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Humidity Measurement Using an Efficient Topology Control and Energy Aware Routing for Wireless Sensor Network

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ABSTRACT

Wireless sensor network continues to be a resource constrained network with limited energy, computing power, memory and communication capabilities. Among all the mentioned constraints, energy consumption is of paramount importance. The network does not maintain standard topology instead, it has dynamic topology. Hence, it necessitates the development of an energy efficient protocol for supporting dynamic topology to increase the lifetime of the network. This study focuses on the development of a hybrid protocol that integrates an energy aware routing over a topology controlled network. To prove the effectiveness of the proposed protocol, a test bed with a multi hop network is deployed and the network lifetime is analyzed under various scenarios.

Key words: Wireless sensor network, zigbee, topology control, routing, network lifetime, energy consumption

INTRODUCTION

Recent developments in the field of Micro Electro Mechanical Systems (MEMS) have lead to the development of low power sensor nodes with a reduced cost (Akyildiz *et al.*, 2002; Zhao and Guibas, 2005). Every sensor node is capable of sensing data from the environment and transmits data over wireless medium either directly to base station or through the gateway nodes (Karl and Willing, 2005; Stankovic, 2008). Wireless sensor networks differ from *ad hoc* networks because of low power battery, low channel bandwidth and its infrastructureless nature. Moreover, Wireless Sensor Networks are designed for information gathering from inaccessible locations. Communication bandwidth and energy are significantly more limited in the design of wireless and mobile systems than in a wired network environment. Innovative techniques and protocols should be proposed for the effective utilization of available energy.

One way of obtaining energy efficient network is to make an energy aware routing over a topology controlled network. The topology of the network is controlled by maintaining an effective set of neighbors (Warrier *et al.*, 2007; Blough *et al.*, 2006; Xue and Kumar, 2004). In this proposed algorithm, residual energy of the individual sensor node is considered for the selection of neighbors as data forwarder. Other neighbor nodes that are not involved in data forwarding are made to sleep. This results in maximum energy saving in the network under consideration (Labrador and Wightman, 2009; Li and Hou, 2004). An energy aware routing over the reduced (topology controlled) network further brings increased energy savings. The proposed topology

control using energy aware routing for humidity measurement is implemented in a test bed scenario using zigbee, comprising of 5 end devices, two layers of routers (each layer with 10 routers) and one coordinator.

Various studies has been carried out in the field of WSN using zigbee protocol stack. A mobile wireless system in the field of agricultural green house is found to be cost effective. The other proposed studies takes over the MAC and network layer of zigbee completely and analyzed the implementation of hardware and software for the industrial applications and health monitoring applications of wireless sensor network system. The features of zigbee standard is described, which has the great solution for wireless sensor network. A real time environmental monitoring systems for sensing temperature, pH value and turbidity is designed using zigbee nodes (Terada, 2009; Zhu *et al.*, 2006; Lin *et al.*, 2007; Varchola and Drutarovsky, 2007; Rasin and Abdullah, 2009). From the observations made by the survey study it is clear that, so far the network implemented with zigbee are application specific and not for an open end application. Also it concentrates only on the application and not on energy consumption and life time. Hence, a new approach that considers the network topology for an effective way of routing is desirable.

NETWORK SCHEMATIC

The WSN finds its application in remote location where human interventions is of high risk. Figure 1 shows the schematic diagram of the entire designed system for the humidity measurement application. In this network, a humidity sensor is attached to every end-device that collects sensory information from the environment and transmits it to the coordinator via routers. Routers are formulated as two layers with ten nodes in each layer. Coordinator is connected with a remote monitoring system that monitors sensory information, consumed energy and residual energy of each node.

IMPLEMENTATION OF NODES

"Network nodes are implemented using zigbee CC2431 which is a true System On Chip (SOC) for wireless sensor networking. It is highly suited for systems where ultra-low power consumption is required. This is achieved by various operating modes. Short transition times between these

End devices
sensing
humidity

Routers
in layer 1

Routers
in layer 2

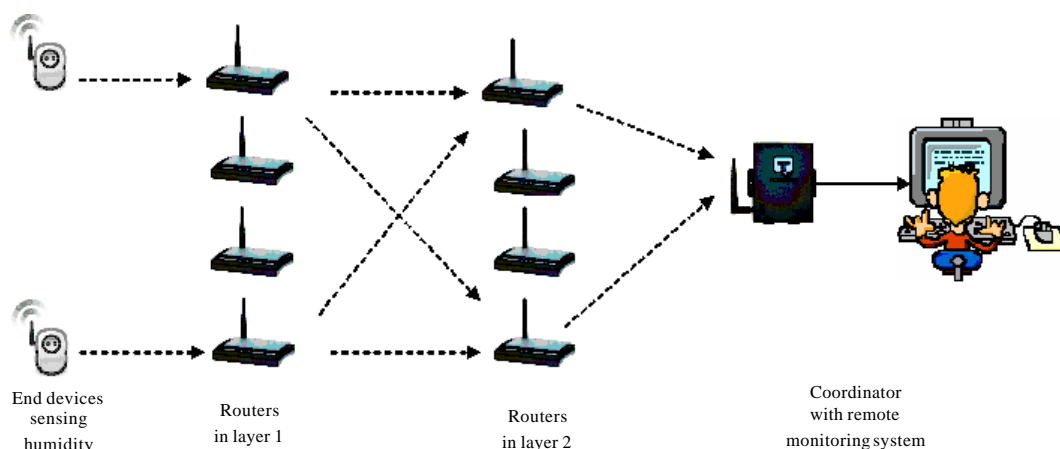Coordinator
with remote
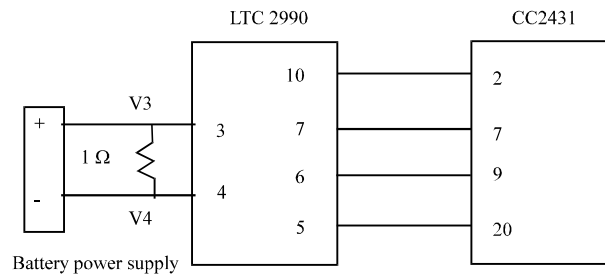monitoring system

Fig. 1: Network schematic

Fig. 2: Circuit for battery monitoring algorithm implemented

modes further ensure low power consumption. Three logical device types are used in a zigbee network, coordinator, router, end-device. Zigbee devices are programmed using IAR workbench using, which nodes are further configured as coordinator, end device and routers. Application identified for the proposed methodology is humidity measurement. Humidity is measured with HSM-20G Humidity sensor modules (from data sheet). Average relative humidity range is 20-95% (Sensirion, 2011).

The power consumption of all the nodes is continuously monitored at the end of every transmission. Since coordinator is connected with a remote monitoring system, power measurement is done for all the end devices and routers, excluding the coordinator. Sensor nodes are interfaced with LTC 2990 for power measurement (Linear Technology Corporation, 2010). The LTC 2990 monitors voltage, current, internal and remote temperatures. It can be configured through an I²C interface to measure any combination of these parameters. Single or repeated measurements are also possible (From data sheet). One of the typical applications of LTC 2990 is to monitor the voltage and current in the battery.

Figure 2 shows the circuit connection for the measurement of voltage and current of a battery. The output of this circuit gives the residual voltage and current through which residual power of the battery is estimated. Consumed power is measured by finding the difference between parametric values available at the initial state and values measured after each transmission. Each node for which power has to be calculated is connected with LTC 2990 and power consumption is measured.

ESTIMATION OF ENERGY

$$P = VI \tag{1}$$

where, P is power in watts, V is voltage in volts and I is current in amperes:

$$1W = 1 \text{ J sec}^{-1} \tag{2}$$

where, 1 watt is equaled to 1 Joule per second:

$$E = Pt \tag{3}$$

where, E is energy in joules, P is power in watts and t is time in seconds.

Two AA batteries are used for each node. Each AA battery has a voltage level of 1.5 V and 836 mAh as an average. Hence, initial power available at each node is calculated as per the Eq. 1-3:

$$V (1.5+1.5) \times 836 \text{ mAh} = 2508 \text{ mWh}$$

$$2508 \text{ mWh} \times 3600 \text{ sec h}^{-1} \times 1/1000 = 9028 \text{ Wsec}$$

$$9028 \text{ Wsec} = 9028 \text{ J}$$

Power consumption of an end device is calculated as:

$$P\_sense + P\_node = P\_tot \qquad (4)$$

Where:
P_sense : Power consumed by the sensor
P_node : Power consumed for the node operation
P_tot   : Total power consumed by the node:

$$(1V \times 0.002 \text{ A}) + (0.08+0.080) = 0.0084 \text{ W}$$

Hence, power consumed by the end device for a single transmission is 0.0084 J/transmission. End device is transmitting for every one second and hence 86400 transmissions per day are done for an end device:

$$\text{End device for a day} = 86400 \times 0.0084 = 725.76 \text{ J day}^{-1}$$

Power consumed by the:

$$\text{Life time of an end device} = \frac{9028}{725.76} = 12.5 \text{ days}$$

Power consumption of a router:

$$P\_node = P\_tot \qquad (5)$$

$$(0.08+0.080) = 0.0064 \text{ W}$$

Hence, power consumed by the end device for a single transmission is 0.0064 J/transmission. Router is transmitting for every one second and hence 86400 transmissions per day are done for an end device:

$$\text{Power consumed by the router for a day} = 86400 \times 0.0064$$

$$= 552.96 \text{ J day}^{-1}$$

$$\text{Life time of a router} = \frac{9028}{552.96} = 16.32 \text{ days}$$

Life time of a single router is average of 16 days. In each layer only one router is transmitting at a time.

ALGORITHM FOR TOPOLOGY CONTROL USING ENERGY AWARE ROUTING

Algorithm implemented for the proposed protocol comprises of two modules-main program, subroutine for process event function. The called main program initializes the parameters of the network and nodes. Parameters such as operating system, stack, memory, power supply check and timer are initialized. After initialization function OSAL address stack is called for initialization of address for all tasks. Next, a function to set priority to the operation is called, where the priority is given in the following order:

- **MAC data length:** MAC data length is given highest priority which assigns the length of the data
- **Network address setting:** Followed by MAC data length network address setting is given the next priority to assign the address of each node in the network layer. This helps in identification of nodes
- **Application process:** This is given the lowest priority which helps in transmission of data. Finally process event function is called for the checking of residual energy. The process event also performs the task of data transmission. The flowchart for the main program module is described in Fig. 3

The flow chart of process event function is shown in Fig. 4. Initially the coordinator (destination node) sends a REQ message to get the sensory information to all the end devices. On receiving the REQ message, the active end devices (source node) transmit its information to coordinator via the routers of the intermediate layers. The coordinator node on receiving the sensory information sends back an acknowledgement ACK message to end device. Different threshold values α are set based on the residual energy for the selection of active routers. Nodes less than α are made to sleep. All the active routers compute their Residual Energy (RE) and exchange the RE values between nodes of each corresponding layers. Active router with maximum RE is selected as best neighbor.

Format of packets: Figure 5 describes the packet format for packets saved to a Packet Sniffer Data (PSD) file. The number of bytes is given for each field.

The size of the data packet is only 4 bytes of information where first byte is the start of data symbol, followed by second and third byte gives sensory data and fourth byte gives end of data symbol. The format of sensory data information is given in the Table 1. When data is transmitted from the end device to coordinator through router layers, initially the process is done in the application layer where it assigns the packet number, time at which the packet is transmitted and length of the data packet. After entering into network layer the MAC address, source address, destination address and information for redundancy check is attached and transmitted. At the receiver end of layer 1 only data packets are received. The same process is adopted at every node till the data reaches the destination i.e., coordinator node.

PERFORMANCE ANALYSIS

The performance of the proposed methodology is evaluated and analyzed under two different modes. In an Idle mode scenario, nodes that are not involved in any event function are also active which consumes same energy as that of transmission and reception. The lifetime of the network in
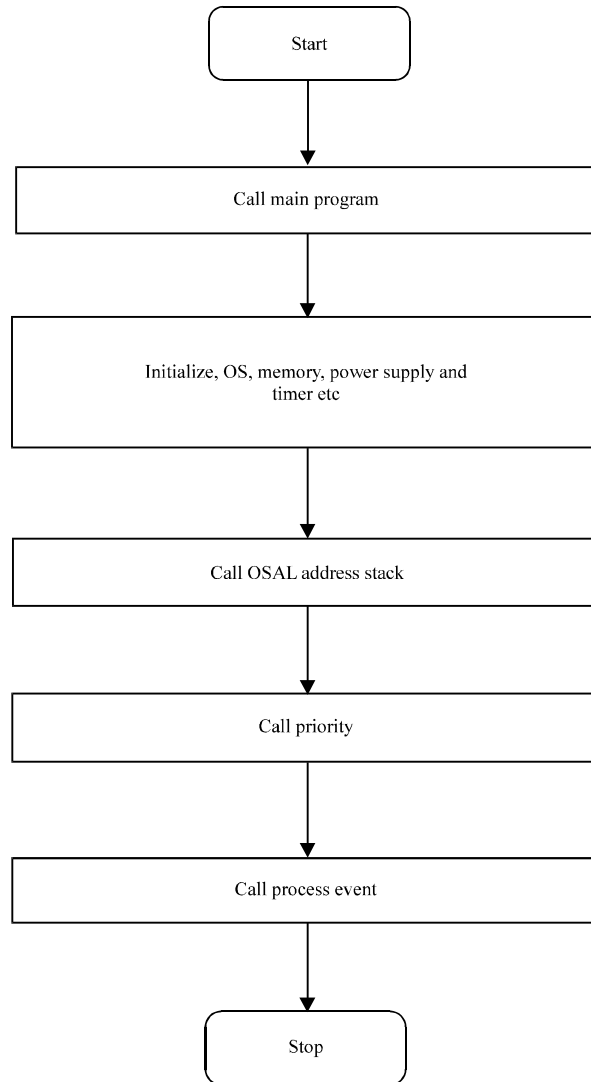
```
┌─────────────┐
│    Start    │
└─────────────┘
       │
       ▼
┌──────────────────────┐
│   Call main program  │
└──────────────────────┘
       │
       ▼
┌──────────────────────────────────────┐
│  Initialize, OS, memory, power supply│
│  and timer etc                       │
└──────────────────────────────────────┘
       │
       ▼
┌──────────────────────────────────────┐
│      Call OSAL address stack         │
└──────────────────────────────────────┘
       │
       ▼
┌──────────────────────────────────────┐
│           Call priority              │
└──────────────────────────────────────┘
       │
       ▼
┌──────────────────────────────────────┐
│         Call process event           │
└──────────────────────────────────────┘
       │
       ▼
┌─────────────┐
│    Stop     │
└─────────────┘
```

Fig. 3: Flow chart of main program routers

End devices/
Humidity sensors

Routers in layer 1

Coordinator/Sink

• Gather the humidity data
• Transmit the gathered data to routers in layer 1
• Repeat every 1 sec

• Receive data from end devices
• Compute the RE for all the routers
• Compare the RE for all the routers
• Router with max RE is declared as forwarder for next layer
• Others are made to sleep
• Repeat the above for every 1 sec

• Receive data from the router in the last layer
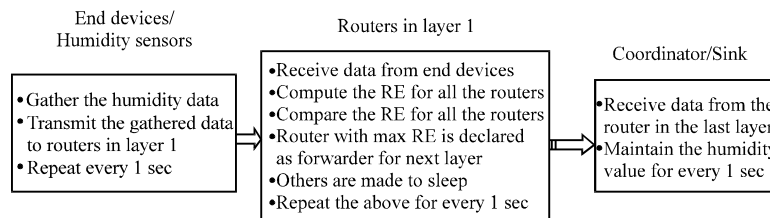• Maintain the humidity value for every 1 sec

Fig. 4: Flow chart of process event function

this mode is 12 days. In sleep mode, different threshold values α are set for the selection of active nodes. For every 1 sec, one end device is involved in sensory data transmission where the other nodes are made to sleep. In the intermediate routers, a reduced set of active nodes are selected with nodes having α = 80, 70, 60 and 50% of initial energy. This has been tabulated in Table 2.
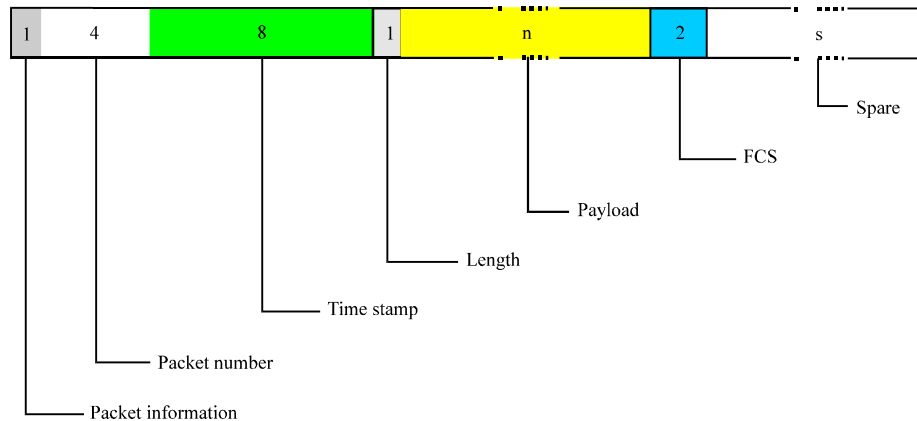
Fig. 5: Packet format in PSD file (from data sheet)

Table 1: Format of sensory data

Bytes	Sensory data transmission
1	Start of data symbol
2	Sensory informationq
3	Humidity data
4	End of data symbol

Table 2: Comparison of energy consumed and lifetime

	Energy consumed (J day^{-1})					Lifetime (days)				
		Sleep mode (α)					Sleep mode (α)			
Nodes	Idle mode	80%	60%	40%	10%	Idle mode	80%	60%	40%	10%
Routers of layer 1	553	386	275	165	55	16	23	32	55	164
Routers of layer 2	553	386	275	165	55	16	23	32	55	164
End device	725	145	145	145	145	12	62	62	62	62

CONCLUSION

Energy consumption plays a vital role in the field of WSN. In this study, an efficient topology control using energy aware routing for humidity measurement is proposed and implemented in a real time environment. The effectiveness of the proposed technique is evaluated and proved using the network lifetime computation. Redundancy of data is also avoided by the proper hibernation of network nodes i.e., when each sensory node is operated to transmit at different time slots, the idle mode energy consumption is avoided and hence lifetime could be extended. In this study, a network of 25 nodes are implemented which works for an average of 160 days. This study could be extended by studying the network lifetime for various transmission time slots. Also a mathematical model could be designed for relating the number of active nodes and connectivity.

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