Adaptive Power Control with Overhearing Avoidance for Wireless Sensor Networks

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Abstract— In this paper, Adaptive Power Control with Overhearing Avoidance (APC-OA) has been proposed. The proposed power control algorithm has been implemented in PICSENSE wireless sensor nodes. The energy consumption of proposed MAC has been compared with that of On Demand Transmission Power Control (ODTPC) protocol and it is shown that the Adaptive Power Control with Overhearing Avoidance gives higher energy conservation compared to ODTPC. The power level convergence towards the optimal power for APC-OA is two times faster than the ODTPC.

Index Terms— **Transmission Power Control, Overhearing Avoidance, Energy consumption analysis.**

I. INTRODUCTION

Wireless Sensor Network is the wireless network of tiny devices called sensor nodes. These sensor nodes consist of an 8 bit microcontroller, a RF transceiver and sensor. In most of the sensor networks sensor nodes are battery powered and in most of the application recharging of battery or replacement of battery for the sensor nodes are impossible or undesirable while the sensor network is deployed in the hostile environment. Moreover this issue makes the sensor network not a viable solution for most of the commercial applications. So energy conservation becomes a paramount concern for wireless sensor network hardware/software developers. More proportion of the energy of the sensor node is spent for the wireless transmission and reception [1]. So energy conservation in the individual sensor nodes can be done by efficiently managing the operation of RF transceiver. The energy efficient operation of RF transceiver is managed in the Medium Access Control (MAC) layer of the sensor network protocols. The various sources of energy wastage in MAC layer of sensor nodes are idle listening and overhearing and control packet overhead[2]. Idle listening is listening in the receive mode for the incoming packet, when there is no actual packet transmission. This constitutes much of the energy wastage as in most of the event driven wireless sensor network applications, sensor nodes are idle for long time. Overhearing is receiving the packet intended for other nodes. It causes significant energy wastage, when number of nodes connected is large. Control packet overhead is the overhead associated with the transmission reception of control packets such as RTS/CTS for the data communication. Though the control packet overhead provides significant energy wastage, it helps in collision free packet transmission and even it can be used for overhearing avoidance and transmission power control. Often energy efficiency is dealt in the Medium Access Control (MAC) layer in the protocol for wireless sensor network by introducing sleep schedule. That is the node will keep its radio off for much time and listens and transmit in the wireless medium for a little while. This kind of sleep scheduling causes a problem of increased end to end latency which is the time elapsed between the time of arrival of data packet at the source and the time at which the packet reaches the destination. Another way of reducing the energy consumption without increasing the end to end latency is the Transmission Power Control. Nowadays many transceivers have the ability to change their transmission power dynamically by changing the amplifier gain setting. By exploiting this flexibility, the transmission power of a link between two nodes can be adaptively varied to keep the optimal connectivity between the nodes. Reducing the transmission power not only gives the minimum power consumption but also gives minimum interference in the network.

In this paper, Adaptive Power Control with Overhearing Avoidance has been proposed and the implementation in the PICSENSE [3] nodes has been reported. Empirical analysis of energy consumption of APC-OA has been done and the energy consumption and the rate of convergence to the optimal power for the proposed MAC have been compared with that of ODTPC.

The paper is organized as follows. Section 2 describes the works related to transmission power control in wireless networks. The section 3 describes about the PICSENSE, a sensor network testbed. Section 4 describes the energy computation technique used in this work and section 5, 6 and 7 describes about APC-OA, optimal power computation and the implementation of APC-OA. Section 8 gives Energy consumption analysis of APC-OA and its energy consumption has been compared with the energy consumption of ODTPC.

II. RELATED WORK

In [4] Shan Lin, Jingbin Zhang et al proposes Adaptive Transmission Power Control (ATPC) in which a predictive model is designed to find the correlation between the transmission power and the link quality. In reference [5] two transmission power control algorithms are simulated and it is also shown that these protocols outperform the fixed power assignment protocols. In paper [6], Alaa Muqattash and Marwan Krunz proposes a power control dual channel protocol (PCDC) which uses one channel for control packet

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(RTS/CTS) transmission with Maximum power and another channel for data packet transmission with less power sufficient to maintain connectivity between nodes. In [7] the empirical analysis of power control algorithms has been done and the reduction in the power consumption has been achieved and it is also stated that the combination of low power MAC design with the power control will yield better energy conservation. It is stated that the asymmetry in the transmission floor will cause the collision of packets. In [8] it is reported that the variable range power control is superior to common range power control. It is also stated that Variable range power control outperforms the common range power control in energy consumption and in the traffic carrying capacity of a node. In reference [9], a power controlled multiple access protocol has been proposed with data and busy tone channel to reduce the floor acquisition done with RTS/CTS exchange. It is also stated that PCMA improves the throughput by two times compared to 802.11 MAC and it is also stated that the performance of PCMA increases when the average distance between the transmitter and receiver decreases. In [10] a power control with blacklisting algorithm has been proposed for wireless sensor networks. PRR is used as a link quality metric and the node will transmit packets at different transmission power level to find the optimal power level. This will obviously reduce the lifetime of the node and in the dense deployment of the wireless sensors; calculation of PRR will become difficult due to collision. In [11] in On demand Transmission Power Control (ODTPC) the node, that wants to transmit the packet, checks its neighbor table for the optimal transmission power . If the neighbor table does not contain the optimal power, then the data packets are transmitted at the maximum power and the receiver measures the RSSI. The receiver calculates the optimal power and the RSSI is sent back to the transmitter with acknowledgment. The performance of the ODTPC is compared with that of PCBL and ATPC and it is also shown that ODTPC outperforms these two power control algorithm.

III. PICSENSE – WIRELESS SENSOR NETWORK TESTBED

The PICSENSE is a single hop wireless sensor network testbed in which sensor nodes send the sensor information to the Base station [3]. The core of the PICSENSE node is its microcontroller PIC18F4620. It has 64K flash, 4K RAM, 13 channel 10 bit Analog to Digital Converter to which the sensor output is connected. It has 1K EEPROM and Capture/Compare/PWM modules.

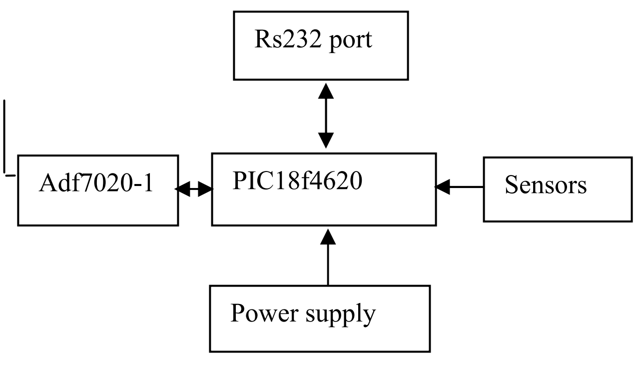

Figure 1. PICSENSE – Node Block Diagram

PICSENSE node has a Analog Devices's RF transceiver ADF7020-1. ADF7020-1 is a low power highly integrated FSK/GFSK/ASK/OOK/GOOK transceiver designed for operating in the low UHF and VHF band. The operating frequency for this transceiver can be set anywhere between 135MHz to 650MHz. By using the divide by two the operating frequency can be reduced to 80MHz. The transmitter output power is programmable in 63 steps from -16dBm to +13dBm. This is the feature which can be used by the researcher for implementing his/her power control algorithm.

Figure 2. PICSENSE –Sensor node with Battery

IV. ENERGY COMPUTATION TECHNIQUE

The energy consumption of the PICSENSE node is measured by measuring the power consumption of PICSENSE node at various states. The power consumption of the PICSENSE node at various states has been tabulated in Table I.

Table I. Power consumption of PICSENSE node

S.No	PICSENSE states	Power Consumption (mW)
1.	Processor Active+ Radio Active (Rx)	185.1
2	Processor Active + Radio Idle	58.8
3.	Processor Idle+ Radio Idle	41.7
4.	Processor Active +Radio Active (Tx)*	232.8

* Transmission Power level +13dBm.

Having known the power consumption of the PICSENSE node at various states, the energy consumption of individual nodes is measured by measuring the time, the node spent on the particular state, Timer 1 of the PICSENSE node is used as a 1ms tick timer, which causes a high priority interrupt after every millisecond and a 32 bit *timer_count* variable keeps track of the time with a millisecond resolution. Though the transition of the state causes higher current consumption as it persists for a short duration, it can be neglected.

ADF7020-1 transceiver has a programmable power amplifier which controls the transmission power in 64 steps. In sensor networks by adaptively changing the transmission power, energy conservation can be done [4]. To do the energy consumption analysis of a Transmission Power Control MAC protocol, it is required to know the power consumption at various transmission power levels. Table II gives the power consumption at various transmission power levels for PICSENSE nodes. These readings are taken by putting the transceiver in the transmit mode after changing the transmission power level by manipulating power amplifier bits in Transmit Modulation Register of ADF7020-1

Table II. Power consumption at various transmission power levels

S.No	TX Power Level*	Power consumption (mw)
1.	0	128.1
2.	3	152.7
3.	7	160.8
4.	11	166.5
5.	15	169.5
6.	19	173.7
7.	23	175.2
8.	27	177.3
9.	31	182.1
10.	35	186.3
11.	39	189.9
12.	43	196.5
13.	47	203.7
14.	51	208.5
15.	55	217.2
16	59	222.3
17	63	229.5

*Tx Power (in dBm) = -16+ (Tx Power Level)*0.45

Figure 3 shows the relationship between transmission power level and the corresponding power consumption.

By least square approximation, a linear relationship between the transmission power level and the power consumption is deduced. It is given in the following expression.

$$P_c = 2.8548 * \mathrm{PL}(\mathrm{dBm}) + 131.6706$$

Where

P_c = Power consumption

PL = Power level in dBm

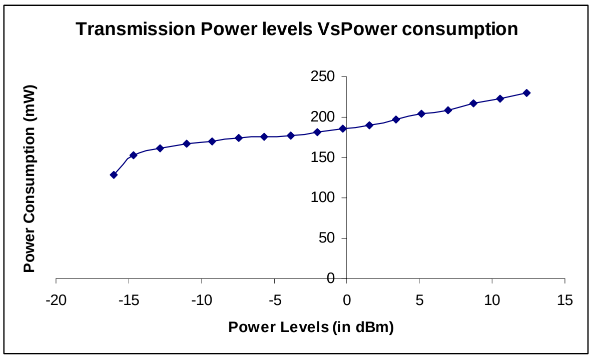

Figure 3. Power consumption at various transmission power levels

V. ADAPTIVE POWER CONTROL WITH OVERHEARING AVOIDANCE

The transmission power control is introduced in the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) with RTS/CTS. The Adaptive Power control with Overhearing Avoidance(APC-OA) is a pairwise transmission power control algorithm.

In the APC-OA protocol, transmission power control is done as described below.

- Initially for a particular receiver, RTS is sent at maximum power (+13dBm) for a unicast packet. RTS packet has a Power Level field which dictates the receiver's transmission Power. Initially this field contains Maximum power level.
- When the node other than the intended node receives RTS packet, it disables the RF transceiver for the CTS-DATA-ACK transfer time to avoid overhearing. This reduces the energy consumption as putting the RF transceiver in the idle mode reduces the power consumption by nearly 67%.
- After receiving the RTS packet, the receiver measures the RSSI and using the empirical channel model coded in the sensor node, optimal power for the transmitter (P_{OPT_TX})
- Now the receiver sends the CTS packet at power, which is dictated by the power level transmitted by the transmitter, along with the optimal power, P_{OPT_TX}.
- The transmitter measures the RSSI for CTS packet and finds the optimal power (P_{OPT_RX}) and send it along with the data packet which is transmitted at the optimal power, P_{OPT_TX}.
- The receiver measures the RSSI for DATA packet. If the measured RSSI is greater than the lower threshold ($RSSI_{Lower}$) and less than the upper threshold ($RSSI_{Upper}$) then there will not be any change in the optimal power for the transmitter. (P_{OPT_TX})
- If the RSSI is less than the $RSSI_{Lower}$ then the power level gets incremented by 1. If the RSSI is greater than the $RSSI_{Upper}$ then the power level gets decremented by 1.
- The receiver sends the ACK packet along with P_{OPT_TX} , at the power level of P_{OPT_RX}
- When the transmitter gets the ACK packet, it measures the RSSI, and finds the optimal power for the receiver (P_{OPT_RX}) and it updates its optimal transmission power for the receiver with P_{OPT_TX}.
- Next time, when the packet arrives at the transmitter for the same receiver, RTS packet is sent at the optimal power level P_{OPT_RX}.
- When a packet, which has to be broadcasted, arrives at the transmitter, then the broadcast happens at maximum power.
- The proposed scheme can be adapted to the sensor networks with no node mobility or limited node mobility.
- This protocol can be adapted for the sensor networks with high mobility, by including the timeout mechanism which resets the optimal power for a particular receiver to maximum power, if there is no packet flow to that receiver for a specific time. This reset happens due to the possibility of the node moving far away from the transmitter over a specific time. The timeout value is selected based on the mobility of the nodes in the network. This timeout mechanism avoids the retransmission of packets.

Adaptive Power Control with Overhearing Avoidance – Algorithm

```
power_table [N] = {Maximum Power};
flag[N] = {0};
Node.Optimal_power = {Maximum Power};
IF Unicast Packet Arrival THEN
        Node.Power_level =Node.Optimal_Power;
        RTS.Transmission_Power_Level = power_table[i]
        Send RTS Packet
END IF
IF RTS Received from Sensor Node i THEN
        Measure RSSI
        IF flag[i] = = 0 THEN
                CALL optimal_power_calc (RSSI)
                Returns optimal_tx_power_level;
                flag[i] = 1;
                IF optimal_tx_power_level = = 0 THEN
                        Optimal_tx_power_level =1;
                END IF
        END IF
ELSE
        CALL Power_adjust (RSSI,
Optimal_tx_power_level) Returns optimal_tx_power_level;
END IF
Power_table[i] = Optimal_tx_power_level
CTS.Transmission_Power_level = Power_table[i];
Send CTS Packet;
IF CTS Received from Sensor Node i THEN
   Measure RSSI
   IF flag[i] = = 0 THEN
        CALL optimal_power_calc (RSSI) Returns
                optimal_tx_power_level;
        flag[i] = 1;
        IF optimal_tx_power_level = = 0 THEN
                Optimal_tx_power_level =1;
        END IF
   END IF
ELSE
    CALL Power_adjust (RSSI, Optimal_tx_power_level)
    Returns optimal_tx_power_level;
    Node.Optimal_Power =CTS.Transmission_Power_Level;
    Node.Power =Node.Optimal_Power;
    Data.Transmission_Power_Level =Power_table[i];
    Send Data Packet
END IF

IF DATA Received from Sensor Node i THEN
   Measure RSSI
   CALL Power_adjust (RSSI, Optimal_tx_power_level)
       Returns optimal_tx_power_level;
  Node.Optimal_Power =DATA.Transmission_Power_Level;
  Node.Power =Node.Optimal_Power;
  ACK.Transmission_Power_Level=Optimal_tx_power_level;
  Send ACK Packet
END IF
IF ACK Received from Sensor Node i THEN
 Measure RSSI
 CALL Power_adjust (RSSI, Optimal_tx_power_level) Returns
                optimal_tx_power_level;
Node.Optimal_Power =ACK.Transmission_Power_Level;
Node.Power =Node.Optimal_Power;
Power_table[i] =Optimal_tx_power_level;
END IF
```

Power_Adjust – Algorithm

```
Parameters: RSSI, Optimal_tx_Power_level
Return Values: Optimal_tx_power_level
IF RSSI <RSSI_LT THEN
        IF Optimal_tx_power_level < Max_Level THEN
Optimal_tx_power_level = Optimal_tx_power_level +1;
        END IF
END IF
IF RSSI >RSSI_UT THEN
        IF Optimal_tx_power_level > Min_level THEN
Optimal_tx_power_level = Optimal_tx_power_level -1;
                END IF
        END IF
        return optimal_tx_power_level
```

Optimal Power Calculation – Algorithm

```
Parameters: RSSI
Return Values: Optimal_tx_power_level
Substitute the RSSI in Empirical Model
Find Optimal_tx_power
        Optimal_tx_power =optimal_tx_power+2.25dBm;
FOR PL =0:63
        IF (-16+PL*0.45) >optimal_tx_power THEN
                break;
        END IF
END FOR
optimal_tx_power_level=PL;
return optimal_tx_power_level
```

Figure 5. Adaptive Power Control with Overhearing Avoidance

Figure 5 shows the pseudo code of entire Adaptive Power Control with Overhearing Avoidance (APC-OA) Protocol.

VI. ESTIMATION OF OPTIMAL POWER

The Optimal power is the minimum power required communicating nodes. Now the question is how to measure the link quality? The link quality is measured by using the Packet Reception Ratio (PRR). If the PRR is 100% then we can say the link is excellent. PRR is the ratio of the number of packets received by the receiver and the total number of packets transmitted. Though PRR is a measure to quantify the link quality, at runtime calculation of PRR is too costly. So instead of PRR, other quantity Received Signal Strength Indicator (RSSI) is used after getting the relationship between the PRR & RSSI.

A. DETERMINATION OF $RSSI_{Threshold}$

To determine the RSSI threshold, above which the PRR is close to 100%, an experiment is conducted with a pair of PICSENSE sensor nodes. The experiment is conducted by keeping the transmission power at maximum power level (+13dBm) and in the indoor environment where the sensor nodes are going to be deployed. The sender node sends fixed number of packets and the receiver is made to receive these packets at various distances from the sender and the RSSI value is noted down in the receiver. For each RSSI value, the ratio between the number of packets received and the number of packets transmitted is calculated and plotted as in the Figure 6.

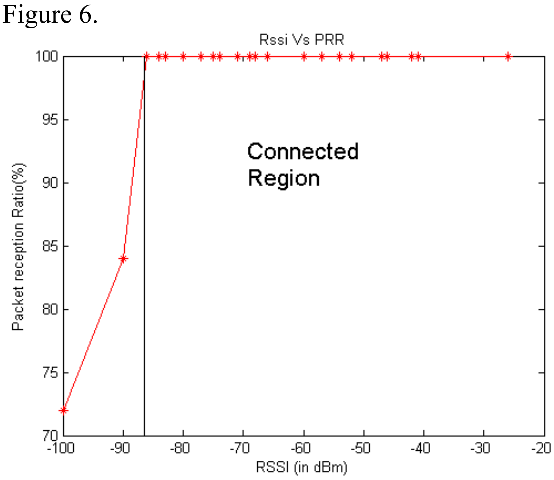

Figure 6. Received Signal Strength Vs Packet Reception Ratio

From these experiments, for the Adaptive Power Control with Overhearing Avoidance (APC-OA) protocol, RSSI lower threshold is set as -75dBm and RSSI upper threshold is set as -80dBm. Both the threshold values are selected such that they are within the connected region in Figure 6.

B. EMPIRICAL CHANNEL MODEL

To calculate the optimal transmission power, a simplified model for path loss as a function of distance is used in every node [12].

$$P_r = P_t K \left(\frac{d_0}{d} \right)^{\gamma} \quad (1)$$

Where

P_r = Received signal power

P_t = Transmitted signal power

K = path loss constant

$$K(dB) = 20\log_{10}\left(\frac{\lambda}{4\pi d_0} \right) \quad (2)$$

d0 = Reference distance for antenna far field
Typical value for d0 = 1 to 10m in indoor environment.

Here we assume the d0 to be 1m and the k value is calculated by using the free space path loss formula (equation 2) as

$$K = -25.18$$

So the model can be represented in dB as

$$P_r(dBm) = P_t(dBm) + K(dB) - 10\gamma \log_{10}\left[\frac{d}{d_o} \right] \text{dB}$$

To find the γ value the experimental data is used. The data are shown in the following table.

Table III. Experimental data to determine the radio model

Distance from transmitter(m)	Pr (measured) (dBm)	Pr (estimated) (dBm)
1.2	-48	-12.18-0.79181γ
2.1	-58	-12.18-3.222γ
3.0	-62	-12.18-4.7712γ
6.0	-72	-12.18-7.7815γ
15.3	-84	-12.18-11.8469γ

Pt = +13dBm

Now the γ value has to be chosen such that the Mean Square Error (MSE) between the empirical Received power (Pr) and the estimated received power (Pr) should be minimum.

MSE Error function can be expressed as

$$F(\gamma) = \sum \left[P_r(measured) - P_r(estimated) \right]^2$$

$$F(\gamma) = 234.67\gamma^2 - 3479.3\gamma + 14885$$

To minimize this function the differentiation of this function with respect to γ should be zero.

$$\frac{d}{d\gamma}\left(F(\gamma) \right) = 0$$

By solving the above equation we get γ =7.413
This concludes the empirical model[13]

1. This model has to be implemented in each sensor node to calculate its optimal transmission power
2. After measuring the received signal strength (Pr) for the maximum power level (+13dBm), optimum power level has to be estimated by using the empirical model.
3. By keeping the Pr as RSSI (threshold), in the empirical model, optimal transmission power is calculated.
4. To compensate the error, δP is added with the estimated Power level.

VII. IMPLEMENTATION OF APC-OA

Initially, a simple CSMA/CA with RTS/CTS has been developed for the PICSENSE nodes upon which the transmission power control algorithm has been implemented. As ADF7020-1 has a 7 bit digital Received Signal Strength Indicator (RSSI), carrier sensing becomes easy and the carrier sense threshold has been taken as -95dBm. A p persistent CSMA/CA has been developed. In this the node senses the carrier and if it finds the medium idle, it will do the transmission of RTS packet for the unicast flow. If the medium is busy, the node waits for random time and senses the carrier again. This happens till the packet gets transmitted.

Figure 7. Topologies

Experimental parameters are summarized in the following table (Table III).

Table IV. Experimental Parameters

S.No	Parameter	Value
1	RF Baud Rate	1400 bps
2.	Frequency	433.92 MHz
3.	MAC	CSMA/CA with RTS/CTS
4.	Tx Power	+13dBm
5.	Carrier Sense Threshold	-95dBm
6.	Size of RTS/CTS/DATA/ACK	7/7/50/7 bytes
7.	Coding	Manchester Encoding/Decoding
8	Packet Integrity	16 bit Cyclic Redundancy Check (CRC)

The single hop star connected topology is taken, as the emphasis is on the energy consumption analysis. Figure 7 shows the 3 and 4 node topologies used for energy consumption analysis. Whenever a node receives the RTS intended for other nodes, it will update the Network Allocation Vector (NAV) for the virtual carrier sense. That is, the node will prohibit any transmission until the completion of the ongoing CTS/DATA/ACK transmission. The packet format of the RTS, CTS, DATA, ACK and SYNC packets have been shown in figure 8.

RTS

CRC1	CRC2	PL	PT	D	S	TPL

CTS

CRC1	CRC2	PL	PT	D	S	TPL

DATA

CRC1	CRC2	PL	PT	D	S	DB	TPL

ACK

CRC1	CRC2	PL	PT	D	S	TPL

SYNC/STOP

CRC1	CRC2	PL	PT	D	S

Figure 8. Packet formats

Where
CRC1,CRC2 – Cyclic Redundancy Check Bytes
PL –Packet Length
PT – Packet Type
0x01 – RTS Packet
0x02 – CTS packet
0x03 – DATA packet
0x04 - ACK packet
0x05 - SYNC packet
0x06 – STOP packet
D – Destination Address
S – Source Address
N – Size of data packet
DB – Data bytes (44 Bytes)
TPL – Transmission Power Level

The experiment has been done as illustrated below.

1. The Base Station broadcasts a SYNC packet.
2. Upon reception of the SYNC packet, the sensor node synchronizes its time (i.e.) it resets its *timer_count.*
3. A packet arrival process is coded, which initiates the packet transmission in the individual node periodically to the Base Station.
4. The period of packet arrival is dictated by a variable, *'next_pkt_arrival_time'*
5. Each experiment last for 100 seconds after which the Base Station broadcasts *stop* message.
6. Upon reception of the stop message, node stops transmitting the packet and gives the time for which the RF transceiver is in the transmission, reception and idle states to the serial console upon request.
7. The power level at which the RTS and DATA have been transmitted from transmitter and the power level of CTS and ACK of Base Station is stored in an array, which are displayed in the serial console at the end of the experiment.
8. The transmission energy in the transmitter is given by

$$TE_{TX} = \sum_{i=1}^{N} 3 * I_{RTS\_Tx\_i} * RTS\_time + \sum_{i=1}^{N} 3 * I_{DATA\_Tx\_i} * DATA\_time$$

The transmission energy in the base station

$$TE_{RX} = \sum_{i=1}^{N} 3 * I_{CTS\_Tx\_i} * CTS\_time + \sum_{i=1}^{N} 3 * I_{ACK\_Tx\_i} * ACK\_time$$

Where
TE_{TX} - Transmission Energy for transmitter
TE_{RX} - Transmission energy of receiver
$I_{RTS\_Tx\_i}$, $I_{DATA\_Tx\_i}$, $I_{CTS\_Tx\_i}$ and $I_{ACK\_Tx\_i}$ are the Current consumption of i^{th} RTS/DATA/CTS/ACK packet transmission at optimal power level at the transmitting instant. RTS_time, CTS_time, $DATA\_time$ and ACK_time are the transmission time taken for transmitting RTS/CTS/DATA/ACK packets respectively.

Total Energy Consumption (TEC) is calculated for a particular packet inter arrival time by

$$TEC = \sum_{i=1}^{N} [TE + 185.1 * (Total\_Time_i - Tx\_Time_i)]$$

Where, N is the number of nodes in the network, $Total\_Time_i$ and Tx_time_i are the total experimentation time and time for which the transceiver is in transmit mode respectively. TE is the transmission energy of the node.

Overhearing Avoidance is achieved by putting the RF transceiver in the power down mode whenever the node receives the RTS intended for other nodes. When the RF transceiver is put into power down mode, the node is said to be in the sleep state. The node is put into sleep state for CTS/DATA/ACK transfer time. In this case this time is measured as 1020ms. ADF7020-1 is put into sleep state by de asserting the chip Select (CS) signal. When the ADF7020-1 is in power down mode, the register values of ADF7020-1 is lost. So when the node wakes up (i.e.) when the ADF7020-1 is enabled, the registers have to be reprogrammed. The entire wakeup and its associated register reprogramming takes 3 milliseconds which is 0.3 % of the sleep time.

Total Energy consumption (TEC) with overhearing avoidance for a particular inter arrival time is given by the following expression.

$$TEC = \sum_{i=1}^{N} [Tx\_Energy_i + 185.1 * (Total\_Time_i - Tx\_Time_i - Sleep\_Time_i) + (58.8 * Sleep\_Time_i)]$$

VIII. RESULTS

The energy consumption of the proposed APC-OA MAC has been compared to that of ODTPC [11]. On Demand Transmission Power Control (ODTPC) does not use RTS/CTS control packets. In this protocol, initially the data has been transmitted at maximum power and the receiver measures the RSSI. The RSSI value is sent with ACK packet to transmitter. After receiving the ACK packet, the transmitter calculates the optimal power. Next time when the transmitter transmits the data to the same receiver, it transmits data at the optimal power. The receiver measures the RSSI and sends it along with ACK to transmitter. The transmitter checks whether the transmission power level is within lower or upper threshold values. If the RSSI is within the threshold values then there will not be any change in the optimal power. If the RSSI is less than the lower threshold, optimal power is incremented and if it is greater than the upper threshold, optimal power is decremented. The optimal power is calculated by the empirical model proposed in reference [14]. For the ODTPC also the lower and upper RSSI thresholds are taken as -80dBm and -75dBm respectively. The margin of power level which is added with the calculated optimal power level is +2.25dBm for ODTPC as well as APC-OA.

In ODTPC, the transmission power control is applied to the transmitter only whereas, in APC-OA, transmission power control is applied to both transmitter and receiver. Even though the control packet size is less than the data packet size, significant energy can be conserved in the receiver, if the receiver receives more packets. Though there are control packet overheads in APC-OA compared to ODTPC, this can be used for energy conservation by introducing overhearing avoidance. If the number of nodes connected is high, then the energy conserved through the overhearing avoidance is also high. The rate of convergence of optimal power for APC-OA is twice compared to ODTPC.

The APC-OA energy consumption of 4 node topology for various packet inter arrival times and for various distances have been compared to the ODTPC energy consumption and shown in Figure 9, 10, 11 and the energy difference between APC_OA and ODTPC has been reported in Figure 13. Figure 12 shows the transmission energy savings for both transmitter and receiver in APCOA and ODTPC protocols. From Figure 12 it is observed that 25% to 42% and 28% to 42% transmission energy savings is obtained in receiver and transmitter respectively in APCOA protocol. But in ODTPC, 14% to 33% transmission energy savings are attained in transmitter and the receiver has no energy savings as the power control is not applied to the receiver. The rate of convergence of optimal power for the APC-OA and ODTPC has been shown in Figure 14. From the Figure 14, it is observed that the rate of convergence of APC-OA is twice faster than the ODTPC.

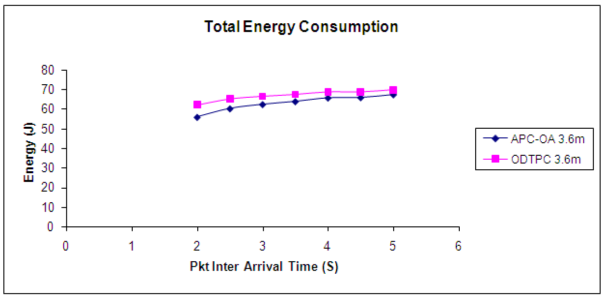

Figure 9. Network Energy Consumption for 4 node Topology- Distance 3.6m

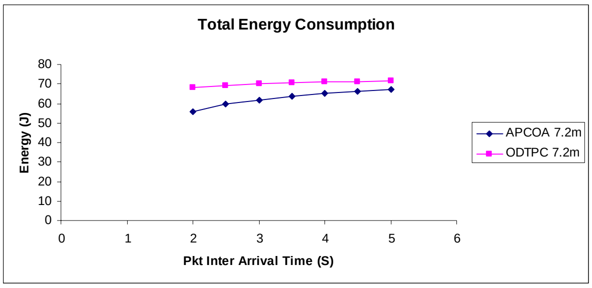

Figure 10. Network Energy Consumption for 4 node Topology- Distance 7.2m

From the results, it is inferred that the Adaptive Power Control with Overhearing Avoidance gives high energy conservation when the traffic is high enough to be handled by the network without any packet loss. That is when the traffic is slightly lower than the saturated traffic, more number of packets are transmitted, which gives greater energy saving. This is because when the traffic increases, the proportion of the transmission energy and idle state energy in total energy consumption dominate than the reception energy. In ODTPC protocol the proportion of transmission energy and reception energy in the total energy consumption is almost equal. So irrespective of the traffic, the total energy consumption is slightly varying with traffic.

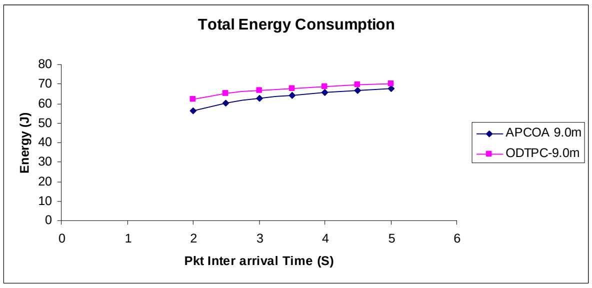

Figure 11. Network Energy Consumption for 4 node Topology – Distance 9.0m

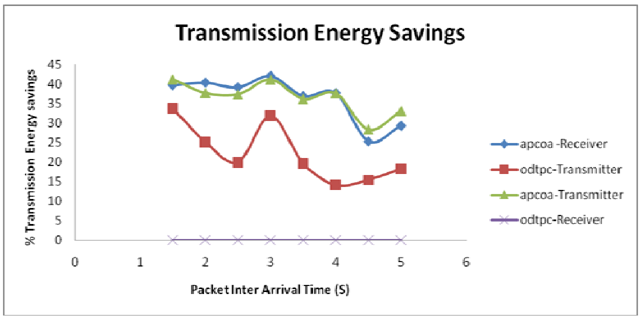

Figure 12. Transmission Energy Savings for 4 node topology – 7.2m

IX. CONCLUSION

In this paper an energy efficient transmission power control protocol, Adaptive Power Control with overhearing avoidance has been proposed. The proposed APC-OA has been implemented in the PICSENSE nodes and energy consumption of APC-OA has been compared with that of On Demand Transmission Power Control (ODTPC).

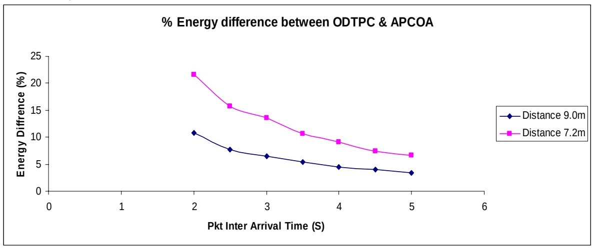

Figure 13. Energy Difference between APC-OA and ODTPC for various Distances

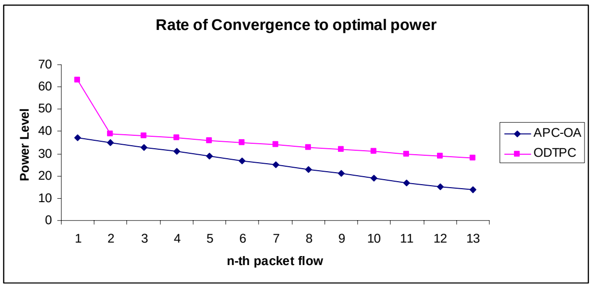

Figure 14. Rate of convergence of Optimal Power

And from the results, it is observed that, in APC-OA, higher energy conservation can be obtained during high traffic conditions, which can be handled by the network without packet loss. The rate of convergence of optimal power is twice compared to that of ODTPC. In future, the transmission power control algorithm proposed in this paper can be implemented in the multihop network and increase in the network throughput can be studied.

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