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LEED-LIFETIME ENERGY EFFICIENT DATA ACQUISITION TECHNIQUE FOR AIRCRAFT STRUCTURAL HEALTH MONITORING SYSTEMS

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ABSTRACT

Implementation of low cost sensor nodes in recent years allows wireless sensor nodes to be applicable for wide range of applications in aircraft control systems. Rapid use of composite materials for aircraft structures, calls for the development of novel methods for aircraft structural health monitoring. Visual inspection of failures due to delamination of layers and cracks developed in metal structures does not prove to be a reliable method for failure detection. However the present scheduled aircraft structure maintenance methods involve a high maintenance cost. To overcome these shortcomings, wireless sensors can be embedded into these composite structures to detect the vibration energy and transmit the same to the central health monitoring unit. For aircraft structural health monitoring the major challenge lies is in the design and implementation of wireless sensor networks to extend the node lifetime by minimizing energy consumption with its limited resources. In this paper we propose a new data acquisition technique that is aimed to maximize both energy efficiency and the lifetime by making use of relay nodes and beacon enabled MAC. An energy efficient route is established between the source and the sink using the relay nodes. Beacon enabled MAC puts all the redundant nodes into sleep mode to save the energy further during data transfer. Through simulation we will show that our technique saves more energy, minimizes packet loss and delay and also increases the reliability of the network by increasing the active time of the relay nodes.

Keywords: *Wireless Sensor Networks, Energy Efficiency, MAC, Aircraft Structural Monitoring, Relay Nodes, Lifetime*

1. INTRODUCTION

A typical aircraft consists of several control systems, such as aircraft engine control, aircraft flight control, engine and structural health monitoring, aircraft cabin environmental control, in-flight entertainment system, etc. There is a wide use of composite materials for building aircraft structures with the best known techniques which may wear out due to ambient excitations or other structural damages such as forces. For structures to meet safety standards an early identification of structural damages is necessary. Most of the failures of the laminated composite structures originate due to delamination of layers. In case of metal aircraft structures, cracks are developed in metal structures which grow over time leading to failures. For both of these cases, visual inspection is not a reliable method for failure detection. This calls for a vibration analysis-based failure detection method. Current systems, based on wired connections are complex, heavy, difficult to route and are prone to damage and degradation. Due to the complexity and sizes of the structures the deployment and/or maintenance of traditionally wired equipment used for monitoring the health of a structure takes time and money. With their fault-tolerant, self-organizing and scalable structure, WSNs can make aircraft structural health monitoring more easier.

Several studies have been conducted to develop health monitoring algorithms which use the data from strain sensors embedded into the composite structure. An aircraft structural health monitoring system based on WSN is studied and described in [1-3]. WSN can be embedded into the composite structure which will harvest the vibration energy and will transmit the real-time data to the central health monitoring unit. These sensors will be used

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to monitor the internal parameters like cracks, strain as well as external parameters like temperature, load, etc. Use of WSN, powered by energy harvesting techniques will increase the number of sensors as well as their life.

1.1 The Structural Health Monitoring Scenario

A typical Structural Health Monitoring (SHM) system using wireless sensors often has hierarchical network architecture in which one or more base stations regularly acquire the data and check the health of the aircraft structure by initiating communication with the deployed sensor nodes. Wireless Sensor Networks (WSNs) consisting of large number of low power nodes with limited processing, communication and storage resources are normally deployed in hostile environment where human intervention is not possible. Today, WSN monitoring an aircraft structure is expected to have a long life. The most important requirements for a data acquisition protocol in the SHM scenario are low communication and computation cost, scalability in form of node additions, high reliability, low and predictable delay of data transfer with low power consumption as long as possible. In order to fulfill these requirements, algorithms used should be energy-efficient and life-time efficient. Scarce energy resource may result in a short lifetime, so that energy management that minimizes energy consumption becomes crucial. Otherwise, an early failure of nodes due to lack of energy might require a reconfiguration or even cause significant malfunctioning within the network. To prolong the overall network operational lifetime, the energy consumption of a sensor node should thus be minimized as far as possible. However, minimizing the energy costs might negatively affect the data delivery ratio. Thus, algorithms that cause low energy costs but high loss rates are often not efficient. In contrast, focusing on energy efficiency turned out to be a very promising acquisition scheme. It trades off the end-to-end delivery ratio of nodes reporting data to a sink node and the energy consumption in the network very well. Limited processing resources and strong energy consumption constraints require MAC methods for WSNs to be simple and energy conserving. In literature some works propose mechanisms based on the idea of separating the energy and power requirements addressing them at different levels of the protocol stack. We introduce a new, energy and radio power management approach that integrates various protocol layers like physical, data-link and network layers in a WSN to minimize the energy consumption and also to increase the overall network lifetime. In this chapter, we first outline the primary attributes of MAC protocols and major reasons for energy waste. Finally, we point out open research issues related with MAC layer design.

1.2 Attributes of MAC Protocol

A well designed MAC protocol should have the following attributes. The first attribute is *energy efficiency*. Energy-efficient protocols should be designed in such a way that they prolong the network lifetime. Other important attributes include *scalability* and *adaptability* to changes. Changes in network size, node density, and topology should be handled rapidly and effectively for successful adaptation. A good MAC protocol should gracefully accommodate network property changes like limited node lifetime, addition of new nodes to the network, and varying interference, which may alter the connectivity and hence the network topology. Other important attributes such as *latency, throughput, bandwidth utilization* and *fairness* may be considered secondary in sensor networks.

1.3 Major Reasons for Energy Waste

Maximizing the network lifetime is a common objective of sensor network research, since sensor nodes are assumed to be ‘dead’ when they run out of battery. Under these circumstances, the proposed MAC protocol must be energy efficient in reducing the potential energy wastes. Several reasons can be quoted to cause energy waste in a resource constrained wireless sensor network. The following are the major reasons to be considered crucial in the network.

Collision: It is the instant when a node receives more than one packet at the same time; Collision calls for retransmission which increases the energy consumption; hence all packets that cause the *collision* have to be discarded.

Overhearing: It is the instant which occurs when a sensor node receives packets that are destined to other nodes.

Control-Packet Overhead: Control packets are required to regulate access to the transmission channel. A high number of control packets transmitted, relative to the number of data packets delivered indicates low energy efficiency. A minimal number of control packets should be used to make a data transmission.

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Frequent Switching: Frequent switching between different operation modes may result in significant energy consumption. Limiting the number of transitions between sleep and active modes leads to considerable energy saving.

Idle Listening: A node is said to be in 'idle listening' mode when it is listening for a traffic that is not sent.

Over Emitting: This factor refers to transmission of a message when the destination node is not ready.

1.4 MAC Layer Design Techniques

Each sensor node within the WSN has limited energy and computational resources. In order to make optimal use of these finite resources, a wide range energy efficient MAC protocols have been developed. They can be broadly categorized into contention-based, TDMA-based, hybrid, and cross layer MAC protocols according to their channel access policy. Contention-based MAC protocols based on the Carrier Sense Multiple Access (CSMA) or Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) require no coordination among the nodes accessing the channel. Some of the typical contention-based MAC protocols are S-MAC (Sensor-MAC), T-MAC (Timeout-MAC), and U-MAC (Utilization-MAC). On the other hand, scheduling based TDMA techniques offer an inherent collision-free scheme by assigning unique time slot for every node to transmit or receive data. TDMA technique can avoid interference between adjacent wireless links and can also solve the hidden terminal problem without extra message overhead. Major TDMA-based MAC protocols include μ-MAC (Energy-efficient MAC), DEE-MAC (Dynamic Energy Efficient MAC), SPARE MAC (Slot Periodic Assignment for Reception MAC). Besides TDMA-based MAC some hybrid MAC protocols have been recently proposed which have the advantages of both contention-based MAC and TDMA-based MAC protocols. These protocols divide the access channel into two parts in which control packets are transmitted in the random access channel, while data packets are transmitted in the scheduled access channel. Compared with the contention-based and TDMA-based MAC protocols, the hybrid protocols can achieve greater energy saving. Some of the hybrid MAC protocols include Z-MAC (Zebra MAC), A-MAC (Advertisement-based MAC) and IEEE 802.15.4. Since MAC protocols focus on energy efficiency and not on reduction in communication delay or packet dropouts, the performance of control systems based on these protocols is limited. Research should be conducted to design MAC protocols which are not only energy efficient, but also offer high Quality of Service in terms of time delay, bandwidth utilization and data loss due to packet collisions. Current research studies show that a cross-layer integrated design framework of wireless networks and distributed controllers, can significantly improve the performance and stability of the controller.

The rest of the paper is organized as follows. In section 2, the current studies on existing methods are briefly reviewed. Section 3 describes the System Model and the Methodology involved in implementing the proposed scheme. Section 4 describes the Characteristics of LEED Technique and Enhanced LEED Technique. In section 5, the Experimental Results are shown. Finally, a Conclusion is given in section 6.

2. RELATED WORKS

To provide a proper insight into data acquisition techniques we here analyze a few of them. In [4], Seada et al. proposed an energy-efficient greedy forwarding technique, in which each node tries to forward packets to nodes that are closest to the sink with respect to geographic distance. In real environment, it turns out that many packets are transmitted on lossy links, leading to bad end-to-end delivery rates with high energy costs. Seada et al. therefore suggest a metric that is based on the product of the packet reception rate and distance. Their simulations have shown that this metric achieves optimal results by balancing longer, lossy links and shorter, high-quality links. Zorzi in GRF [5] and Chen in SPAN [6] consider the energy efficiency as a performance indicator, which is attained by algorithms under the routing layer and above the MAC layer so-called bridge layer. In both protocols only a fraction of the nodes in a certain area are activated at any given time. A major weakness of GRF is precisely the requirement that the routing feature be guaranteed, which results in inefficiency in terms of latency and energy consumption. In SPAN, the energy consumption significantly increases as the number of nodes increases. In ATMA [7] Ray propose a distributed TDMA-based MAC protocol that utilize the busty or periodic nature of the traffic to prevent energy waste through advertisements and reservations for data slots. In ETD MAC [8], Ping Liu et al. propose an event-tracking detection and a sleeping mechanism using tight scheduling mechanism. In PAMAS [9], introduced by Singh et al, sensor nodes switch off their radio and go to

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sleep mode whenever they can neither transmit nor receive successfully i.e., whenever it detects that other nodes are transmitting phase. However, when the node is in idle reception mode i.e., when it has no packets to send or there is no activity on the channel, a considerable amount of energy goes into waste. B-MAC [10] repeatedly turns off the radio tens for several of milliseconds (tens or hundreds); to send a packet, a node transmits a preamble long enough to ensure that the destination will be "online" to receive it. This imposes a considerable energy penalty on the sender for each packet, which is aggravated with network density impacts. S-MAC [11] proposed by Yee et al. specifically aims at reducing energy consumption in listening to idle channel by incorporating a periodic sleep mechanism. The nodes conserve energy by going into sleep mode and then waking up periodically to listen and check if any of its neighbors are ready for communication with it. Since all messages are packed into the active mode, instead of being 'spread out' over the whole frame, the time between messages, and therefore the energy wasted on idle listening, is reduced. T-MAC protocol [12], automatically adapts the duty cycle fluctuations in network traffic. Instead of using a fixed-length active period, T-MAC uses a time-out mechanism to dynamically determine the end of the active period. IEEE 802.15.4standard [13], a hybrid MAC mechanism offers more flexible quality of service to several classes of applications.

Given the availability of numerous techniques to reduce energy consumption and to ensure reliability and low delays, a cross-layer optimization is a natural approach to integrate the protocol layers. Some cross-layer design challenges of the physical, MAC, and network layers to minimize the energy consumption of WSNs have been surveyed in [14-20].After a careful study on existing approaches we propose a simple design technique based on IEEE 802.15.4standardthat offers a computationally attractive solution of adequate accuracy. The solution is uses relay nodes, cost metric path for data acquisition and CSMA/CA MAC to jointly optimize the energy consumption and network lifetime. Our proposed technique proves to be simpler and efficient cross-layer protocol including all the relevant characteristics of the physical layer, MAC, routing, duty cycling, and load balancing to minimize the energy consumption maximize the network lifetime.

3. SYSTEM MODEL AND METHODOLOGY

This section describes our system model, assumptions and the energy modelused followed by the methodology of the proposed technique.

3.1 System Model

Consider a Wireless Sensor Network consisting of N sensor nodes uniformly deployed over an area of interest. Let$S = \{S_1, S_2, . . . , S_N\}$, where $|S| = S_i$ denote the sensor node set and S_i denote the i^{th} sensor node in the set S. To specify the WSN scenario, we adopt the following assumptions:

- All nodes are homogeneous and have the same radio and computing capabilities.
- All the nodes are assumed to be static and can directly communicate with each other and perform broadcast communication.
- The sink node is very powerful. It has sufficient computation and communication capabilities so that it cannot be compromised.
- All the sensor nodes are within the same radio range.
- Synchronization of all nodes is needed.

The sensor nodes that are scattered over a region of interest detect the occurrence of events, and forward the messages towards a static sink for further data processing. To determine the amount of energy consumed by a radio transceiver, we assume that the energy spent in transmitting a bit over a distance d is proportional to d^2 (i.e., first order radio model characteristics in free space). For each packet transmitted by a source node to sink in its neighborhood, the energy is calculated as given in equation (1).

$$\boldsymbol{E = E_T + M \cdot E_R} \qquad (1)$$

where$E_T$and $E_R$denote the amount of energy required to transmit and receive respectively, and M (M<N) the total number of neighbors in the transmission range. Considering two arbitrary nodes a distance d apart from each other, this model can be intuitively described as follows: Below a distance d_{av}, nodes are assumed to be almost fully connected, i. e., the packet reception ratio is mostly equal to one. In contrast, there is high probability that two nodes will be disconnected if they are more than a distance d_{av} away from each other, i. e., the packet reception ratio is zero. This behavior can be modeled for any arbitrary wireless path using equation (2) as

$$\boldsymbol{prr(d) = \begin{cases} 1 & d < d_{av} \\ 0 & d \geq d_{av} \end{cases}} \qquad (2)$$

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where d_{av} is the node's average transmission range.

3.2 Methodology

We design a wireless sensor network consisting of multiple source nodes; several relay nodes and a sink. The source nodes detect the occurrence of events and forward them to the sink with the help of relay nodes. Nodes are classified into uneven clusters according to their deployment properties and geographic location. In each cluster, only one best *relay node* with respect to residual energy is said to be active, while all other 1- hop neighbor nodes called the member nodes operate in sleep mode. The relay node is responsible for all its assigned nodes and performs special application tasks, like data handling, medium access control and providing routing-related functions. The source nodes wake up as soon as they sense any data to be transmitted. Before sending packets, the source node waits for a beacon message from the relay nodes of each cluster. Beacon messages carry information related to the control parameters like node ID, requests for residual energy, and its distance to the sink. The LEED technique uses a network routing mechanism which maintains the network connectivity through selection of only a few relay nodes to form the data acquisition path in order to reduce the energy consumed and enhance the network lifetime. Furthermore, it explicitly considers path qualities by measuring the packet delivery ratios as packet losses are very common due to low-power radios, reflections, attenuation, and multipath/fading effects. Enhanced LEED Technique uses a MAC based on a CSMA/CA mechanism similar to the IEEE 802.15.4. Both data packets and beacon packets are transmitted using the same MAC. The CSMA/CA checks the channel activity by performing Clear Channel Assessment (CCA) before the transmission can commence. Transmitting data through relay nodes consumes less energy than routing directly to the sink. LEED and Enhanced LEED technique, therefore, performs an efficient energy control to increase the lifetime through coordination with different layers of the network.

4. LEEDTECHNIQUE

Every sensor, whose location is randomly distributed, is assumed to have the same initial energy and radio range. Both the sensor nodes and the sink nodes are stationary. LEED Technique consists of two components: the relay node selection mechanism and LEED path selection mechanism. The relay node selection mechanism describes the method of selecting the relay node for a clustered network topology supporting multi hop communication. The section on LEED path selection mechanism discusses on the metrics used in selecting the best data acquisition path that would be lifetime energy efficient from a sensor node to the sink.

4.1 Energy Efficient Relay Node Election Mechanism

Assume a system model of a typical wireless sensor network, consisting of a multiple sources*(S_i, i= 1,…,N)*, a single sink node and *K* relay nodes *(R_i, i= 1,…,K)*. The source nodes intend to transmit data to the sink through the relay nodes. The relay node selection process works as follows: Nodes are classified into uneven clusters according to their deployment properties and geographic location. The best relay node with respect to residual energy is determined among all 1-hop neighbors. Each node discovers its neighbors within one hop along the forward direction towards the sink by broadcasting beacon messages that carry information related to the control parameters like node ID, requests for residual energy, and its distance to the sink. Each node calculates its drain rate $'DR_i'$ and the remaining lifetime $'RLT_i'$ using the following equations (3) and (4).

$$\boldsymbol{DR_i = RE_i/\mathrm{dt}_i} \quad (3)$$

$$\boldsymbol{RLT_i = RE_i/DR_i} \quad (4)$$

The drain rate indicates the amount of average energy consumed by each node per second during a certain time interval '*dt*'. A node with highest residual energy $'RE'$ is selected as the best relay node as shown in Figure 1.

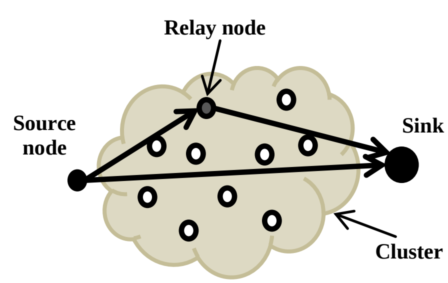

Figure.1. Relay Node Selection

All other nodes within its 1-hop neighborhood will be assigned to it, and will no longer be relay node candidates. Some nodes within the transmission range of more than one relay node are

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assigned to just one cluster. However, if the node is already a relay node and has found another one whose cluster timeout has not expired and whose residual energy is higher, it will change its state and become part of the newly formed cluster. If the node's remaining lifetime is more than the time needed to send data packets, it broadcasts the beacons again, otherwise it will drop it. In this way, the relay nodes with energy less than that is required for sending the control packets are prevented to establish an energy efficient path between the source node and the sink. After a node has been selected as a relay node, it will set a relay node timer T_r, during which it will not change its state. Due to load and energy balancing, it will try to find another cluster it could join to if T_r expires. The running time T_r for each relay node is defined is given as in equation 5.

$$\boldsymbol{T_r = MIN\{\gamma, l_i\}. L_i^{initial}} \quad (5)$$

with $\gamma \epsilon [0 \dots 1]$ being the relay node time out factor $L_i^{initial}$ being the initial energy assigned and l_i is the fraction of node i's residual energy which is defined as the remaining power of a sensor node whenever topology changes, which can be an indicator of the stability of a path and the survival time of a node. Relay nodes store and forward data packets to sleeping nodes as soon as these wake up. Besides the node's id and a sequence number, beacons contain information concerning the packet reception ratios the node has measured in order to identify asymmetric paths. As every node in a cluster is assigned to a relay node, which in turn maintains connectivity to the sink, local events are thus propagated and processed at any time.

4.2 Selection of LEED Path

Each node periodically broadcasts beacon messages in order to inform neighbors that it is still alive. If a sleeping node detects an event to be forwarded, it wakes up immediately and sends its data to the relay node, which forwards the data on to the sink. Determining which of these relay nodes become active is a great challenge. Figure 2 shows the mechanism behind the selection of LEED data acquisition path. There are three main requirements that should be taken into account to connect different relay nodes in an optimal way, i.e.,

i. *packet reception ratio (prr)* between relay nodes should be maximized,
ii. connection established between active relay nodes should be long-lived, and
iii. number of selected active relay nodes should be minimum to maximize the network's lifetime.

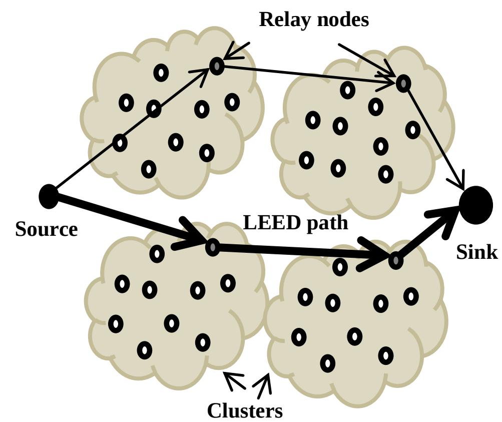

Figure.2. Selection Of LEED Data Acquisition Path

Acquisition path composed of one or more number of relay nodes satisfying the above requirements is selected as the best path. To reflect both the path's packet reception ratio and its lifetime, path costs are introduced. The role of the path cost metric is to combine energy-efficient acquisition with maximum lifetime acquisition in order to find a good trade-off between both performance metrics. To select the best energy efficient acquisition path, each node tries to optimize the equation 6.

$$\boldsymbol{E_i^{eff} \cdot E_i^{el} \rightarrow max.} \quad (6)$$

Here E_i^{el} denotes the expected life time of the entire acquisition path towards the sink, which is influenced by the minimum residual energy along that path.

4.2.1 Packet Reception Ratio

Given a path containing k relay nodes R_1 to R_k, let prr_i, $1 \leq i \leq k$, be the packet reception ratio between R_i and R_j and $prr_{i-1,i}$ and $prr_{i,i-1}$ be the packet reception ratio between two successive relay nodes. We then define the packet reception ratios (prr_i) of a acquisition path 'i' as given in equation 7.

$$\boldsymbol{prr_i = \begin{cases} 1 & i = 1, \\ \prod_{j=2}^{i} prr_{j-1,j} \cdot prr_{j,j-1} & i = 2 \dots k \end{cases}} \quad (7)$$

4.2.2 Lifetime Factor

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Also, the lifetime factor of a virtual path is defined as

$$LT_i = \begin{cases} RE_i & i = 1, \\ min(LT_{i-1}, RE_i) & i = 2 \dots k \end{cases} \quad (8)$$

Where RE_i is the residual energy of the relay node R_i .

4.2.3 Path Cost Metric

The cost of a path is defined using a priority function f that combines the path lifetime and packet reception ratio as

$$PathCost_i = 1 - f(prr_i, LT_i) \quad (9)$$

The priority function f uses two parameters, the packet reception ratio and a lifetime factor. Based on both values, it determines the node's priority expressed as a value within [0…1]. We propose a two-dimensional linear function controlled by two parameters $\alpha$and β which is defined as

$$f(prr, LT) = prr[(1-\alpha)\cdot LT + \alpha] + (1-prr)\cdot\beta\cdot LT. \quad (10)$$

Higher is the node's priority, higher is the probability to visit the next node. Certainly, there are many possible functions that would fulfill this requirement.

4.3Enhanced LEED Technique

Enhanced LEED Technique is based on beacon enabled CSMA/CA based on IEEE 802.15.4together with the relay node selection mechanism and the LEED path selection mechanism. A perfect MAC layer and error-free communication paths are assumed, but no communication is possible once the energy of a sensor node has been depleted. This technique uses a new energy aware sleep scheduling depending on nodes' current residual energy information, traffic and channel conditions to extend the network lifetime. Beacon enabled CSMA/CA section allows efficient radio power control at the physical layer through randomized sleep and wake schedules. A sensor node once initialized can be in one of five states: *sleep, wake-up, listen, data transmit* or *CSMA/CA* state as shown in Figure3.Once a node is powered on, it will be in the *initialization* state with its radio turned on until a timer *Ti* expires. Each node does not stay active all the time, but goes to sleep for a random amount of time, depending on the traffic and channel conditions. Beacons are broadcast by non-sleeping nodes each time an announcement timer T_a expires. Beacons contain the node id, state, residual energy, a timeout value, 1-hop neighborhood information and also information related to path qualities and path loss.

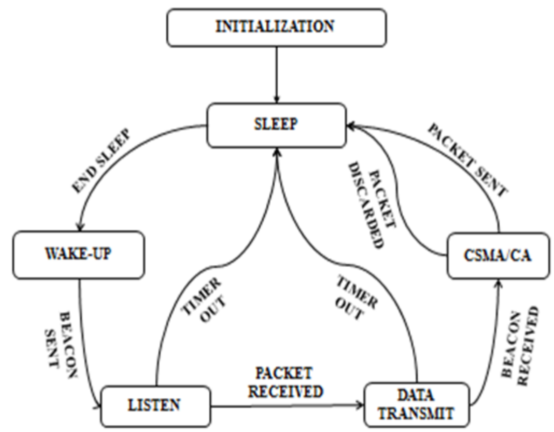

Figure.3. State Machine Diagram

In this state, nodes overhear packet transmissions, build a neighborhood table, and measure path qualities to adjacent nodes. After time *Ti* has elapsed, a node will go to sleep state to save energy.

Sleep State: A node that enters into the *sleep state* turns its radio power off, sets a timer T_s and goes to sleep. As soon as T_s expires, the node moves into *passive state*. As in the initialization state, passive nodes overhear ongoing packet transmissions and keep their neighborhood tables updated. Additionally, in the case of any network disconnections, they will become active to act as relay nodes. Otherwise, they stay passive for a time T_p until they go to sleep to save energy. Meanwhile, when a node detects an event, it wakes up and goes to *listen* state immediately. The node calculates the next sleeping time $T_{s,}$ turns off its radio and starts the sleep timer whose duration is an exponentially distributed random variable with average $1=\mu_k$. μ_k is computed such that the cumulative wake-up rate of the cluster μ_c is ensured. When the timer T_s expires, the node enters into the wake-up state.

Wake-up State: In this state the node turns its beacon channel on, and broadcasts a beacon indicating its location, and residual energy. It then switches to the listen state.

Listen State: The node starts a timer of a fixed duration T_l and listens to the data channel. On receiving the data packet, the timer is discarded and the node goes to the next data transmit State with

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its radio is switched from the data channel to the beacon channel. If the timer T_l expires before any data packet is received, the node goes back to the sleep state again.

Data Transmit State: During this state the node starts a waiting timer of a fixed duration. If the node receives the first beacon coming from a relay node within this waiting period, it goes to the CSMA/CA State. Otherwise, on the expiry of the waiting timer before receiving a beacon, the node goes back to the sleep state.

CSMA/CA State: In this state the node switches on its radio to hear the data channel, and tries to send a data packet to the relay node of the next cluster along the data acquisition path by the CSMA/CA MAC. If the channel is not clear within the maximum number of tries, the node discards the data packet and goes to the sleep state. If the channel is clear within the maximum number of attempts, the node transmits the data packet using an appropriate level of radio power and goes to the sleep state.

5. PERFORMANCE ANALYSIS

Simulations are performed on static networks using a random distribution function over an area of 100×100 m^2 with a node density 20, specifying the average number of neighbors within a node's radio transmission range. Based on the model presented, the packet reception ratio is computed for each pair of nodes. We assume that all nodes know their neighbors and have sufficient information about their packet reception ratios.

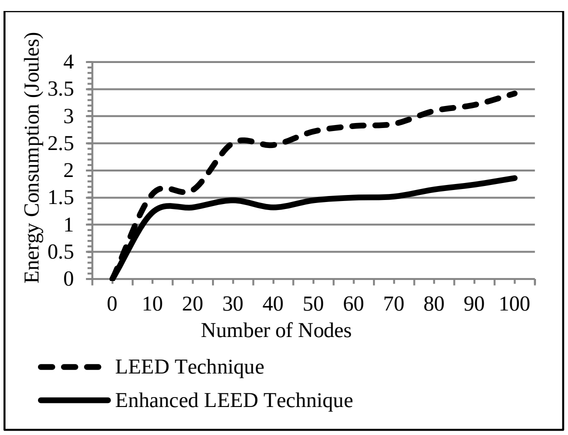

Figure.4. Effect Of Number Of Nodes On Energy Consumption

As β can only be evaluated for different path lifetimes, the node's residual energy fraction will be randomly chosen within (0..1). In addition, path lifetimes of connected relays should not be neglected in order to balance the energy consumption among all nodes. At the end of the network's lifetime, it is beneficial to use nodes with more residual energy because non-active nodes will then sleep longer. Hence, we set both $\alpha$and β to zero. Due to the differences in the number of active nodes, there were significant differences in the overall energy consumption of the network, as shown in Figures 4 and 5.Thus, the proposed can be expected to prolong the network's operational lifetime most if the node density increases.

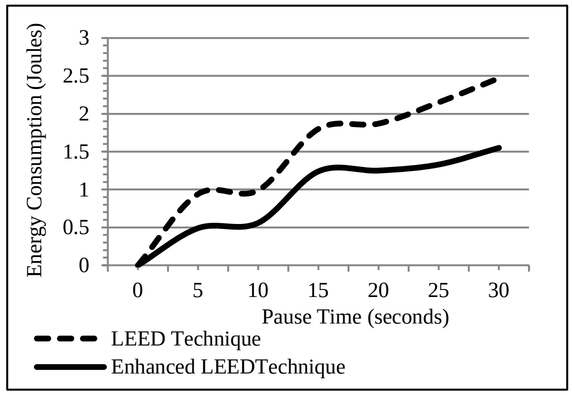

Figure.5. Effect Of Pause Time On Overall Energy Consumption

And the average active time of the nodes has increased as shown in Figure6.This shows that communication overhead is decreased for increase in number of packets.

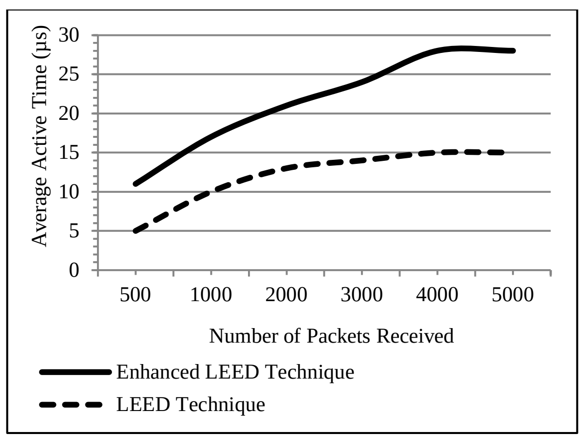

Figure.6. Effect Of Average Active Time On No. Of Packets Received

Figure 7 shows that there is a considerable reduction in the packet delay. In addition, the proposed technique is able to achieve the best energy balance among all nodes. Also it requires only a small fraction of active nodes in order to

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maintain connectivity which shows an increase in the network lifetime.

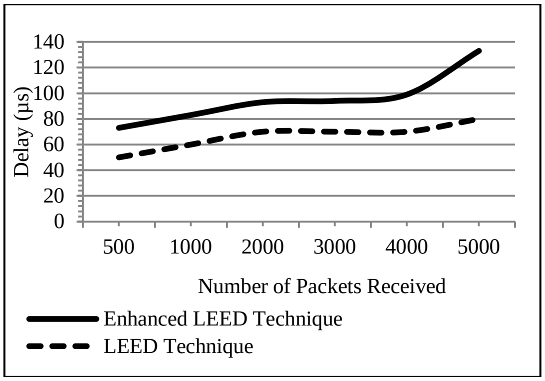

Figure.7. Delay Characteristics

It is also shown in Figure 8 that there is an increase in reliability of the network, which means that the technique is scalable.

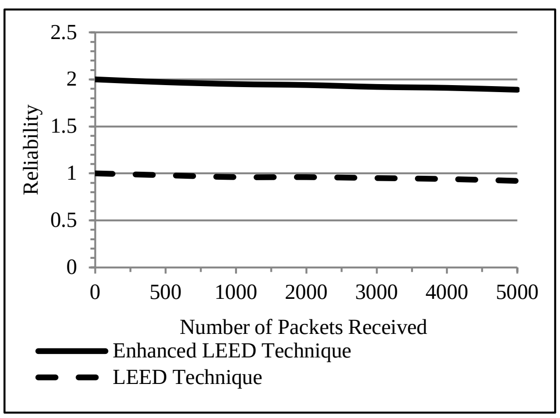

Figure.8. Reliability Response

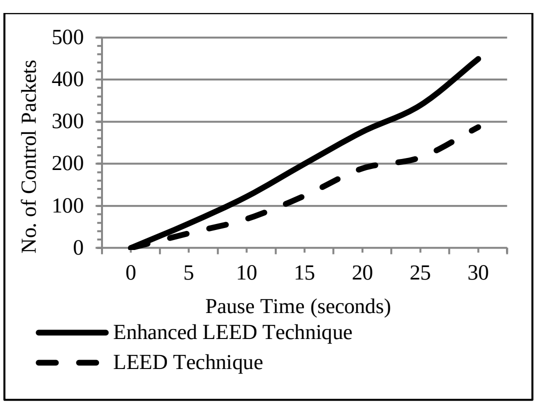

Figure.9. Control Packet Vs Pause Time

Figure 9 and 10 shows the relationship between pause time and number of nodes with respect to number of control packets. Our proposed algorithm uses only a fewer control packets with various pause times.

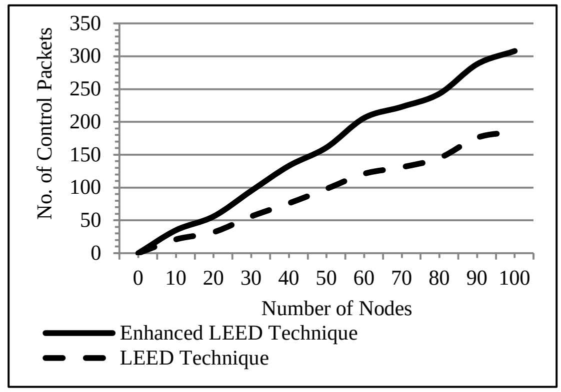

Figure.10. Control Packets Vs Number Of Nodes

Figure 9 and 10 shows the relationship between pause time and number of nodes with respect to number of control packets. Our proposed algorithm uses only a fewer control packets with various pause times.

6. CONCLUSIONS

In this paper we have presented a lifetime energy efficient data acquisition technique for aircraft structural health monitoring system. The proposed LEED technique utilizes the fact that a sender node communicates with only a small portion of the relay nodes taking into accounts of the residual energies and packet delivery ratios of nodes thereby greatly reducing the communication and computation overhead in transmitting the acquired data to the sink node. In Enhanced LEED technique, while active nodes keep their communication radios turned on, redundant nodes switch to a low-power energy saving mode and turn their radios off completely. In doing so, a significant amount of energy can be conserved, extending the system lifetime substantially. Our performance analysis and simulation results show that the network parameters such as reliability, packet loss, energy consumption and control overhead can be tuned to optimize energy preservation and increase the lifetime. Furthermore, it is also able to adapt to different environments and application requirements by accounting for node densities, packet losses, and path lifetimes. In our future work, we plan on exploring the effect of intrusions on the LEED Technique.

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