| Sampling interval | 300 seconds | 600 seconds | 900 seconds |
| Distance between nodes in meters | 200 | 100 | 200 | 100 | 200 | 100 |
| Average Energy (Joules) | 0.0158 | 0.0261 | 1.8162 | 1.8275 | 3.6166 | 3.6292 |
| Average Percent Energy (%) | 0.000077 | 0.000128 | 0.00894 | 0.009 | 0.01781 | 0.01787 |
| Routing Packets | 724 | 6937 | 1040 | 8467 | 1356 | 9997 |
| Routing Load | 42.5882 | 115.616 | 30.5882 | 70.558 | 26.5882 | 55.5388 |
| Average Delay (seconds) | 0.0059 | 0.0103 | 0.0045 | 0.0075 | 0.0041 | 0.0066 |
| Packet Delivery Ratio (%) | 100 | 100 | 100 | 100 | 100 | 100 |
| Data Packets sent | 17 | 60 | 34 | 120 | 51 | 180 |
(b) Routing Load: *With large number* of nodes the routing packets that are moving in the network are in large number contributing to *higher value of routing load*. (For the first 300 second the routing load is found to be 55.375 and 42.588 with 200 meter distance between nodes for square and hexagonal topology whereas this value is 143.75 and 115.616 for 100 meters for the two topologies respectively. The routing packets obtained is 1329 and 724 for square and hexagonal topology respectively for 200 meter distance between nodes whereas the packets are 11500 and 6937 with 100 meters distance for the respective topologies).

(c) Delay: *Larger the number of nodes* larger is the drops due to collision and retransmission resulting in *larger delay*. (0.0067 seconds for square topology, 0.0059 seconds for hexagonal topology at a distance of 200 meters between them whereas 0.0112 seconds for square and 0.0103 seconds for hexagonal with 100 meters distance).

It is inferred from the Table 3.4 that *denser network can have higher consumption of energy*. IEEE 802.15.4 does not support heavy broadcast, which necessitates the reduction in the usage of number of nodes. In other words, it will not establish a path as desired when new path is established based on flooding of broadcast packet.

### 3.7 Summary

Creation of a simulation environment close to the ideal situation is essential for proper implementation of the protocols. In this regard, in this chapter the discussion regarding the calculation of the initialization of parameters are carried out. Tinynode is used as the mote based on which power and other parameter is considered. It is calculated that a minimum of 1.8 J of energy is required for at least one transmission to take place including the idle period between two transmission intervals. This is followed by study of three topologies. Efficient node deployment
minimizes the cost (in terms of the energy consumed and number of nodes used), computation and communication. In the resource constrained application where cost of sensors is high, optimal usage of sensors is a necessity. The variation in the energy consumption, based on the distance between the sensors, the topology, the number of nodes, the efficiency of the network based on topology is studied. It is found that with the hexagonal approach the network consumes less amount of energy. Square consumes more than hexagonal approach whereas the triangular approach uses more nodes and consumes higher energy. In the coming chapters square and hexagonal topologies is used with the distance between the nodes as 200 meters.