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Energy Aware Multi-hop Routing Protocol for Internet of Things based Wireless Sensor Network

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Abstract: The Internet of Things (IoT) has started to give rise to real-world applications. It is used to connect the various objects with each other through the internet without any human interaction that shape our daily lives. Wireless Sensor Network (WSN) is one of the most fundamental technologies of the Internet of Things (IoT). Various IoT devices are connected through the internet by making a wireless sensor network. A wireless sensor network is composed of various nodes transmitting wirelessly the information they captured. Each node consists of sensors and actuators. As sensors are battery operated, so power consumption is a very important issue while connecting IoT devices. In this study, we proposed a multi-hop routing protocol which aims to reduce the energy of the network while transmitting data to a central micro-controller and then to the internet, thus increases the network life time.

Key words: Internet of Things (IoT), microcontroller, RFID, arduino, interaction, information

INTRODUCTION

The advancement of internet technologies is expanding the boundaries of the internet connectivity. Internet of thing (Atzori *et al*., 2010) is one of the recent technology where several physical objects computable or non-computable are connected through network using sensors and actuator. The physical objects surrounding us are increasingly equipped with RFID tags (Radio-Frequency Identification) (Samaniego and Deters, 2016), NFC tags (Near Field Communications) or other electronic bar code that can be read by smart devices such as tablet, smart phone and other web applications. The physical objects or IoT objects are uniquely identifiable and addressable while connected through the internet. WSN consist of many low power sensor nodes (Akyildiz *et al*., 2002) takes an important role in the integration of smartthings to the future internet which helps in assembling several surrounding information. The sensor nodes that are deployed in the field sense the phenomena (Borges *et al*., 2014) as an analog signal and using an analog to digital converter convert it a digital signal. Those signals are then forwarded from the sensor nodes to the sink or to the microcontroller from where they go to the internet. In this study, we have used two types of sensor node. Data are forwarded from the sense and the identification layer to the application layer. At the bottom layer (sense and identification layer) a WSN node consists of a sensor and an actuator known as slave node. At the middle layer (network construction layer) data have been forwarded using multi-hop technique from bottom layer sensor node to master node. Each master node is connected to a certain number of neighboring slave nodes. Each slave node should be in the radio range of their master node. Each master node is connected to a central controller (known as arduino microcontroller). In arduino microcontroller the forwarded data are being processed and transmitted to the upper layer known as an information application layer. In the application layer through web or android application anyone can access the data and invoke command back to the microcontroller so that it generate the signal to the bottom layer through network construction layer to trigger the actuator to do the necessary action for the physical devices (IoT devices). Since, sensors are battery operated devices, there fore we have considered multi-hop routing so that less energy should consume while transmitting the data to the next higher level (De Rango *et al*., 2016). Figure 1 shows the block diagram of each layer.

In multi-hop data routing techniques each slave node senses the environment and forwards the sensed data to the master node for. Master node aggregate data and directly forward them to the microcontroller for further processing. Longer distance between master node and the microcontroller node makes the network more energy consuming (De Rango *et al*., 2016).

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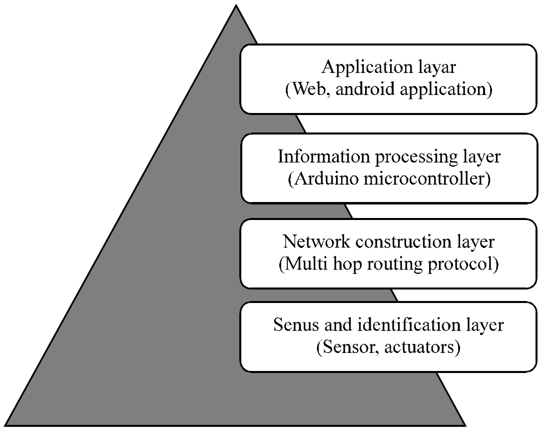

Fig. 1: Block diagram

MATERIALS AND METHODS

Proposed architecture: Our proposed architecture contains a number of sensor nodes deployed in an area. The bottom layer consists of sensors and actuators. The sensors sense the physical phenomena as an analog signal and using an analog to digital converter convert it a digital signal. Those signals are then forwarded from the sensor nodes to the Arduino microcontroller from where they go to the internet. At the bottom layer a wireless sensor network node which is given in Fig. 2 consists of a sensor node unit and an actuator unit. At the middle layer a wireless sensor network node consists of only sensors.

The master node consists of sensors. The architecture of a master node is given in Fig. 3. The master node identifies its slave node which is in the radio range of each other. Based on the wireless sensor node architecture, this study presents a proposed model which is illustrated in Fig. 4 and proposes a feasible formulation to express the overall energy consumption of a generic wireless sensor network application in terms of its energy constituents.

Multi-hop data routing algorithm: In this study, we have proposed a multi-hop data routing algorithm (Cai *et al*., 2008) which consumes less energy as compared to single hop. The algorithm is divided into three phases. The sensitive data of IoT devices from the bottom layer transmitted to the application layer with multi-hop fashion. We have fixed the position of each sensor node and also the microcontroller. The position can be easily tracked by using the coordinate system, over a range of area.

Each sensor node in this field can be uniquely identified by its address. Each sensor node address is

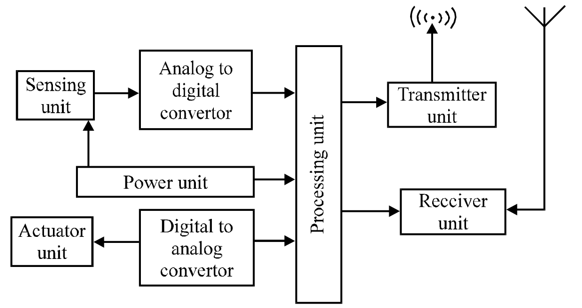

Fig. 2: Bottom lartyyer wireless sensor node (slave node)

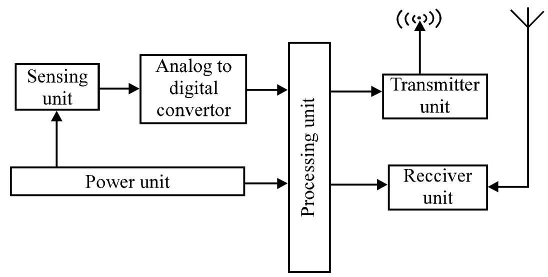

Fig. 3: Master node architecture

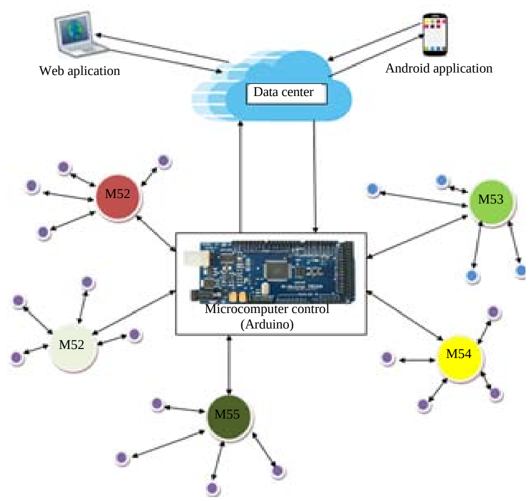

Fig. 4: Proposed model based on wireless sensor node architecture

16 bit long where most significant 8 bit represent the x coordinate and the least significant 8 bit represent the y coordinate. That is a single address space is expressed as (x, y) in two-dimensional coordinate system. Its address will have a form of (x, y) where x and y are both nonnegative. The algorithm consists of the following phases. The first phase is a connection establishment phase. After connection establishment the next phase is the data transmission phase from bottom layer sensor to

the web or android application and finally from the web or android application to the actuator which do the necessary action.

Connection establishment phase: The microcontroller sends signal to all master node. After receiving the signal from microcontroller master node sends JOIN request to all slave nodes which are in their radio range of each other. The JOIN request message packet format comprises of following fields.

JOIN request message packet format:

- Source addess (8 bit x-coordinate, 8 bit y-Coordinate)_16 bit_
- Destination address (8 bit x-coordinate, 8 bit y-Coordinate)_16 bit_
- 16 bit message
- Join field = 0

After receiving the JOIN request by master node the slave node sends back the acknowledgement to them that now they can transmit data to their master node. The ACK packet comprises the following fields:

- Source address (8 bit x-coordinate, 8 bit y-coordinate)_16bit_
- Destination address (8 bit x-coordinate, 8 bit y-coordinate)_16bit_
- 16 bit message
- Join field = 1

Data transmission phase: The sense data from the bottom layer are forwarded to each master sensor node which belongs to the radio ranges of their slave node. The master node maintains a routing table which stores the information about the data or message coming from the slave node. For each sensor node 'i', associate a routing variable $X_{i,j}$ with each link (i, f) indicate that node 'i' sends data to node 'j'. If $X_{i,j}$>0 means that the link (i, f) is active. If $X_{i,j}$ = 01 means that the link (i, f) is inactive. The master node forward the data to the central controller or the arduino microcontroller (Razzaque *et al*., 2016) from this Central controller the data goes to the application layer. On the reverse way when in application layer the user sends an HTTP request to the Arduino microcontroller. A web application server runs on Arduino, accepting HTTP request. That request is handled by the controller and sends to the master node. From the master node the request goes to the appropriate slave node for immediate action. We have implemented a routing table which is shown in Table 1 in the Arduino microcontroller to forward messages to the master sensor node.

Table 1: Routing table

Message	Sensor node ID	Master node ID	Arduino microcontroller
M1	(x1, y1)		Address
M2	(x2, y2)	(a1, b1)	
M3	(x3, y3)		
M4	(x1, y1)		(A1, B1)
M5	(x1, y1)	(a2, b2)	(16 bit)
M6	(x1, y1)		
M7	(x1, y1)		

The master node also maintains a routing table to track their slave node. Suppose the data are coming from a sensors having coordinate (x1, y1) to its master node (a1, b1) then the table group the master node with their slave node. The packet format send by the sensor node to its master node:

- Master node ID (destination)
- Sensor node ID (source)
- Message

The master node forwards the data to the central server (or Arduino microcontroller) by adding the address of Arduino microcontroller in the packet format:

- Arduino microcontroller ID (destination)
- Master node ID (source)
- Sensor node ID
- Message

Finally, the data is forwarded to the client application in the form of message (Luong *et al*., 2016). The data is rectified by the client and also the address from which the data has come. In application layer client gives an HTTP request to the arduino microcontroller. A web server is running in the microcontroller process the HTTP request and forward to one of the master node. Finally, the message has delivered to the receiver end of the wireless sensor network node from there it goes to the actuator in the form of an analog signal which actuates the proper IoT devices.

Energy calculation phase for the overall process: The wireless sensor network aims to sense a certain natural phenomenon for the IoT devices. In this study, we have designed a multi-hop protocol that sends the sensed data to a central server or Arduino microcontroller. As compared to single hop transmission the proposed protocol takes less energy and increase the network lifetime. For calculating the energy we have used the energy model for Wireless sensor network. Mainly two types of energy consumptions (Abo-Zahhad *et al*., 2014) are there the transmission energy and the receiving energy (Bouabdallah *et al*., 2009). Transmitted signals are subject to attenuation that varies with distance. We assume that the transmission rate is a constant that is the same for every sensor, transmitted energy $E_t(i, f)$. It is the energy consumption per second for transmitting one unit of data from node i to node j. Received energy $E_r(i, f)$ is the energy consumption per second for receiving one unit of data from node i to node j. For each sensor node i, we have associate a routing variable $X_{i, j}$ with each link (i, f) indicate that node i sends data to node j. If $X_{i, j}>0$ means that the link (i, f) is active. If $X_{i, j} = 0$ means that the link (i, f) is inactive. Suppose we are sending n bit long packet then the transmission energy will be (Seung *et al*., 2004):

$$E_t(i,j) = E_{tc}(n)+E_{emp}(n,d) =$$
$$n\times E_{trans}+n\times e_{emp}\times d^a$$

Where:

- $E_{tc}(n)$ = The energy that the radio circuit needs to consume in order to process n bit long packet
- $E_{emp}(n, d)$ = The energy needed by the radio amplifier circuit (Fig. 5) to send n bit long packet over a distance
- d = The value of a should be between 2-5
- E_{trans} = The energy needed to process a single bit by the radio transmission circuits
- e_{amp} = The constant known as the transceiver's energy dissipation or radio amplification constant which can be given by equation (Heinzelman *et al*., 2000)

$$e_{amp} = \frac{\frac{S}{N_r} NF_{RX} N_o BW \left(\frac{4\pi}{\lambda}\right)^{\gamma}}{G_{ant}\eta R_{bit}}$$

Where:

- S/N_r = The signal to noise ratio at the receiver
- NF_{RX} = The noise at the receiver side
- N_o = The noise power
- BW = The channel noise bandwidth
- λ = The wavelength
- G_{ant} = The antenna gain
- η = The transmission efficiency
- R_{bit} = The channel data rate in bit per second

Similarly, the receiving energy is given by:

$$E_r(i,j) = n\times E_{receiver}$$

where, $E_{receiver}$ is the energy needed to process a single bit by the receiver electronic. Therefore, the total energy consumption is given by:

$$E_{total} = E_t(i,j)+E_r(i,j)$$

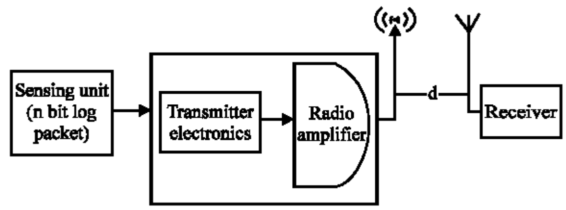

Fig. 5: Radio amplifier circuit

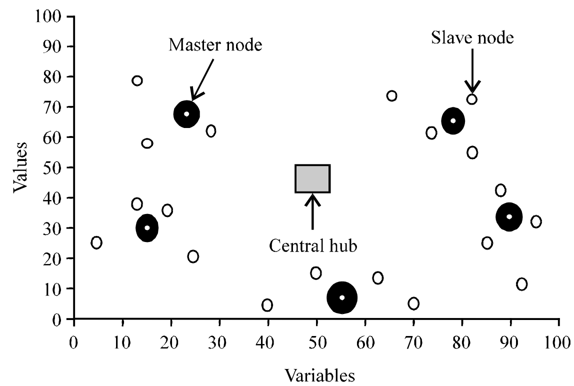

Fig. 6: Sensor node deployment; sensor node deployment with central hub

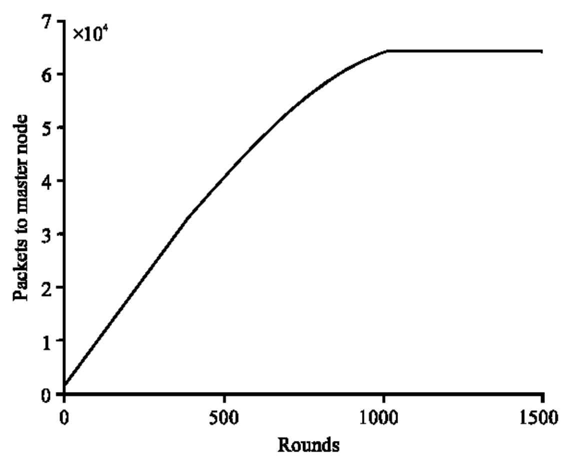

Fig. 7: Number of data packets transmitted; data transmission from slave node to master node

RESULTS AND DISCUSSION

In the simulation environment, the WSN consists of 25 sensor nodes deployed with considering their position over a monitoring area of 100×100. There exist two types of sensor nodes, slave node and master node, respectively. We have used MATLAB to simulate our proposed method. Figure 6 shows the sensor node deployment with their master node in proper position.

Figure 7 shows the number of data packets transmitted by the slave node to their master node for a

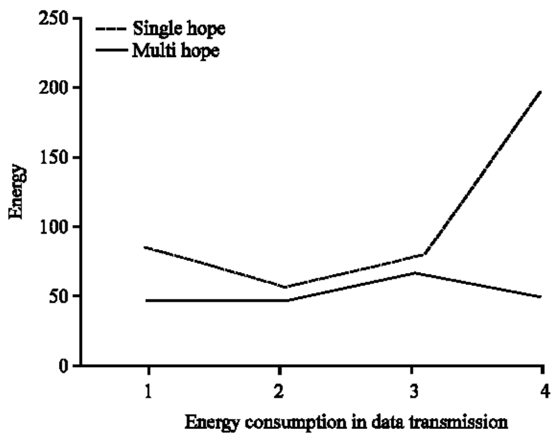

Fig. 8: Comparison between the overall energy consumption in single hop data transmission versus multi hop data transmission emergy consumption in data transmission

particular round. Figure 8 shows the comparison between the overall energy consumption in single hop data transmission versus multi hop data transmission.

CONCLUSION

The multi-hop protocol reduces the energy of overall network while forwarding the data from the lower level sensor node to the microcontroller. We have calculated the distance between each node to the microcontroller. A threshold distance is taken. If the distance of each node is greater than the threshold than the nodes send the data to the master node otherwise it sends data directly to the microcontroller.

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