A Lightweight Algorithm To Optimize Power Consumption In Sensor Node Through Parametric Tuning Of Communication Interface

Hiren Patel, Vipul Shah

Abstract**: *Wireless sensor network is widely used to monitor sparsely generated events through a centralized system. The coverage provided by the network to monitor region of interest vary and rely on the system components of sensor node. While monitoring events from cluster head or sink through sensor nodes located at a distant, it experiences increased communication cost due to prone errors which are proportional to losses due to distance and interferences. Biotelemetry application is reviewed for the derivation of the research problem which is worked upon in the present paper. The animals move around in their habitat performing various activities which are to be monitored. The sensing tags are mounted on the animals to study the behaviour of the animals. These animals roam around in their habitat generating variation in the interferences caused for communication. Due to wide variations, the inefficiency of the sensor node in communication results in draining battery rapidly and thereby life of sensor node. So in order to improve lifetime the optimization at the sensor node is very essential to keep network alive. The technique that performs optimization needs to be lightweight in terms of processing required as well as tuning of parameter which are required for model based optimization methods. In the paper, we proposed a technique which is lightweight and can dynamically optimize operating state. It is done by adaptively configuring communication parameters to patch losses and conserve energy to enhance Sensor node lifetime. The optimization technique proposed, does parameter tuning to minimize the communication cost in sensor node through efficient search method. The results are compared with traditionally employed technique with static setting and Online Greedy Optimization Algorithm. NI LabVIEW is used to do simulation of the model and for estimating the effect of parameter reconfiguration upon application of optimization techniques.***

Index Terms**: *Wireless Sensor Network, Sensor Node, MSP430, NRF24L01+, Optimization, Search Methods, Energy Consumption, Throughput.***

I. INTRODUCTION

Wireless sensor network(WSN) has wide range of applications in medical, defence, agriculture, environment, industrial and many more. Each application scenario leverage vivid requirements in terms of functionality and metrics such as throughput, reliability, lifetime, coverage, size and so on.

Revised Manuscript Received on July 06, 2019.

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Each WSN consist of deployed number of sensor nodes(SN) in region of interest for monitoring which in turn form topology to organize communication of sensed events to Base Station (BS). Each SN is equipped with a processing unit, communication interface and sensing interface along with conditioning and calibration unit. The system architecture varies depending on metrics, peculiarly suitable to the application. With changing technologies, the architectures have evolved to best fit the requirements for optimum functioning. Several studies and research work indicated methodologies to apply for optimum designing of system architecture to precisely meet the application needs. The limited energy source with the SN open scope for post-design optimization at each level of design space. Various optimization methodologies are used to optimize WSN performance for example, optimization at clustering, routing, deployment, data collection, coverage and more to improve WSN efficiency and lifetime. Out of most of the techniques, reconfiguring the peripherals and its operating modes significantly optimize SN lifetime under changing scenarios. Once the sensor node architecture is designed, functioning of the peripherals vary with the environmental conditions and requirements. Optimization methodologies can be applied to get the optimum functioning of SN by making best use of the available resources. For the sake of which, the peripherals are reconfigured to work efficiently under the condition. Reconfiguration of the peripherals basically does tuning of the parametric setting in peripherals based on profiling statistics. WSN is widely used for Biotelemetry and habitat monitoring for ecosystem studies. The SN is mounted on tags of species to record routine activities for study as well as analysis. The SN used and designed for the purpose undergo transitions which brings stochastic operating variations. Due to positional variance, the working efficiency of SN changes proportional to distance from sink and obstacles in line of communication. In the paper we have considered a scenario of mobile SN for Biotelemetry. For the SN that is changing its position in region, communication interferences incur cost inhibiting performance and lifetime. The performance can be optimized by adjusting operating state to patch losses due to inefficient communication. In the proposed work, optimization is employed at reconfiguration of communication unit. Based on the profiling statistics, dynamic reconfiguration through parametric tuning of communication unit is invoked to fit the requirements and at the same time conserving energy loss to improve lifetime. The paper is organized in following sections: Introduction to the topic followed by the review of the past work and methods. Section 3 discuss research problem identified from review of literature conducted. Section 4 defines the system model designed to optimize by applying algorithm devised. Section 5 discuss the algorithm devised for optimization which is followed by the estimation model discussion in section 6 which is used to validate the results achieved by implementation. Finally, section 7 discuss the simulation results followed by conclusion and future work with possible extension in section 8.

II. RELATED WORK

When SN are functioning in scarce of energy source, many factors are considered for improving lifetime and efficient operation. Foremost criteria are precisely designing the architecture i.e. processing unit communication unit and sensing system[1,2]. Apart from architecture design, other causes of consumption and conserving techniques at different layers of design proves effective [3,4]. Various optimization techniques are studied and applied for routing[5–7] as well as for clustering[8–13] to efficiently route the data and form the clusters respectively. Optimization through functional reconfiguration is widely explored and employed in recent applications on account of achieving increased efficiency and functional variations. Reconfiguration is inevitable under the changing scenarios of operating environments. The static configuration proves inefficient so far as changing environments are concerned especially for communication interface when node is mobile. Reconfiguration can be employed for software and/or hardware to optimize the performance[14,15]. At software level reconfigurations can be for protocol related or for tasks and their scheduling by OS in node. The techniques for reconfigurations typically support runtime reconfiguration that do not require restart or wait state while functioning[16]. To make the system reconfigurable, architectures designed using SRAM-FPGA[17], FPGAs[18,19], PSOCs[20] are used to reconfigure SN functions. Also few research presents reconfigurable architectures using Atemga128[2,21,22], MSP430[23] Recently, sensor nodes compliant to ISO/IEC/IEEE 21451 family of standards are developed for making smart sensor nodes or so called TEDs[24,25]. Architecture based on ISO/IEC/IEEE 21451 family of standards do not support runtime reconfiguration and complete file needs to be sent for reconfiguration. Reconfiguration can be done for various parameters of sensor node. Typically, voltage and MCU frequency scaling is widely applied in most of dynamic reconfigurable sensor nodes[26,27]. Along with Dynamic Voltage Scaling(DVS) and Dynamic Frequency Scaling(DFS), selective powering to the required hardware blocks and peripherals based on battery capacity is also useful and applied[28]. Apart from voltage and frequency scaling, parameters related to communication i.e transmission power[23,29] and packet length[29,30] is optimized to conserve energy spent for sending and receiving data. In [31], the author addressed transmission range distribution optimization problem for the nodes that send packets over variable transmission ranges. The problem optimizes transmission range instead of fixed range considering it to be dominant over sensing and processing consumptions. Optimization methods employed for WSN vary from simple search methods to extensive processing required techniques. Various optimization techniques are used to identify the optimum parameters for tuning in sensor node such as Linear programming[31], Search methods [32], proximity search methods[33], Markov Decision Process[34], Genetic Algorithm[35][36], Differential Evolution[37,38], Particle Swarm Optimization[39], evolutionary optimizations[40] and many more[41].

III. RESEARCH PROBLEM

In most of the techniques reviewed, the techniques employed to estimate parameter values for optimum operation incur processing overhead. Due to heavy processing involved in such techniques, SN architecture needs to be capable for intensive processing. Some of the techniques uses models and its parameters which needs to be tuned or updated frequently upon detecting change in model or in case error function crosses thresholds. Those parameters are communicated by base station to the SN. So along with the processing cost, communication cost is added which altogether accounts for SN lifetime. Secondly, depending upon the SN architecture and technique used, huge description or command files are to be sent to reconfigure the SN which incurs communication cost. Few of the studies evolved to address the drawback of full reconfiguration by making use of selective reconfigurations. Still the reconfiguration file size for selective alternations tends to be much larger than MCU based reconfiguration design which simply takes few bytes for full reconfiguration of peripherals[42]. In the proposed technique, simple but efficient techniques are used to optimize lifetime of SN by tuning communication parameters.

IV. SYSTEM MODEL

In the proposed work, Hierarchical topology is considered, where cluster Heads (C)collect data from SNs(S) in Cluster and pass it on to Base Station(BS). We considered here a WSN, where WSN is formed of i clusters and in each cluster, there are N-number of sensor nodes(SNs) within a cluster. Thus, $S_{i,j}$ indicates i^{th} cluster and j^{th} SN in WSN hierarchical topology. Each S_j is separated by distance from C_i, that vary depending upon communication range of deployed SN in cluster. Let $d_{i,j}$ indicates Euclidian distance between C_i and S_j. The communication cost for a $S_{i,j}$ depends on $d_{i,j}$ and surrounding environment. The Biotelemetry application is considered to monitor animals and their activities using WSN. The SN is mounted on to the tags of animal for recoding the events and reporting it to the BS. In this work we assume $d_{i,j}$ is changing and thus surrounding environment is also changing when animal is roaming in the habitat. It is assumed that cluster head is static and is equipped with sufficient energy source which is derived from solar.

A. *Tuneable Parameters State Space*

The tuneable parameters forms state space S as:

$$S = P_1 \times P_2 \times P_3 \times .... \times P_m \tag{1}$$

Which is Cartesian product of tuneable parameters and values of each tuneable parameter. Let *m* be the number of parameter that are tuneable in a SN and *n* be the values of each parameter *P*, such that,

$$P_k = \{ p_{k_1}, p_{k_2}, p_{k_3}, ..., p_{k_n} \} \tag{2}$$

P_k is the k[th] parameter having *n* tuneable values. So at any instant the set of parameters used to configure a state of SN be represented as

$$s_t \in S, s_t = \{ P_{1_l}, P_{2_l}, P_{3_l}, ..., P_{m_l} \} \tag{3}$$

Where, k ∈ { 1, 2, 3, . . . , m} and l ∈ { 1, 2, 3, . . . , n}.

For large k, the state space is huge for searching algorithms taking more time to find optimal solution from the cardinality.

So here we derived a hybrid algorithm by cutting down number of parameters to minimize search space and thereby reduce time to find optimal solution.

B. *Objective function*

The parameters are tuned to optimal value such that objective function $f(S_t)$ is maximized.

$$\{ P_1^*, P_2^*, P_3^*, ..., P_k^* \} = \{ s_t^* \mid \max f(s_t^*) \} \tag{4}$$

$$s_t^* \in S \tag{5}$$

Where, $P_1^*, P_2^*, P_3^*, ..., P_k^*$ are the optimum parameter values identified to achieve optimum functioning state of SN, s_t^*, making efficient use of resources and leading to optimum node lifetime.

Algorithm I: Hybrid Algorithm for Dynamic Reconfiguration (HADR)

Input: PER
Output: Optimal RF Setting

If($\mu_{t,i} + \sigma_{PER,i} > B_{th,max}$) **then**
  Read configurations of i[th] node in cluster
  Nearest Neighbour Search (ρ,τ)
  If($B_t > B_{th}$) **then**
    Golden Section Search (Payload Length)
  End
  Identify the optimal configuration values
  Send(Invoke Reconfiguration(S_i^*) **)**
  while (**!** Acknowledge);
  Send(Exit–command)
End

C. *Optimization Methodology*

For a SN communication cost is most prominent of all other consumptions at node level. Communication cost depends on channel condition to great extent. To optimize communication cost, three parameters are considered for tuning and reconfiguration; Transmit power, Data Rate and Packet Length, which are optimized such that the efficient communication takes place between cluster head and sensor nodes. Algorithm-I indicate the optimization process that is invoked based on Packet error rate(PER) status. B_t indicates Bit Error Rate at an instant *t* and B_{th} indicates threshold value of Bit Error Rate. μt is the average bit error rate at an instant t for SN, $\sigma_{PER,i}$ is variance and $B_{th,max}$ is maximum threshold value of bit error rate which is used to invoke the process. The average and variance are calculated based on previously received values at the cluster head. Transmit Power(ρ) and Data Rate (τ) are used as parameter for tuning through NSS. To overcome the complexity in searching with increase in dimension, optimization is performed in 2 stages by clubbing proximity search and 1D section search technique.

V. HYBRID ALGORITHM FOR DYNAMIC RECONFIGURATION (HADR)

Hybrid algorithm is combination of a proximity search technique and section search technique. The proximity search technique looks for the parameter values in its proximity for optimization. This technique takes advantage of the fact that the state of sensor node deviates gradually from optimal state derived previously. So the function does not change drastically and thus by fine tuning the values optimization can be reinstated. So checking the function value in the contiguous of current setting, optimization can be performed. Nearest Neighbour Search (NNS) technique is a kind of proximity search technique used to perform optimization by probing the search space. NNS technique overcomes burden of scanning whole search space for optimum values by taking an advantage of tuning current values to its next neighbour.

To form the search space for the problem here, optimizing RF parameters, the neighbouring values of settings for Transmit Power(ρ) and Data Rate (τ) are estimated such that it is *r*-step after and before the current value, as per condition given below.

$$\theta(\rho, r) = \{ \rho^* \mid d(\rho, \rho^*) = r, \rho^* \in (\rho_{\min}, \rho_{\max}) \} \tag{6}$$

$$\theta(\tau, r) = \{ \tau^* \mid d(\tau, \tau^*) = r, \tau^* \in (\tau_{\min}, \tau_{\max}) \} \tag{7}$$

Where, r is the minimum step difference in current and neighbouring element. Using the NNS algorithm for the best nearest neighbouring combination value, optimum throughput value is reached and corresponding energy consumption value is estimated. The optimum setting of Transmit Power(ρ) and Data Rate (τ), derived (s_t^*)is used to reconfigure RF module of SN.

$$(\rho^*, \tau^*, l^*) = \{ s_t^* \mid \max f(s_t^*) \} \tag{8}$$

Here, l^* is optimum packet length derived by applying Golden Section Search Algorithm[43] to minimize packet rejection under erroneous channel condition.

VI. ESTIMATION MODEL

Major cause of energy depletion for SN in WSN is due to Communication of data over the wireless link. With the increased losses in the channel the estimated cost increases to the extent node dies creating a blind spot in WNS.

Table I nRF24L01+ Paramerters And Its Consumption

RF Parameters (Condition)	Typical	Units
Idle modes		
Supply current in power down	900	nA
Supply current in standby-I mode a	26	µA
Supply current in standby-II mode	320	µA
Average current during 1.5ms crystal oscillator start-up	400	µA
Transmit		
Supply current @ 0dBm output power	11.3	mA
Supply current @ -6dBm output power	9	mA
Supply current @ -12dBm output power	7.5	mA
Supply current @ -18dBm output power	7	mA
Average Supply current @ -6dBm out-put power, ShockBurst™	0.12	mA
Average current during TX settling	8	mA
Receive		
Supply current 2Mbps	13.5	mA
Supply current 1Mbps	13.1	mA
Supply current 250kbps	12.6	mA
Average current during RX settling	8.9	mA

Communication cost is divided into transmission and reception cost. Transmission cost is majorly decided upon the transmit power set in SN which again is proportional to distance and losses in link. Typically, communication cost is given as:

$$E_c = E_{tx} + E_{rx} + E_{idle} \qquad (9)$$

E_c is the energy consumed by the communication unit depending upon contribution in 3 stages: transmitting, receiving or in idle state. E_{idle} is the energy consumed when communication unit is idle for the time between transmit and receive. In proposed system here, during idle state the SN is sensing as well as waiting for ping from cluster head to send data so there is no separate state for receive and idle/wait. During active state, SN consume E_{tx} to communicate the data gathered to cluster head, which can be given as:

$$E_{tx} = E_{start} + (E_{tx} + E_{rx})(1+R) \qquad (10)$$

Where R, is number of retransmission for packets not acknowledge due to error or loss. E_{start} is the start-up energy along with settling time, E_{tx} is the transmit energy while E_{rx} is the receive energy. The value of the energy consumption is calculated based on current consumptions given in Table I[44]. Secondly, other metric for evaluation concerned is throughput. When it comes to the actual data reaching destination without error, an important metric evaluates the system is Throughput. Throughput(T_p) relies on probability of error(P_b) and bits to transmit making an allowance for data as well as other overhead [45].

Throughput for the module used can be estimated as:

$$T_p = \left(\frac{L}{L+P+A+PC+CRC}\right) \times \tau \times (1-P_b)^{L+P+A+PC+CRC} \qquad (11)$$

Where, L – Payload length (1 to 32 byte), P – preamble (1-byte), A – receiver address (3 to 5 byte), PC – packet control field (9 bit), CRC – 1 or 2 byte, which altogether forms packet size and τ is the Data Rate. Other consumptions due to sensing and processing is considered to be constant throughout as is not altered for optimization under the work presented here.

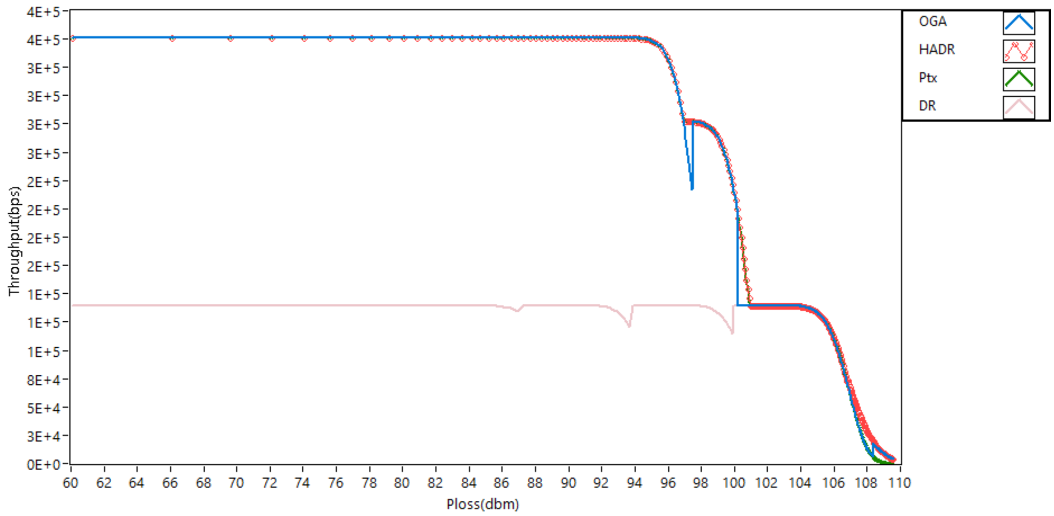

Figure 1 Throughput(bps) For Optimization with Increasing Power Loss(dbm)

VII. SIMULATION RESULTS

Here to demonstrate the performance and for validation of the algorithm we have proposed an estimation model that is designed with an ultra–low power MCU from Texas Instrument and nRF24L01+ RF module from Nordic Semiconductors. Two metrics are evaluated for the optimization, Energy consumed (10) and throughput (11). Three parameters for communication unit, Transmission power, Data Rate and Payload Length, are considered for optimization. Transmission power vary from 0dbm to -18dbm in four levels starting from 0 to 3, whereas

Data rate vary with values 250kbps, 1Mbps and 2Mbps indicated with level 0 to 2 and Payload length can be 1 to 32 bytes. The results of the proposed technique is compared with three other techniques of optimization. Firstly, Online Greedy Algorithm (OGA) technique which does searching of parameter space in defined order to optimize function[46]. Other two techniques use only one parameters, transmission power or data rate, for 1-Dimension probing keeping other parameter constant along with payload length. One of it is a fixed heuristic policy π^{Ptx}, it selects lowest transmission power keeping data rate constant. Another is a fixed heuristic policy π^{DR}, which selects optimum data rate keeping transmission power constant.

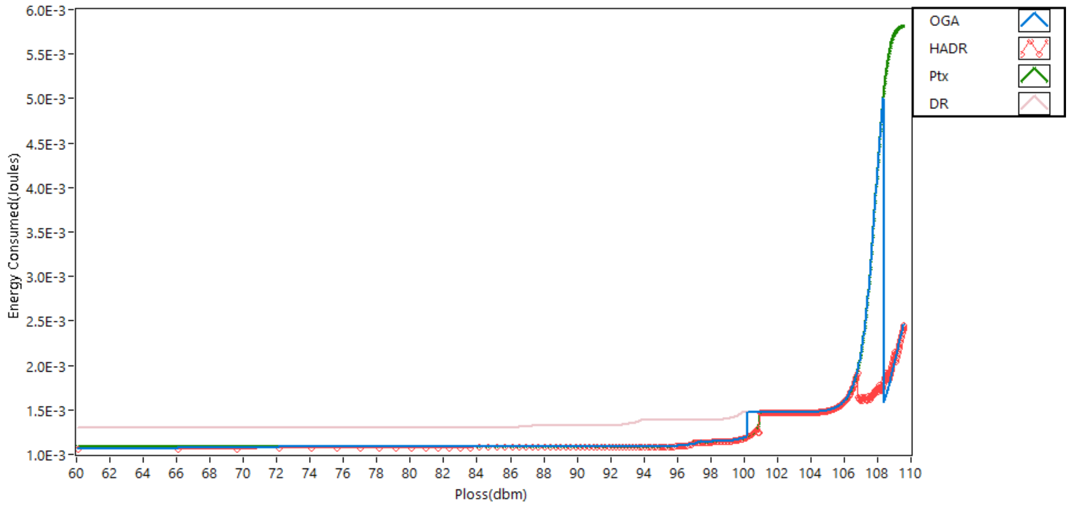

Figure 2 Energy Consumption(Joule) Optimization For Increasing Power Loss(dbm)

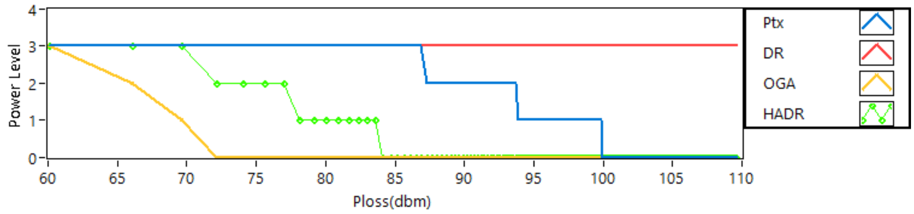

Figure 3 Transmission Power Level Upon Applying Techniques With Power Loss Changes

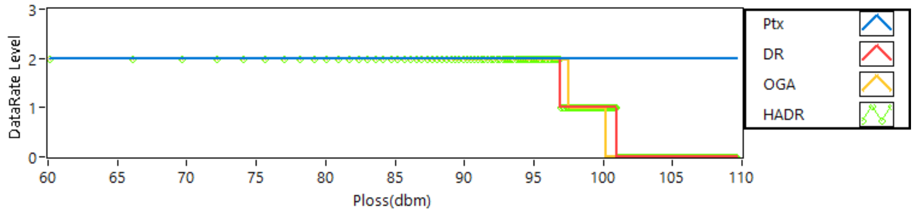

Figure 4 Data Rate Level Upon Applying Techniques With Power Loss Changes

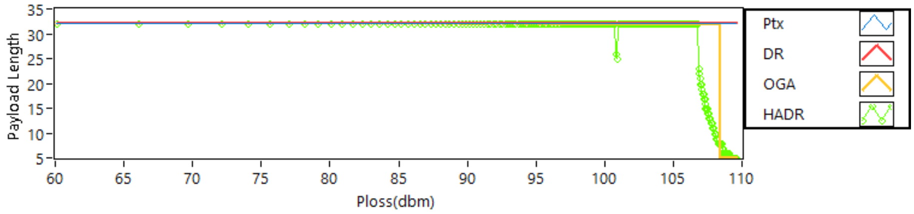

Figure 5 Payload Length(Bytes) Upon Applying Techniques With Power Loss Change

The results are derived by simulating the scenario of sensor node moving away from the cluster head thereby increasing losses in communication. With increase in loss, packet loss increases thus the optimization technique tries to reconfigure parameter settings to minimize consumption and maximize throughput. On applying optimization, sensor node parameters for communication are reconfigured to achieve best performance. Figure 1 shows graph indicating effect on Throughput with increasing power losses upon applying the optimization techniques. The throughput graph for OGA follows curve of π^{Ptx} but deviates upon experiencing major packet loss by adjusting packet length to meet optimality. While HADR gradually optimize parameters and follow optimum curve which is evident from energy consumption curve shown in Figure 2, which is depicting energy consumption for same condition. The trailing curve shows hike in energy consumption caused due to increased power loss especially for OGA as compared to HADR. For OGA, the consumption increases from about 1.86mJ to about 5.23mJ whereas in HADR the consumption is minimized by adapting optimal packet length and increases maximum upto about 2.72mJ. Figure 3 shows the graph for change in transmit power during optimization technique. The power level is shifted to maximum at the initial stage in OGA technique while for HADR the change to peak level is distributed in mid stage. For π^{Ptx}, the changing phase is stretched to last stage as it only rely on single parameter for optimization. Figure 4 shows changes in Data rate with increasing losses. Almost for all techniques the data rate changes occur in same stages. So far as packet length is concerned, Figure 5 indicates how OGA and HADR vary packet length. The HADR gradually decrease packet length to cope up with the packet losses.

Table II Comparison Of The Results For Throughput And Energy Consumption

Technique	Average Throughput(bps)	Average Energy Consumption (J)
π^{DR}	100864.5997	0.002259
π^{Ptx}	171836.1242	0.002169
OGA	171106.4539	0.001703
HADR	174415.9971	0.001475

VIII. CONCLUSION AND FUTURE WORK

In this paper we proposed a lightweight hybrid algorithm for optimization to improve performance of sensor node and conserve energy by reducing dimension to apply technique. The first phase of optimization work upon communication parameters, transmit power and data rate using NSS. If the interference is still higher resulting in major packet loss, the packet length is optimized using GSS. The algorithm dynamically reconfigures sensor node by parameters tuning derived from HADR. The proposed technique, HADR, outperforms other three techniques i.e π^{DR}, π^{Ptx} and OGA by 72.92%, 1.5% and 1.93% respectively for Throughput and 34.71%, 32% and 13.39% respectively for Energy conservation. Further, future work includes inclusion of other parameters related to MCU and acquisition unit to optimize the performance. In the proposed work, the reconfiguration settings are communicated to the sensor node for optimum performance instead a lightweight algorithm to make the process autonomous be focused in our future work.

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