

Effectiveness of a Novel Power Control Algorithm in Heart Rate Monitoring of a Mobile Adult: Energy Efficiency Comparison with Fixed Power Transmission

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Abstract

In this paper, experiments are conducted to evaluate the efficacy of a novel adaptive power control algorithm in terms of energy efficiency in heart rate monitoring scenario of a mobile adult in a typical home environment. As part of health care, persons with heart related problems are required to be monitored by logging for example, their heart rate on a regular basis to check for any anomaly. At the same time, it is expected that the person in question should be able to move freely within the given facility. The wireless sensors that are attached to the person send periodic data to the central base station. Since the person is mobile, the distance between the transmitting sensor and the base station changes with time. Since the signal path-loss is primarily dependent on distance and the number and type of obstructions between the transmitter and the receiver, it may be wise to use transmission power control to modulate the transmit power. Using power control, the sensor can adjust the level that is sufficient to send the data through the wireless channel without wasting energy. Conservation of energy is critical in wireless sensor network scenarios because they are powered by batteries which have limited lifetime. A critical application like the heart rate monitoring sensor is expected to operate for a reasonable amount of time before the battery dies. The novel adaptive power control algorithm uses intelligent modulation methods to ramp up or ramp down the transmission power level as and when required. By this method, the operational lifetime of the wireless sensor can be extended. As part of the experimental methodology for this paper, two subjects of different age groups have been used. Experimental results show that there is at least a 12% increase in the energy savings using the proposed algorithm.

Keywords: Mobile wireless sensors; Heart rate monitoring; Energy consumption optimization; Adaptive power control

Introduction

The proliferation of low power wireless sensor networks and their discreet presence have introduced a new paradigm in data collection and analysis of target parameters in both indoor and outdoor environments. Especially in healthcare, body wearable and implantable sensors are used to continuously monitor the vital physiological parameters of patients in hospitals and elderly at home who enjoy independent living [1]. From such "living records", medical practitioners can draw useful inferences about the health and well-being of an individual. This can be used for self-awareness and analysis to assist in making behaviour changes, and to share with caregivers for early detection of any ailment and allow appropriate intervention. At the same time such procedures are effective and economic ways of monitoring age-related illnesses [2]. An overview of a simple WSN application in healthcare is shown in Figure 1 [3,4]. The wearable and implanted sensors collect vital health parameters like the pulse rate, EEG, blood insulin level, etc. and transmit to the access point. The gateway that is shown in Figure 1 can be with the person or with the access point.

One unique challenge with body wearable sensors is that these sensors are mobile. Therefore, the communication layer must adapt quickly with the changing environment so that the transmission power can be re-calibrated for reliable transmission [5].

Need to control power for wireless mobile sensor nodes

When a sensor is mobile, it means that its communicating distance from the base station is changing with time. The energy loss is primarily dependent on distance. Unwanted obstructions can also lead to signal degradation due to absorption. Beside there are effects of fading and multipath propagation of radio signal in indoor wireless communication [6].

For acceptable performance, the average received E_b/N_0 at the base station should be above a threshold value. If that value is maintained on average, then it means that the wireless sensor is performing as expected. Since most of these mobile wireless sensors are battery powered, they have limited energy resources. Therefore, if a mobile node is near to a base station and the received E_b/N_0 far exceeds the required threshold, then there is waste of energy. Similarly, when the same sensor node is far from the base station, the node is required to pump in more power than the present value. It may also happen that due to an obstruction between the transmitting node and the base station, the node is transmitting at a power level that is enough to deliver packets. If that obstruction is removed or the node moves to a position in which the obstruction is cleared, then it should adjust its transmitting power down.

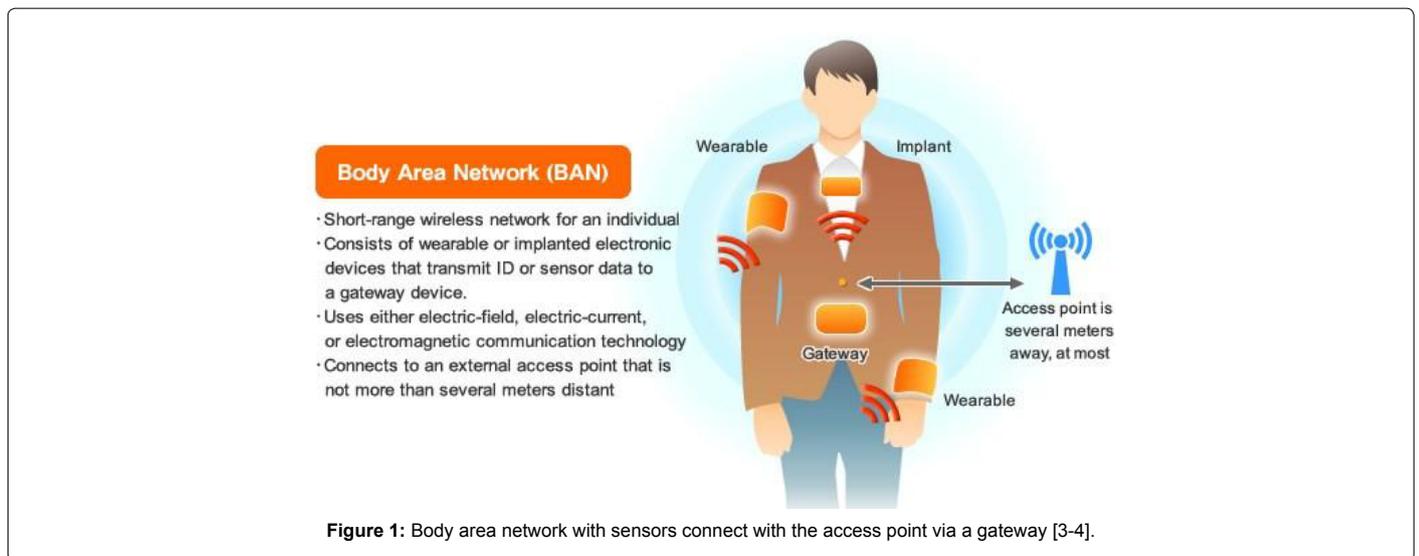
Previous work [7] has provided an empirical analysis of the impact of power control for mobile sensor network. The focus of this research paper is on residential health monitoring, in-hospital patient monitoring and sports monitoring that require mobile sensing. Cellular networks deal with mobility by using different types of hand-

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shake mechanism. However, the emphasis is on the energy constrained sensor nodes. This paper suggested that received signal strength indication (RSSI) data may not be sufficient to evaluate link quality when sensor nodes are mobile. They proposed an active probing scheme for sensor applications that send data periodically and those which are triggered by an event (i.e., event driven). In active probing scheme, the mobile node counts the number of consecutive packets that are successfully transmitted at the current power level. If that is more than a predefined threshold, then the power level is decremented by one level. However for any un-acknowledged packet, the transmission power level is incremented by one level, until the maximum power level is reached. This paper has also modified this approach by using the link quality indication (LQI) values that are provided by CC2420 transceiver modules. In order to make good use of the LQI values of the acknowledgement packets, it allowed the radio to transmit several packets at each of the power levels. It finds the optimal power level region where consistent LQI values higher than 100 is observed. This optimal value is used as the benchmark to set the new transmission power level.

In GSM, a power control algorithm is employed to achieve desired signal strength for faithful communication between the mobile station (MS) and the base transceiver station (BTS). Power control also reduces interference and improves cell capacity. During a connection between the BTS and the MS in a cell, the MS measures the channel's RF link quality after every 480 milliseconds [8]. In this way an acceptable link quality is maintained which can also improve the battery lifetime of the mobile device. However, the research work that is presented here has aimed at saving energy by cutting down on the cost of sensing the RF channel *before* actual transmission. This is because the wireless sensor devices are battery-powered with capacity in the order of 250-300 mAh [9] and have far less capacity than the batteries used by mobile devices (~1500 -3500 mAh) [10-12].

There are a few non-RSSI based power control algorithm that uses matrices like the packet delivery ratio (PDR) or the packet reception rate (PRR) to estimate link quality rather than RSSI or LQI. Among them Practical-TPC [13] and ART [14] are worth mentioning.

P-ATPC is a receiver oriented protocol that is considered robust in dynamic wireless environments and uses packet reception rate (PRR) values to compute the transmission power that should be used by the

sender in the next attempt. The receiver monitors all incoming packet and counts the successes and failures of the packet transmission within the current sampling window. After the sampling window period is over, the P-TPC protocol computes the next transmission power level and sends to the transmitter. This new power level will be used during the next sampling window. P-ATPC has two main components. One component (fast online model identification FID) estimates the model between the PRR and the transmission power. It initialises or reconfigures the second component proportional-integral with anti-Windup (PI-AW). The PI-AW computes the transmission power level based on the difference between the current PRR and the application specific PRR requirement. P-ATPC runs two feedback loops. The inner loop involves the PI-AW that adapts the transmission power based on the PRR measurement. The outer loop involves FID to adjust the parameters based on the updated power model that defines the relationship between the PRR and transmission power. P-ATPC also initializes the power model parameters before the feedback loops kick in. In this initial phase, each link is set to transmit a sequence of probe packets using highest to lowest power level to build the transmission power model.

ART (Adaptive and Robust Topology control) protocol has been designed for complex and dynamic radio environments. It adapts the transmission power in response to variation in link quality or degree of contention. Empirical studies presented in this paper have shown that the PRR and the signal strength can vary over time. This is primarily due to effect of movements of objects and people in between the transmitter and the receiver during the busy hour of the day and corresponding fading of signal. Analysis of the paper has suggested that RSSI and LQI may not be good or the most reliable indicators of link quality, especially in dynamic indoor radio environment. ART changes the transmission power of a link based on the observed PRR. It has an initialization phase when the ART protocol monitors all the outgoing packets for its successful or failed transmission within a sliding window of predefined size. It compares the number of failures within that window with a minimum and a maximum threshold failure. Based on the comparison, it does any one of the following:

- 1) Remains in the same power level or
- 2) Increases the transmission power level or

3) Reduces the transmission power level and enters a trial to compare the new failure rate count with the predefined threshold.

In these type of non-RSSI based adaptive protocols, there is a running overhead cost as the link quality is sampled after a given interval of time. The sampling period will itself depends on the dynamics of the link quality.

The novel non-RSSI based channel estimation and output power control algorithm is proposed in our earlier papers [15,16]. It does not use RSSI/LQI data as side information for channel link quality estimation. The basis of this lightweight adaptive algorithm is the states where each state represents one cycle of packet transmission. The details of the adaptive power control algorithm are explained in the next section.

Basics of an Adaptive Power Control Algorithm

The packet success rate performance of a mobile sensor node depends primarily on the distance between the base station and the sensor, obstacles in the communication path, and fading due to movement of objects in between. In particular, when a node operates on the fringes of the communicable distance, the power amplifier pumps in maximum power so that it is discernible at the receiving station. It uses its allocated retry limit to achieve the threshold packet success rate. On the other hand, the radio conditions can be most favourable so that successful data communication is possible at the lowest available output power. At intermediate stages of communication distances, the transmitter may use higher power levels. In a non-RSSI based power control approach, the key is to keep track of the success or failure of packets at a particular transmission power. The outcome of the last packet transmission gives an indication as to what is the expected outcome when a new packet transmission starts. This adaptive power control can be most successfully applied when a node transmits quite frequently. Nodes that transmit once every hour or a day do not come under the purview of this research. The reason is that the transmitter does not send probe packets for channel estimation neither it can avail RSSI information of the last data transmission. Therefore, the last power level is an indicator of the channel condition. Now, this channel condition can be transient or semi-permanent. Transient condition can occur because of momentary dip in the signal level due to fading or due to change of distance or any obstruction in between the transmitter and receiver.

In case the channel change is transient, the adaptive algorithm must drop-off fast to the lower state. When the change in the link quality or the channel condition is not transient, then the adaptive algorithm

State	1	2	3	4
Available Power Levels	Minimum (M)			
	Low (L)	Low (L)		
	High (H)	High (H)	High (H)	
	Maximum (X)	Maximum (X)	Maximum (X)	Maximum (X)
Number of retries	3	2	1	3

Table 1: States, power levels, and retry limits.

		Next State			
		1 (MLHX)	2 (LHX)	3 (HX)	4 (X)
Current State	1 (MLHX)	Succeed at level M	Succeed at level L	Succeed at level H	Failed or Succeed at level X
	2 (LHX)	Not applicable	Not applicable	Succeed at level H	Failed or Succeed at level X
	3 (HX)	No transition	Not applicable	Not applicable	Failed or Succeed at level X
	4 (X)	No transition	No transition	Not applicable	Not applicable

Table 2: State transition matrix when state levels go up.

must continue to transmit at a higher power level to ensure that packets are delivered successfully. Even in this case, when the distance between the transmitting node and the base station improves or the obstruction is removed, then the transmitter should be able to back off to a lower state.

Non- RSSI/LQI based channel estimation and power control algorithms for energy efficiency

The basis of this lightweight adaptive algorithm is the states where each state represents one cycle of packet transmission. In each state there are output power levels in increasing order which can be used by the transmitter. State transition occurs depending on the power level at which the transmission is successful or failed. State 4 uses only the maximum power level and is allowed to transmit 4 times. There is no direct transition from state 4 to state 1 or 2. Similar conditions hold true when transiting from 3. The most energy efficient state is 1. The more it stays in state 1, the more it saves energy. State 4 is where the maximum energy may be used to transmit the packet. The adaptive algorithm is designed in such a way that it takes into account of performances in each state. It also has a unique drop-off algorithm that allows it to drop down to a lower state when deemed necessary. It is guided by the drop-off factor R. In this paper, R values of 0.01, 0.05, 0.1, 0.5 and 1 are used. Higher value of R means higher rate of drop-off. Figure 2 shows the state transition diagram of the adaptive power control algorithm. State transition occurs depending on the power level at which the transmission is successful or has failed.

The objective of the adaptive power control algorithm is to respond to the packet error rate and move to a new state with different retry limits. The adaptive algorithm is designed in such a way that it takes into account the performance in each state. Each state has a different retry limit. Increasing state number indicates poorer channel quality. The proposed adaptive algorithm does not allow retransmission in the same power level except when it is in state 4 and transmitting at 0 dBm. When the system is in state 4, it is considered the worst channel condition and three retries are allowed. The retry limit of state 1 is three. However, the retry limit of states 2 and 3 have been set at 2 and 1. The asymmetry is because the increase in the retry limit in states 2 and 3 can increase the current consumption while only marginally improving the packet success rate.

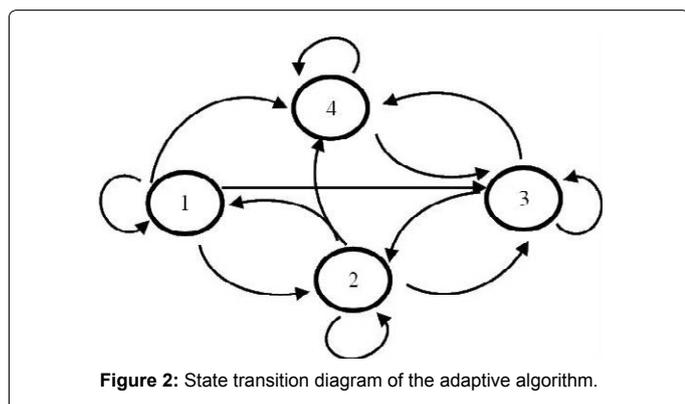


Figure 2: State transition diagram of the adaptive algorithm.

		Next State			
		1 (MLHX)	2 (LHX)	3 (HX)	4 (X)
Current State	1 (MLHX)	Success at state M	Not applicable	Not applicable	Not applicable
	2 (LHX)	Probabilistic model that depends on the number of successes in level L	Probabilistic model that depends on the number of successes in level L	Not applicable	Not applicable
	3 (HX)	No transition	Probabilistic model that depends on the number of successes in level H	Probabilistic model that depends on the number of successes in level H	Not applicable
	4 (X)	Not applicable	Not applicable	Probabilistic model that depends on the number of successes in level X	Probabilistic model that depends on the number of successes in level X

Table 3: State transition matrix when state levels go down. Here, $P_{drop-off}$ = probability of drop-off; S=the number of successes in that power level of the higher state; R=drop-off factor.

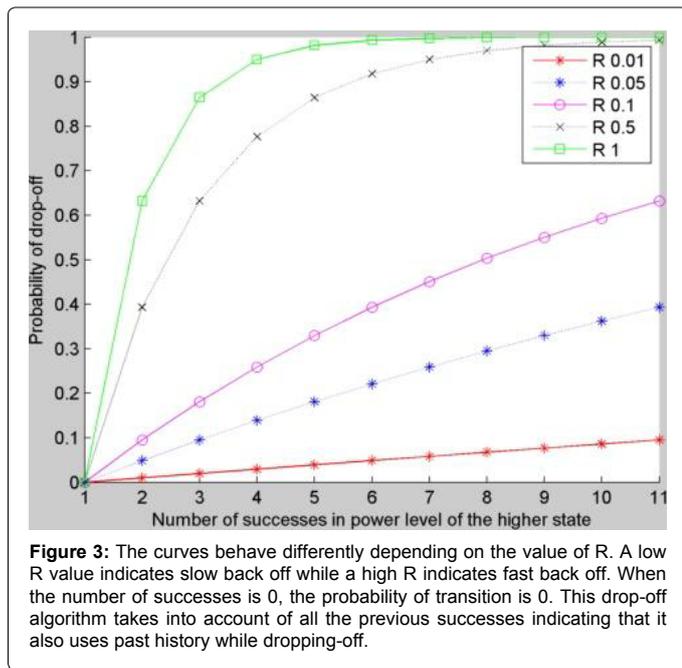


Figure 3: The curves behave differently depending on the value of R. A low R value indicates slow back off while a high R indicates fast back off. When the number of successes is 0, the probability of transition is 0. This drop-off algorithm takes into account of all the previous successes indicating that it also uses past history while dropping-off.

Table 1 shows the available power levels based on the states. Transmission starts at the lowest available power level of that particular state. The transmitter can be in any one of the states during the start of transmission of a packet. There are two separate algorithms that determine the state transitions, one from a lower state to higher state and the other from a higher to lower states. The logic to transit to lower states also includes situations when it remains in the same state or transit to a lower state.

Table 2 describes the state transition matrix when state level goes up. All the state transition decisions depend on the success or failure of the packet being transmitted to the destination hub.

Table 3 describes the state transition logic when state level goes down. The primary objective of the adaptive algorithm is to save energy by transmitting at a power level that is enough to send the packet

successfully through the channel. For example, when the system is in state 4, it is transmitting at the maximum power. With time, the channel condition can improve and packet can be successfully transmitted at a lower power level. If the system drops down to state 3, the transmission starts at a lower power level. This drop-off from a higher state to a lower state is determined by a drop-off algorithm which is probabilistic in nature.

In the proposed adaptive algorithm, the drop-off or the back-off process is dependent on the number of successes (S) in the higher power level and a drop-off factor (R). By default, the drop-off factor is 1. The probability of the system to drop-off to a lower power level is represented by Equation (1).

$$P_{drop-off} = 1 - (-RS) \quad (1)$$

Here, $P_{drop-off}$ = probability of drop-off; S=the number of successes in that power level of the higher state; R=drop-off factor.

The plots in Figure 3 show the state transition probability based on different values of R. When there is a state change, the value of S is reset to 0. Overall, the value of R indicates how fast the system will fall from a higher state to a lower state. When there is no success, the probability of state transition is 0, meaning that there will be no state transition. At the same time, when the number of successes is too high, it converges to 0.

Back-off algorithms are extensively used in data communication (both wired and wireless) by MAC protocols to resolve contention among transmitting nodes to acquire channel access. In a MAC protocol, the back-off algorithm chooses a random value from the range [0, CW], where CW is the contention window size. The contention window is usually represented in terms of time slots.

The number of time slots to delay before the nth retransmission attempt is chosen as a uniformly distributed random integer r in the range $0 < r < 2k$.

Where $k = \min(n, 10)$, 10 is the maximum number of retries allowed.

The nth retransmission attempt also means that there have been n collisions. For example, after the first collision, it has to retransmit. Based on the back-off algorithm, the sender will choose between 0

Device: Receiver (Hub)	nRF24L01p with PA and LNA
Arduino Mega Development board	Microcontroller board based on the ATmega2560 [20]
Transmission mode peak current	115 mA
Reception mode peak current	45 mA
PA gain	20 dB
LNA gain	10 dB

Table 4: Features of nRF24L01p receiver [19].

Device : Transmitter	nRF24L01p
Arduino Mega Development board	Microcontroller board based on the ATmega 2560
Transmission @ 0 dBm output power (MIN)	Current drawn: 11.3 mA
Transmission @ -6 dBm output power (LOW)	Current drawn: 9 mA
Transmission @ -12 dBm output power (HIGH)	Current drawn: 7.5 mA
Transmission @ -18 dBm output power (MAX)	Current drawn: 7 mA

Table 5: Features of nRF24L01p transmitter [21].

and one time slot for the retransmission. After the second collision, the sender will wait anywhere from 0 to three time slots (inclusive). After the third collision, the senders will wait anywhere from 0 to seven time slots (inclusive), and so forth. As the number of retransmission attempts increases, the number of possibilities for delay increases exponentially [17,18].

Similarly, an exponential operator is used in this novel adaptive algorithm to decide to switch from a higher state to a lower state. The drop-off algorithm is dynamic as it re-evaluates at every successful transmission. It gets reset to 0 when it leaves the state and jumps to a lower state and starts a new packet transmission at a lower power level [17,18].

Experimental Methodology

Choice of hardware

The adaptive power control algorithm has a unique channel estimation method without RSSI side information. The hardware used in the research includes the nRF24L01p transceiver module that acts as a transmitting sensor. For the receiver at the hub, another nRF24L01p transceiver module is used that has an additional PA and LNA. The receiver has a maximum output power level of 20 dBm. The reason to choose a high power transmitter at the hub is to make the path between the hub and the sensor practically error free. The primary features of the receiver and the transmitter receiver are presented in Tables 4 and 5 respectively [19-21].

The transceiver can transmit at four power levels: -18 dBm, -12 dBm, -6 dBm and 0 dBm. In general a wireless transceiver has different modes of operation. All the software programming was done in C in the open-source Arduino (version 1.0.5-r2) software (IDE) [22]. The programs or sketches in Arduino are used to interface with the nRF24L01p modules to do the necessary changes.

With regards to the heart rate data, a set of heart rate data are preloaded in the transmitter module and made to transmit after every 5 seconds. These data has been borrowed from PhysioNet which offers free web access to large collections of recorded physiologic signals [23,24]. Here we are testing the energy efficiency of the protocol, so we have used heart rate data from PhysioNet while the subjects provide the sensor mobility.

Location and subject

The experimental setup is a typical house with the base station powered by Mains while the transmitting sensor is piggybacked on the subjects. Two subjects of different age groups ([30-35] years and [65-70] years) are chosen to observe the effect of age on the adaptive protocol. The subjects are allowed to roam freely inside the house and follow their routine activities. In this paper, subject 1 refers to the person in age group 65-70 and subject 2 refers to age group 30-35. Data were collected for a period of approximately five hours on different days of the week, starting from afternoon till late evening. In the 1st set of experiments, the mean distance between the subject and the base station was approximately 5 meters. During the 2nd set of experiments, the mean distance was changed to roughly 10 meters. The different distances are expected to have an effect on the evaluation parameters which are presented in subsection 3.3.

Evaluation parameters

The evaluation parameters are

- Average cost per successful transmission

- Expected success rate or protocol efficiency [25]

One of the parameters for the optimization is the energy consumed per useful bit transmitted over a wireless link [26,27]. Similarly in this paper, the cost per successful transmission has been considered.

$$C_{s_avg} = \frac{C_T}{P_s - P_L} \tag{2}$$

Where

C_{s_avg} = average energy cost per successful transmission

C_T = total cost of transmission

P_L = number of lost packets

P_s = Number of packets to send

Fixed power transmission			
Output power	PSR %	Avg. Cost per successful transmission mJ	Protocol Efficiency %
-18 dBm	96.99	0.03489	87.08
-12 dBm	99.61	0.0333	97.42
-6 dBm	99.86	0.03944	98.67
0 dBm	99.86	0.04945	98.81
Non-RSSI based adaptive power control			
Drop-off factor R	PSR %	Avg. Cost per successful transmission mJ	Protocol Efficiency %
0.01	99.75	0.0438	93.58
0.05	99.8	0.03272	96.49
0.1	99.78	0.03217	96.68
0.5	99.82	0.03155	96.94
1	99.86	0.03137	97.25

Table 6: Average cost, PSR and protocol efficiency with subject 1 and mean distance equals to 5 meters.

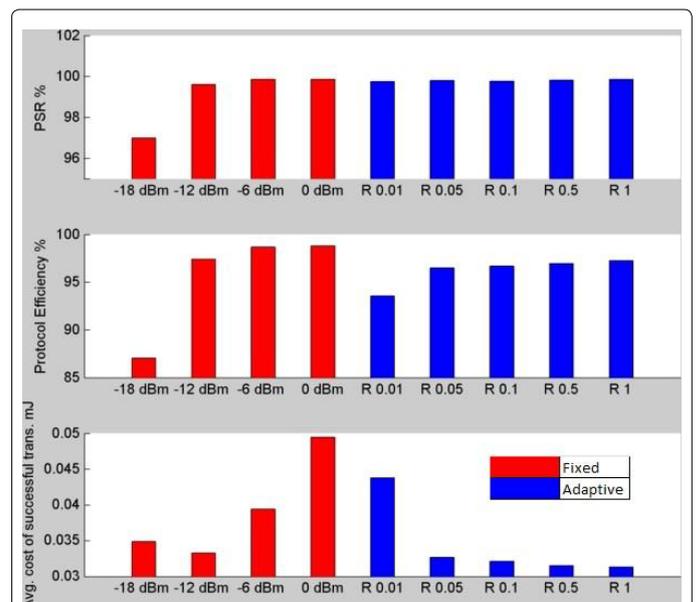


Figure 4: Subject 1: Comparison of the minimum cost and the corresponding PSR and protocol efficiencies due to different transmission strategy for subject 1 shows that the adaptive protocol can save upto 6% energy when R=1 as compared to fixed transmission at -12 dBm.

All cost values are measured in mJoules. The total cost of transmission includes the expenditure for the first transmission attempt of a packet and the subsequent retries if the first attempt fails. The total packet to send count does not include the retry packets. Therefore the denominator in equation 3 is only the count of successfully transmitted packets.

The expected success rate or efficiency is defined as the expected number of successes and takes into account the average number of retries [3]. It can also be defined as the expected number of successes per 100 transmissions. Mathematically,

$$Succ_{rate} = \frac{P_s - P_L}{P_s + Ret_T} \tag{3}$$

$$Succ_{rate} = \frac{P_s - P_L}{P_s + Ret_T} \tag{4}$$

Where

$Succ_{rate}$ = expected success rate

Ret_T = total number of retries

Here $P_s - P_L$ = total number of successes (P_{succ}). If both the numerator and denominator are divided by P_s , then in percentage term,

$$Succ_{rate} (\%) = \frac{PSR}{P_s + Ret_{avg}} \tag{5}$$

where Ret_{avg} = average number of retries per packet and is defined as

$$Ret_{avg} = \frac{Ret_T}{P_s} \tag{6}$$

Here,

$$PSR = \frac{P_{succ}}{P_s} 100 \tag{7}$$

This parameter indicates the total number of transmissions (on average) to achieve a given packet success rate (PSR).

Experimental Results and Analysis

The results and analysis of the experiments are presented in this section.

Fixed power transmission			
Output power	PSR %	Avg. Cost per successful transmission mJ	Protocol Efficiency %
-18 dBm	98.40	0.03325	91.28
-12 dBm	99.95	0.03257	99.55
-6 dBm	99.95	0.03915	99.38
0 dBm	99.95	0.04918	99.34
Non-RSSI based adaptive power control			
Drop-off factor R	PSR %	Avg. Cost per successful transmission mJ	Protocol Efficiency %
0.01	99.95	0.03334	98.08
0.05	99.95	0.03073	99.06
0.1	99.95	0.03054	99.38
0.5	99.9	0.03063	99.14
1	100	0.03058	99.1

Table 7: Average cost, PSR and protocol efficiency with subject 2 and mean distance equals to 5 meters.

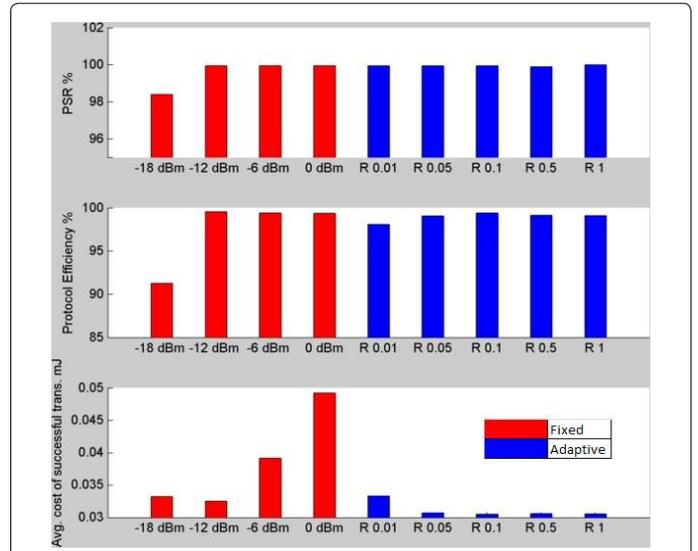


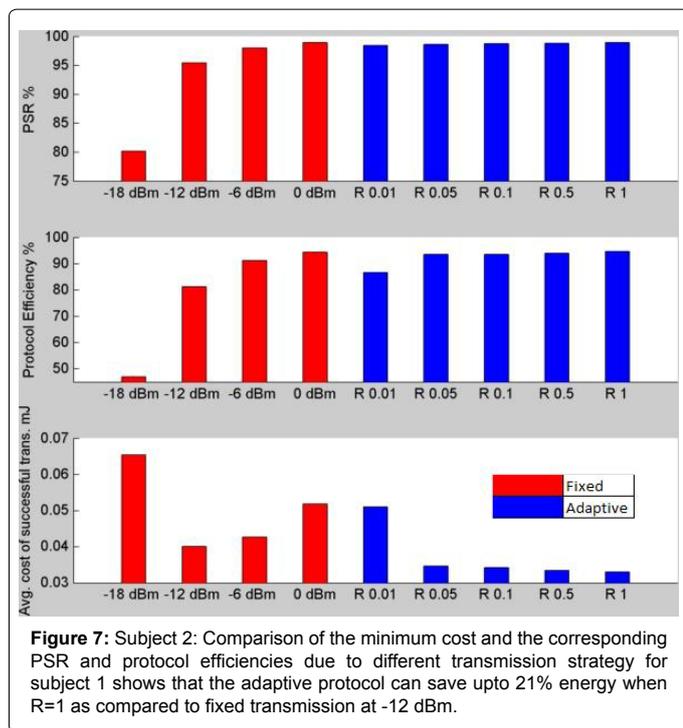
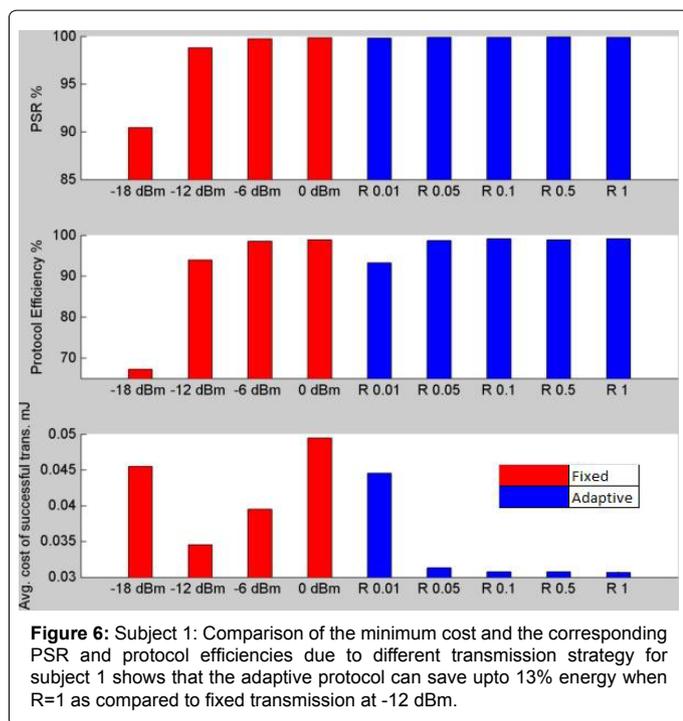
Figure 5: Subject 2: Comparison of the minimum cost and the corresponding PSR and protocol efficiencies due to different transmission strategy for subject 1 shows that the adaptive protocol can save upto 6% energy when R=1 as compared to fixed transmission at -12 dBm.

Fixed power transmission			
Output power	PSR %	Avg. Cost per successful transmission mJ	Protocol Efficiency %
-18 dBm	90.45	0.04547	67.27
-12 dBm	98.79	0.03458	93.94
-6 dBm	99.73	0.0395	98.52
0 dBm	99.86	0.04944	98.82
Non-RSSI based adaptive power control			
Drop-off factor R	PSR %	Avg. Cost per successful transmission mJ	Protocol Efficiency %
0.01	99.79	0.04455	93.22
0.05	99.87	0.03134	98.66
0.1	99.9	0.0308	99.12
0.5	99.92	0.03079	98.87
1	99.9	0.03069	99.09

Table 8: Average cost, PSR and protocol efficiency with subject 1 and mean distance equals to 10 meters.

Fixed power transmission			
Output power	PSR %	Avg. Cost per successful transmission mJ	Protocol Efficiency %
-18 dBm	80.18	0.0654	47.08
-12 dBm	95.40	0.04015	81.23
-6 dBm	98.00	0.04275	91.2
0 dBm	98.92	0.05186	94.29
Non-RSSI based adaptive power control			
Drop-off factor R	PSR %	Avg. Cost per successful transmission mJ	Protocol Efficiency %
0.01	98.43	0.05102	86.64
0.05	98.6	0.03475	93.51
0.1	98.75	0.03427	93.47
0.5	98.79	0.03354	93.91

Table 9: Average cost, PSR and protocol efficiency with subject 2 and mean distance equals to 10 meters.



Scenario 1: Mean distance is 5 meters

Table 6 presented the average values of three runs of the experiments with subject 1 when the distance between the base station and the transmitting mobile node is varying with mean distance approximately equal to 5 meters.

Figure 4 compares the compares the performance parameters of each of the transmission strategies based on the PSR.

Based on Figure 4 it can be observed that the PSR in all the cases are ~100%. The protocol efficiency values are all above 95%. Since the mean distance is very small (~ 5 meters), the adaptive protocol could only marginally perform better than the fixed power transmission. It is still able to save 6% energy. A low value of R means that the adaptive system will back-off at a slow pace. This is the reason that the minimum cost is achieved at R=1 because it has the ability to back-off fast to a lower state and transmit at a lower power as compared to when R is set at 0.01.

Not much change is observed when the experimental data for subject 2 is analysed. Table 7 and Figure 5 present the experimental results in details.

It can be observed from the Figures 4 and 5 that since the mean distance between the subjects and the base station are very small, power control may not be able to save significant amount of energy.

Scenario 2: Mean distance is 10 meters

In this 2nd set of experiments, the mean distance is changed to approximately 10 meters. The results are tabulated in Tables 8 and 9 and comparison are presented in Figures 6 and 7 respectively for subjects 1 and 2.

The minimum amount of energy per successful transmission is consumed in fixed transmission mode when the power level is set at -12 dBm. Figure 6 shows that if the drop-off factor is set at 1, the adaptive protocol can save 13% energy as compared to fixed transmission at -12 dBm.

Table 9 and Figure 7 present the analysis and graphical comparison of the evaluation parameters when data from subject 2 is used with a mean distance of 10 meters.

The minimum amount of energy per successful transmission is consumed in fixed transmission mode when the power level is set at -12 dBm. Figure 7 shows that if the drop-off factor is set at 1, the adaptive protocol can save 21% energy as compared to fixed transmission at -12 dBm.

Overall, it can be observed that the use of adaptive protocol in typical home environment for sensor monitoring purposes can save energy and extend the operational lifetime before batteries are replaced. The younger adult as subject 2 of the experiment is expected to move faster as compared to the elder adult, denoted by subject 1. This variability in the mobility is not reflected in the 1st set of results as the distance is small. As the mean distance changed, the experimental results show that the savings for subject 2 is more than subject 1. This is because subject 2 is more active than subject 1 and the adaptive protocol finds enough space to modulate the power level, thereby saving more energy.

Conclusion

The results in this paper demonstrate the advantages and limitations of using power control under different channel conditions to achieve energy efficiency. When the link quality is good (mean distance ~5 meters and very few obstructions in between the transmitter and the receiver), the adaptive power control algorithm is able to save energy marginally as compared to fixed power transmission. This is because there was no scope of output power manoeuvring to achieve energy efficiency. When the mean distance is roughly doubled to 10 meters, the adaptive power control approach has proved to be energy-saving as compared to fixed power. It is able to save upto 21% energy. It can be observed from Table 5 that the output power levels scale poorly with

the corresponding current rating. A drop in output power by 63 times only halves the current consumption approximately. Considering this values, the energy savings by the adaptive protocol is significant. More experiments will be conducted as part of future research scopes in other types of radio environments.

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