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IMPROVED VIRTUAL CIRCUIT ROUTING ALGORITHM FOR WIRELESS SENSOR NETWORKS UNDER THE ASPECT OF POWER AWARENESS

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Abstract: *Routing algorithms have shown their importance in the power aware wireless micro-sensor networks. In this paper first we present virtual circuit algorithm (VCRA), a routing algorithm for wireless sensor networks. We analyze the power utilized by nodes to lengthen the battery life and thus improving the lifetime of wireless sensor network. We discuss VCRA in comparison with the Multihoprouter, an algorithm developed by UC Berkeley. Then we present Improved Virtual Circuit Routing Algorithm (IVCRA) which is an improved form of VCRA. In IVCRA node failure detection and path repairing scheme has been implemented. We also present the energy analysis of IVCRA and prove that IVCRA is the best choice. We first implement our routing algorithms in simulator TOSSIM and then on real hardware of mica2 mote-sensor network platform and prove the reliable routing of the data packets from different nodes to the base station. The motes used as nodes in our mote-sensor network are from Berkeley USA. By using simulator POWERTOSSIM, we estimate and present the energy utilized by different nodes of the network. At the end we present a comparison of our work with the network layer of Zigbee/IEEE 802.15.4, which is an emerging standard for wireless sensor networks and then compare its energy efficiency with the packet size chosen for our algorithm.*

Keywords: *wireless sensor network, power awareness, routing protocol, mote, ZigBee, TOSSIM, PowerTOSSIM.*

1. INTRODUCTION

Wireless ad hoc sensor networks consisted of hundreds of tiny nodes. Each node is comprised of sensor(s) and a small computer for example mica2 mote [1].

For our experiment, we use mica2 mote. It is 3rd Generation, tiny, wireless platform for smart sensors designed specifically for deeply embedded sensor networks. Major components of mica2 mote are ATMega 128L processor with 128 kb program flash memory, 512 kb measurement (serial) flash, configuration EEPROM 4kb, 10 bit ADC channel. It uses two AA batteries. Its battery life is more than one year if sleep mode is used. Both mica2 and sensor board are supplied by *crossbow* [2]. Six different sensors are available on the sensor board, namely, temperature sensor, light sensor, microphone, buzzer, magnetometer and accelerometer. When the sensor board is attached with the mica2 mote then it is considered as a node of wireless sensor network.

Our group has been using these nodes in our laboratory as a test-bench platform for the development of applications and routing protocols. There is a dedicated operating system for such nodes called TinyOS, developed by University of California at Berkeley [3]. *TinyOS is an open-source operating system designed for wireless embedded sensor networks. It features a component-based architecture which enables rapid innovation and implementation while minimizing code size as required by the severe memory constraints inherent in sensor networks.*

Motes can be used in dozens of applications. All applications can be classified under three categories; *Environmental data collection, Security monitoring and Sensor node tracking* [4]. Few examples of these applications are, to monitor the patients in their houses outside the hospitals (Intel Digital Home, CodeBlue, MobiHealth, "Detect the Falls of the Elderly" project) [5], monitoring of sensitive wildlife and habitats (Great Duck Island Project) [6], for highway and traffic application [7], in agriculture field to monitor the crops condition down to individual plant (Vineyard Computing) [8], location awareness and object tracking [9], (shooter localization in urban terrain[10], MoteTrack project [11], to find movement of major forest fire or fire in a building) [5], Monitoring of contamination in the environment (detection of chemicals effluents near chemical industry to minimize the health hazards, radiation detection [12]), monitoring of electric power system (a deeper understanding of physical nature of aging processes of cables may be achieved through distributed sensing) [13], health monitoring of machinery and system without maintenance personnel having to go to measure all of those parameters themselves [14] and Several applications deployed throughout building that monitor conference room occupancy and environmental statistics and provide access to room reservation status in a ubiquitous manner [15].

In section 2, we present the power awareness in wireless micro sensor networks. In section 3, Virtual Circuit Routing Algorithm [16] is presented and its comparison with multihoprouter, a routing algorithm by Berkeley [3]. The packet length analysis and comparison with Zigbee is also presented in this section. Improved Virtual Circuit Routing Algorithm [17] is discussed in section 4. In section 5, research work is concluded.

2. POWER AWARENESS IN WIRELESS MICROSENSOR NETWORKS

It is the *awareness of the exact performance demands of the user and the environment* [18]. For the energy awareness designer must look for it at all levels of design. One must look the least required energy for a function to be performed accurately.

Energy efficiency is the crucial H/W and S/W design criterion for a sensor node platform. It is clear from Fig. 1, that, scientists and engineers are putting their continuous efforts to make sensor node as energy aware as possible [19].

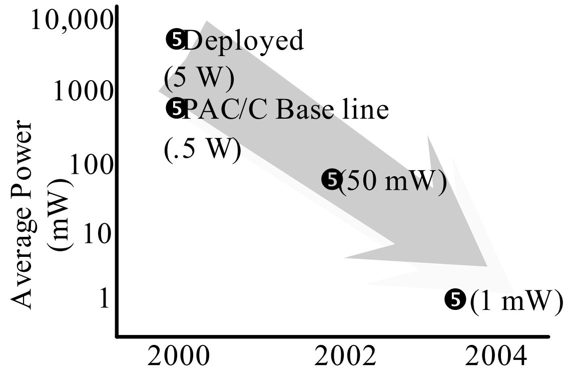

Figure 1. Sensor Node Energy Roadmap (DARPA/ PAC/C)

Most of the energy is utilized in *processing*, *Radio*, *Sensors*, and *Actuators*. Processor power is fairly significant (30-50%) share of overall power. If we look at the energy utilized in sensing, computing and then transmitting, most of the energy is used in the transmission. According to [20], *communication remains one of the most energy consuming operations, with each bit costing as much energy as about 1,000 instructions*. There are some other important aspects like, choosing appropriate mode of operation, using power management techniques at each level of design, choosing optimal time for transmission as is clear from Fig. 2.

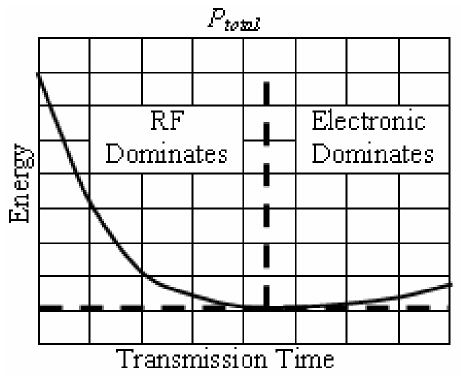

Figure 2. Optimal time of transmission

Energy can also be saved by shutting down radio as shown in Fig. 3, using energy scaling and using dynamic voltage scaling. Radio transceiver energy is very important in communication [21]. The energy consumption of the radio consists of static power dissipated and radiated RF energy. Static power dissipated by the analogue electronics. *Radiated RF energy, which scales with transmitted distance* *as d^2 to d^4 depending on environmental conditions has historically dominated radio energy*.

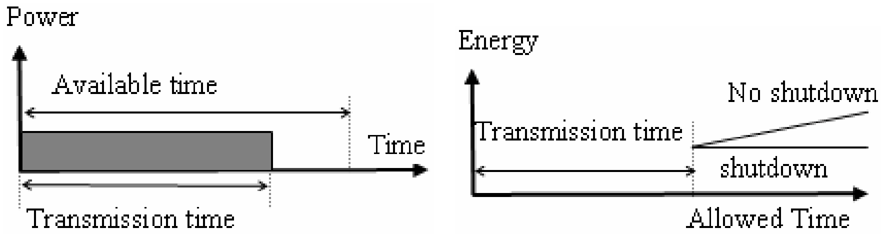

Figure 3. Energy dependency on shutting down [19]

The average power consumption of a microsensor radio can be described by:

$$P_{radio} = N_{tx}[P_{tx}(T_{on\text{-}tx} + T_{st}) + P_{out}T_{on\text{-}tx}] + N_{rx}[P_{rx}(T_{on\text{-}rx} + T_{st})]$$

$N_{tx/rx}$: is the average number of times per second that the transmitter/receiver is used. It largely depends on application scenario and media access control protocol being used.

$P_{tx/rx}$: is the power consumption of the transmitter/receiver

P_{out} : is the output transmit power

$T_{on\text{-}tx/rx}$: is the transmit/receive on-time (actual data transmission /reception time).

$$T_{on-tx/rx} = \frac{L}{R} = \frac{\text{Packet size in bits}}{\text{radio's data rate in bits per second}}$$

T_{st} : is the start up time of the transceiver and it is of significant concern.

2.1 RELATED WORK

Network protocols for sensor networks are of great importance to meet specific design goals [22]. Different routing protocols have been proposed in the literature to improve the effective lifetime of a network. Some of the important routing algorithms are, Low-Energy Adaptive Clustering Hierarchy (LEACH) [23] [24], Directed Diffusion [25] [26], Power Efficient Gathering in Sensor Information Systems (PEGASIS) [27] [28], Sensor Protocols for Information via Negotiation (SPIN) [29], Geographic and Energy Aware Routing (GEAR) [30] and Base Station Controlled Dynamic Clustering Protocol (BCDCP) [31].

LEACH [23] is *protocol architecture for microsensor networks*. It is reported in [22] that *it is an algorithm which is efficient and self-organized*. However some drawbacks can be seen in it. *LEACH is not suitable for network bigger than 111 nodes. Second, LEACH results in a long latency for the base station (BS) to receive the sensed data. Finally, the number of clusters may not be fixed every round* [22]. Another point is that LEACH has not been implemented on real hardware of wireless sensor network.

Directed diffusion [25] [26], is robust and fault tolerant. According to [22] that *the low-data rate paths and the periodic broadcast of the interest reduce network lifetime. The few nodes that are within the radio range of the BS may die quickly, reducing network lifetime too*.

PEGASIS [27] [28] is *a near optimal chain based protocol that is an improvement over LEACH. It is centered on two ideas: chaining and data fusion with the concept of leader node. PEGASIS assumes that nodes have location information about all other nodes. Simulation results showed that PEGASIS performs better than LEACH energy-wise by about 100 to 300% when 1%, 20%, 50%, and 100% of nodes die for different network sizes and topologies*. [22] shows that there is long latency problem with PEGASIS, which is of the order of N(number of nodes) and proposes solution of *multi-level chaining*. *Moreover, every node needs to have location information about all the nodes in the network. Also, a node may need to expend extra energy to find its closest neighbour. Finally, the quality of the sensed data may not be that good* [22].

SPIN is a family of routing protocols. It offers the solutions to the problems of implosion, overlap, and resource-blindness. However, the network lifetime as a performance metric should have been studied. *One factor that may affect network lifetime is that high-degree nodes may consume more energy than others, which may reduce network lifetime. Also, the energy model could be more sophisticated* [22].

GEAR algorithm [30] depends upon the query-response model. It assumes each node knows its location, energy level, and its neighbour's locations and energy levels. It has been reported in [22] that according to simulation results *for non-uniform traffic, GEAR delivers 70% - 80% more packets than the Greedy Perimeter Stateless Routing (GPSR) algorithm and 25% - 35% more for uniform traffic*.

Since a large number of low-power nodes have to be networked together, conventional techniques such as direct transmissions from any specified node to a distant base station have to be avoided [31]. When a sensor node transmits data directly to the base station, the energy loss incurred can be quite extensive. In such a scenario, the nodes that are farther away from the base station will have their power sources drained much faster than those nodes that are closer to the base station [23].

Because of the shortcoming of various routing algorithms, we decided to develop our own simple, efficient, *application-specific* routing algorithm that should meet our design goals.

3. DESIGN AND EVALUATION OF VIRTUAL CIRCUIT ROUTING ALGORITHM

Network protocols for sensor networks are of great importance to meet specific design goals [22]. There are some unique constraints in wireless ad hoc sensor networks. Due to these constraints the network protocol needed are different from conventional protocols.

3.1 DESIGN GOALS AND DESIGN PROCEDURE

Our first design goal is that network should *work for long time*. Wireless sensor networks are battery operated, therefore, the efforts should be made to make the network power aware and energy efficient. Proper resource management is the second goal. Our third goal is *scalability*.

The application for which we are developing the routing algorithm is using mesh topology.

Description of *Virtual Circuit Routing Algorithm* is following:

Each node is programmed with its own unique ID

ID = Identification No. of Current node

PID= Parent Identification No.

Each node recognizes its own ID

MN = Maximum No. of nodes

i_{max} = Maximum No of rows

j_{max} = Maximum No. of columns

// Variable declaration

```
buffer_release = TRUE
int MN, imax , jmax
K = imax × (jmax-1)
while (MN = (imax × jmax)+1) {
      input (MN, imax , jmax )
}
// packet receiving
if  (PID < > ID)  {
      call reject(packet)
}
else {
      call accept(packet)
}
// packet making
if  (timer = fired) {
      call stop(receive)
 }
      if  ((ID < > 0) AND (K < ID < MN)) {
            PID = 0
      }
// transmission
      if (buffer_release = TRUE) {
 //put the packet in queue
      get_buffer()
      call send(PID)
}
else {
```

```
        TryAgain()
    }
    if  (return = success) {
        release_buffer()
        call start(receive)
    }
```

3.2 IMPLEMENTATION AND EVALUATION USING TOSSIM/ POWERTOSSIM

TOSSIM is simulator for simulating the applications developed in the environment of TinyOS [3]. During our simulation we used the *lossy model* as a radio model in TOSSIM. Initially we have chosen only ten motes (nodes) in order to execute our algorithm. A java tool, *tinyviz*, which has interaction with TOSSIM is used. This tool provides a graphical user interface with the TOSSIM. It also offers some *plugins* for the detailed analysis and visualization. We used *tinyviz* to look at the packet routing among different nodes. A screen shot of the tinyviz during the execution of our algorithm is shown in figure 4. Different arrows can be seen in this figure. Each arrow shows the path of each packet being routed from one node to the next. If packet is not being sent from one node to other, then there will be no arrow. Figure 4 depicts the perfect execution of our routing algorithm. In this way by simulating we can say that our routing algorithm works well as per our design goals.

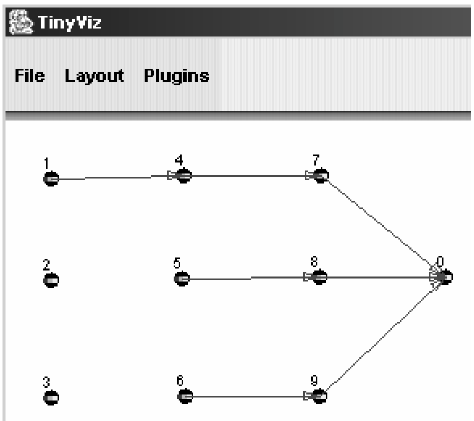

Figure 4. Execution of algorithm in TOSSIM

PowerTOSSIM, a simulator for estimating the values of energy dissipated for a particular application running under certain routing algorithm. We implement our routing algorithm in PowerTOSSIM in order to estimate the energy values. All these energy values are in mJ. We use PowerTOSSIM both for MultiHopRouter and for our algorithm VCRA. PowerTOSSIM is run for many times for different situations. In this way a large amount of data is generated. After analyzing the data, the results are compared in figure 5. It is very clear that our algorithm is also energy efficient.

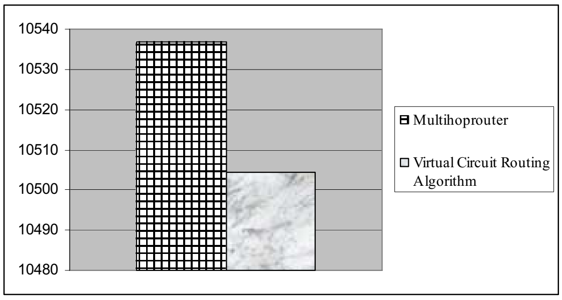

Figure 5. Comparison of energy dissipated

3.3 ALGORITHM IMPLEMENTATION ON MOTE-NETWORK

After successful implementation and execution of our algorithm in simulator TOSSIM, we then implemented our routing algorithm on mote-network with the configuration shown in figure 6.

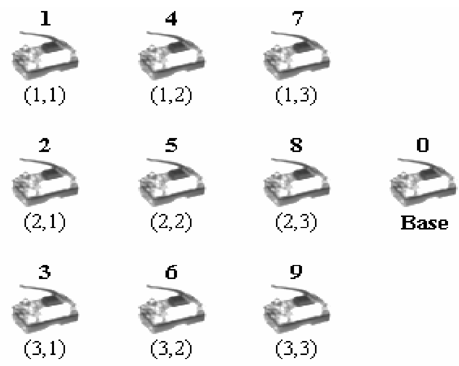

Figure 6. Execution of algorithm on real motes.

We are able to look the packets arriving at the base station successfully. A java tool is used to look at the online connection of each node in mote-sensor networks with the base station. When a mote is capable of sending the data packet to the base station in a multihop fashion as per routing algorithm, a straight line is drawn from that node to the base station on the screen. This straight line never means that the routing algorithm is single hop.

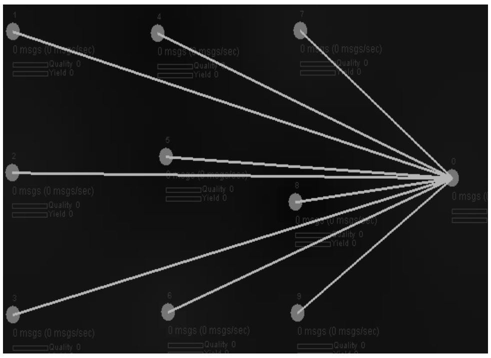

Figure 7. Execution of VCRA on real motes.

We captured a screen shot while using java tool for monitoring online mote-sensor network and is shown in figure 7.

3.4. ZIGBEE PACKET IMPLEMENTATION AND EVALUATION

Zigbee is an emerging standard for wireless micro sensor networks. Its full details have not been issued till now. Zigbee alliance has released some information about the network layer and the packet size and format. The recommended packet description is as following.

<table>
<tr><td rowspan="6">NWK Header</td><td colspan="2">Frame Control</td><td>Octets: 2</td></tr>
<tr><td rowspan="5">Routing Fields</td><td>Destination Address</td><td>2</td></tr>
<tr><td>Source Address</td><td>2</td></tr>
<tr><td>Broadcast Radius</td><td>1</td></tr>
<tr><td>Broadcast Sequence Number</td><td>1</td></tr>
<tr></tr>
<tr><td>NWK Payload</td><td></td><td>Frame Payload</td><td>Variable</td></tr>
</table>

We use the packet size and format recommended by the Zigbee for our virtual circuit routing algorithm and estimate about the energy efficiency. We then compare these energy values to the energy values already estimated for our packet used initially with our algorithm. The comparison is shown in figure 8.

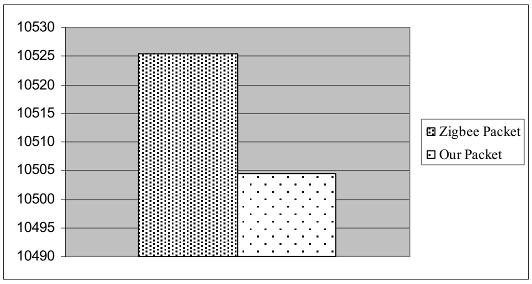

Figure 8. Comparison of energy dissipated

Figure 8 shows that the energy values estimated for the packet size we are using initially are comparable with that of Zigbee packet. There is not much difference in the energy values.

4. DESIGN AND EVALUATION OF IMPROVED VIRTUAL CIRCUIT ROUTING ALGORITHM

In VCRA, one of the deficiencies is that if a node fails in the path then that path is broken. All the nodes present before that defected node will be unable to send their data to the base station. Therefore a technique is needed to cope with this problem. To overcome this problem, improvement is made in virtual circuit routing algorithm. Here we briefly discuss the procedure of design of improved virtual circuit routing algorithm presented in [17].

4.1 DESIGN GOALS

Our first design goal is that network should work securely in case of a node failure and second goal is that it should work for long time. Thirdly, these networks are resource-constrained. A sensor node has a limited memory, limited communication bandwidth, limited energy, and limited computation capabilities. Therefore, the resources should be managed in an efficient way.

4.2 DESIGN PROCEDURE

IVCRA works in a way that when a node receives a packet, it looks its address and accepts according to the address. After acceptance of the packet the node sets its parent identification (PID) by looking at the active node in the path. It checks for the node failure by using acknowledgement technique. For a certain PID, if a node has failed it changes the route of the packet for its safe delivery. Once it finds the active nodes with safe path, it transmits the packet. During transmission there is no reception. Since each node is sensing the data itself as well. Therefore, if timer fires to indicate that packet is ready, it stops receiving the packets and transmits its own packet by setting its PID in the same safe way as discussed above. Here is our improved virtual circuit multihop routing algorithm using mesh topology:

```
buffer_release = TRUE
int MN, imax , jmax
K = imax × (jmax-1)
     while (MN > (imax × jmax)) {
     input (MN, imax , jmax )
     }
     // packet receiving
     if (PID < > ID)  {
     call reject(packet)
     }
     else {
     call accept(packet)
     }
     // packet making
     if (timer -> fired) {
     call stop(receive)
      }
     // Setting PID and Checking ACK
     call pathclear()
     while (ACK < > TRUE){
     PID = ID + imax

     if (PID = imax) {
     PID = ID + 1
     }
     if ((ID < > 0) AND (K < ID < MN)) {
     PID = 0
     }
     }
     // Transmission
     if (buffer_release = TRUE) {
     //put the packet in queue
     get_buffer()
     call send(PID)
     }
     else {
     TryAgain()
     }
     if (return = success) {
     release_buffer()
     call start(receive)
     }
```

We use the mesh topology as recommended for wireless micro sensor networks. Specifying the positions of our motes and using the java tool for lossy model, we generate a file containing the bit errors for each pair of nodes in the topology of the network. At the bit level, TOSSIM can capture many causes of packet loss and noise in a TinyOS network, including missed start symbols, data corruption, and acknowledgement errors.

4.3 ALGORITHM IMPLEMENTATION USING TOSSIM

We implement our application with IVCRA in a bit level simulator, TOSSIM. We also use a java tool, TinyViz in conjunction that provides graphical user interface and some tools for the analysis. Initially we implement it for ten nodes as can be seen in figure 9. Node zero is serving as base station. When a data packet is transmitted and successfully received by the other node, an arrow is drawn between these two nodes by the java tool to indicate the successful arrival of the packet.

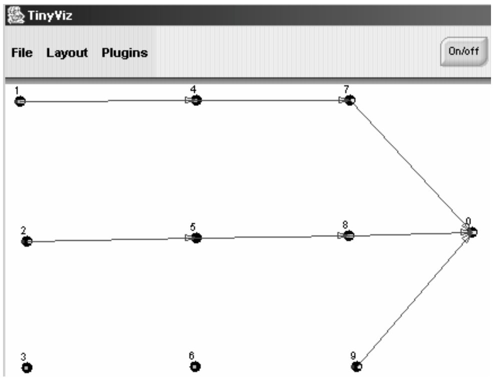

Figure 9. TOSSIM TinyVIZ output for all nodes active

During our simulation, we confirm reliability of IVCRA by switching off different nodes and by looking at the re-routing of data packets for their safe transmission. As an example, if we switch off node 4 as can be seen in figure 10, that its colour has become gray, the algorithm finds that the parent, node 4, is no more alive and path has been ruptured, it repairs the path and re-route the data through the node 5. The arrow between node 1 and node 4 is removed after the node failure. But before the removal of the arrow between node 1 and node 4 this screen shot is captured.

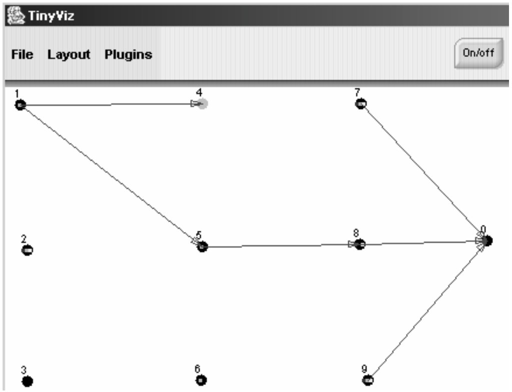

Figure 10. TOSSIM TinyVIZ output for Normal packet size, when node 4 is off

4.4. ALGORITHM IMPLEMENTATION ON REAL MOTE-NETWORK

We implement our algorithm on the real mote network deployed at our institute, using a mesh topology. Each mote is attached with the sensor-board. Our application runs with IVCRA. We switch off different motes and verify that our algorithm is capable of finding the dead node and changing the route of the packet in an energy efficient way. We use a java tool that displays the online status of the mote-network. During active state of mote-network, when we switch off test node(s), we are able to look re-routing of the data packets in two ways. Firstly, by looking LEDs on the motes and secondly, by looking at the connection breakage on screen of computer supported by the java tool. When we switch off node number 7 and 8, we get the connection break at the screen as can be seen in figure 11.

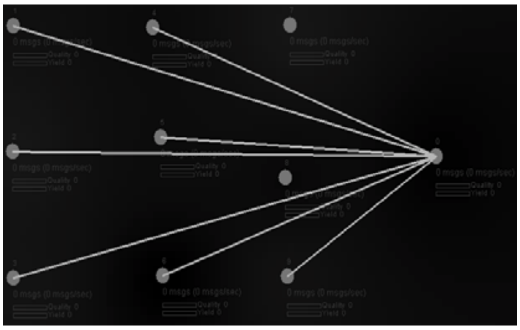

Figure 11. Execution of VCRA on real motes

4.5 ENERGY EFFICIENCY EVALUATION USING POWERTOSSIM

Using simulator, PowerTOSSIM, we present here the comparison of energy utilized by IVCRA and Route, for our temperature sensing application. Route is another name given to multihoprouter. The energy comparison is given in figure 12.

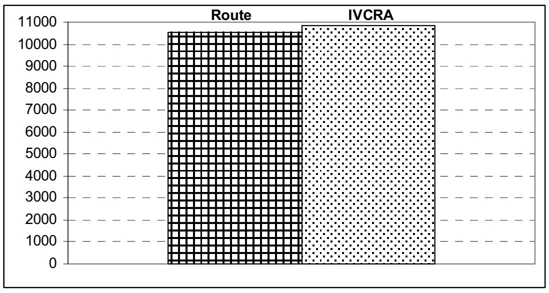

Figure 12. Energy (mJ) Comparison of routing algorithms with normal packet size

4.6 ZIGBEE PACKET IMPLEMENTATION AND EVALUATION

Zigbee is a specification set of high level communication protocols designed to use small, low power digital radios based on 802.15.4 standard. ZigBee alliance has recently released some information about the network layer. The recommended format of data packet is already mentioned in section 3.

We use this data packet in our application with IVCRA and find the energy values for this specific packet. Then we compare these energy values with the energy values of the data packet we are using for our application. The comparison of energy values is shown in figure 13.

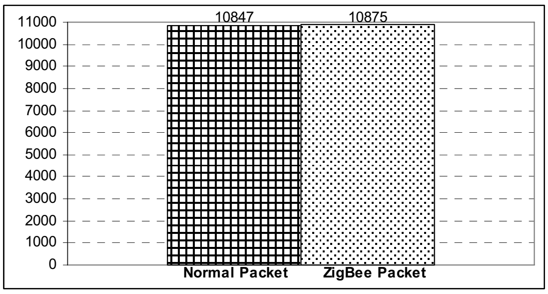

Figure 13. Energy (mJ) comparison of IVCRA routing algorithm with normal packet size and with ZigBee packet size

5. CONCLUSION

We developed *virtual circuit routing* algorithm for wireless sensor networks. In order to verify its working first we implemented it in simulator TOSSIM and verified that it was working perfectly. In order to verify it further, we implemented it on real wireless sensor network comprised of mica2 motes. It was done by programming each mote and then placing at some pre-specified location in our institute according to application requirement. The deployed network at our institute of mica2 motes with mesh topology is used to sense the temperature of the environment at different locations. For on line monitoring of each node we used java tool and proved that data routing was working perfectly. Then we performed energy analysis of VCRA by using simulator PowerTOSSIM and compared it with multihoprouter. The energy difference was not substantial but worth noting. Important point is that VCRA is much simpler than multihoprouter. While performing experiment using VCRA, we encountered the problem of node failure. Due to node failure we were not only unable to get the data of that particular node but also for those nodes that were using this node as a router. To cope with this problem, we introduced the technique of *node failure detection and path repairing scheme* and developed IVCRA. First we simulated IVCRA in simulator TOSSIM and later on, it was implemented on real mica2 mote network. We verified its working by switching off different nodes in the network and looking the rerouting of the data through new paths and reaching the base station safely. We also performed the energy analysis of IVCRA. We concluded that although there was not sufficient saving of energy yet IVCRA was offering a very safe routing of the data packet. Reliable routing of IVCRA overcomes the energy aspect. Another important thing is the simplicity of IVCRA algorithm. IVCRA is simple as compare to multihoprouter. Multihoprouter is using a broadcast technique and is very complex as compare to IVCRA. We also verified that packet loss rate for IVCRA is less as compare to the broadcast technique. We conclude that IVCRA is the best choice for our application.

6. FUTURE WORK

We would like to improve our routing algorithm from its scalability point of view so that it can be used for any number of nodes. We would like to measure experimentally, the energy dissipated by different nodes in the network both offline and online and then to make the network more energy aware.

7. ACKNOWLEDGEMENTS

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