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Improved Energy Efficient in Wireless Sensor Networks

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Abstract

Wireless Sensor Networks are usually composed of a lot of distributed sensor nodes that organize themselves into a multi-hop wireless network. Several of the main problems in wireless sensor networks are actually energy usage, lack of authentication data integrity as well as instability of road link between sensor nodes which brings down the acceptance of the sensor network. Recently, the present strategies have focused on attaining both security or perhaps energy usage. The study work involves enhanced multipath routing, residual energy based routing, authentication as well as scheduling based approach to create the wireless sensor networks safer with the least energy usage. A brand new Multipath Routing Approach (NMRA) is actually created for raising the energy efficiency in wireless sensor networks. The multipath routing is built to attain higher throughput as well as load balancing. Residual Energy-based Multipath Routing Approach (REMRA) is recommended which attains the integrity as well as minimum residual energy. It utilizes load balancing to stop congestion issues of the network as well as the road stability is actually established based on link price, link bandwidth, and quality of the link.

INTRODUCTION

Wireless sensor technology is playing a vital role in many of the commercialized industrial automation processes and various other real life applications. It is particularly suitable for harsh environment applications where deploying of other network infrastructure is difficult and/or almost impossible such as in battlefield, in hazardous chemical plant, and in high thermal environment. It is not uncommon to see that most of the crucial surveillance and security applications also rely on sensor based applications. Sensors which are tiny in size and cheap in cost have the capabilities to be deployed in a range of applications as explained. Essentially all sensor networks comprise some forms of sensing mechanism to collect data from an intended physical environment either by a time driven approach or by event triggering approach. By these approaches a sensor will convey the sensed data to a destination or sink (multiple destinations/sinks are also possible) via some kinds of routing algorithm such as Minimum Cost Forwarding Algorithm (MCFA), Directed Diffusion Routing Protocol (DDRP), or one of the cluster based routing protocols. Being very small in size, sensor nodes are built with limited computational capacity, small storage memory, and finite battery power capacity.

The structure of a typical WSN node consists of four main components: a sensing element, normally used for sensing a physically measureable parameter; an Analog to-Digital Converter (ADC), used for converting analog signals to some digital formats; a processing unit, providing simple/basic data processing and computation capabilities; and a power unit, responsible for sensor node's operation life span. It is a known fact that WSN is a resource constrained network in which energy efficiency is always the main issue since the operation of WSN depends heavily on the life span of the sensor nodes' battery. The most energy consuming operation in WSN is the data packet routing activity. The characteristics of the WSN are different from the conventional networks. These unique characteristics are often taken into account for addressing the issues and challenges related to network coverage, runtime topologies management, node distribution, node administration, node mobility energy efficiency/consumption, network deployment, application areas/environment, and so forth.

Nodes in a WSN are generally energy, computation, and memory constrained. Consequently, there is a need for research and development into low-computation resource aware algorithms for WSNs, targeting at small, highly resource constrained embedded sensor nodes. Energy consumption is of prime importance in WSNs and thus some algorithms and hardware were designed with energy efficiency or energy awareness as a central focal point of interest. Enhancing energy efficiency of WSN with respect to the communication routing protocol is the primary concern of this research. We propose a new routing protocol entitled "Position Responsive Routing Protocol (PRRP)" and compare its performance with the well-known LEACH and CELRP protocols. The simulation results show a significant improvement over the aforementioned protocols in terms of energy efficiency and the overall performance of the WSN.

Elements of WSN

A typical wireless sensor network can be divided into two elements. They are:

- Sensor Node
- Network Architecture

Sensor Node

A Sensor Node in a WSN consists of four basic components. They are:

- Power Supply
- Sensor
- Processing Unit
- Communication System

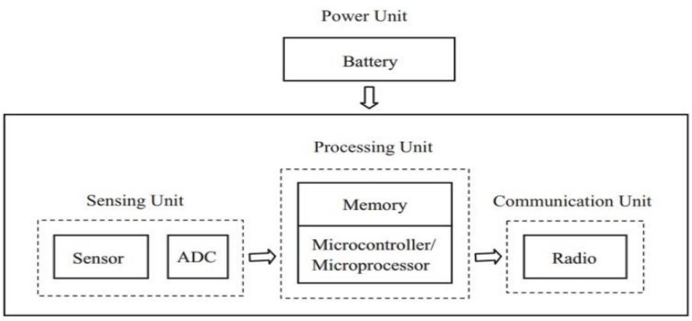

Figure 1: Element structure of WSN

The sensor collects the analog data from the actual physical world as well as an ADC changes this data to digital data. The primary processing unit, that is often a microcontroller or a microprocessor, performs a wise data processing as well as manipulation.

Communication system consists of radio system, often a short range radio, for data transmission as well as reception. As all of the parts are low power products, a tiny battery as CR 2032, is utilized to power the whole system.

Regardless of the title, a Sensor Node consists of not just the sensing part but additionally various other essential features as processing, communication & storage devices. Along with these functions, enhancements and pieces, a Sensor Node accounts for actual physical world data collection, network analysis, data correlation & fusion of data from some other sensor with the very own data of its.

Network Architecture

When a lot of sensor nodes are actually used in a big area to cooperatively monitor an actual atmosphere, the networking of these sensor nodes is also essential. A sensor node in a WSN not just communicates with some other sensor nodes but additionally with a Base Station (BS) by using wireless communication.

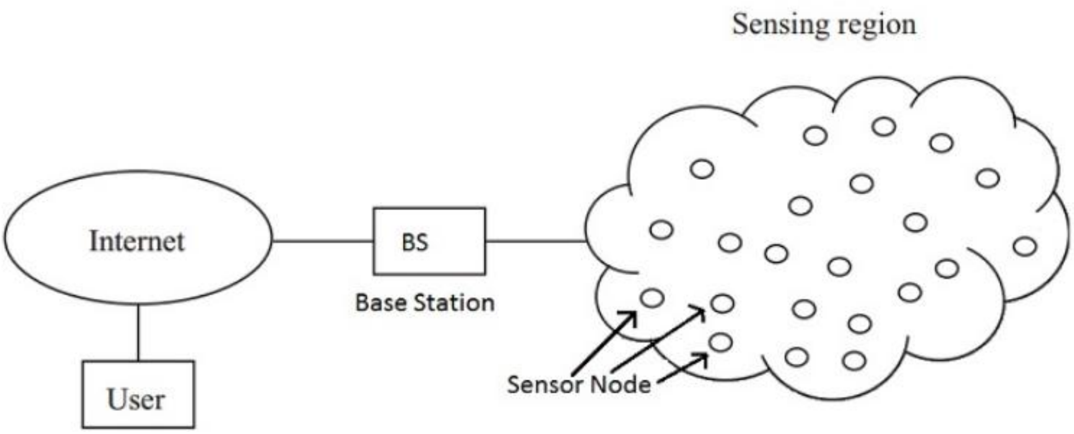

Figure 2: Network Architecture

The base station transmits commands to the sensor nodes as well as the sensor node performs the task by collaborating with one another. Right after collecting the required data, the sensor nodes send the data again to the base station.

A base station additionally functions as a gateway to various other networks with the web. Right after getting the data from the sensor nodes, a base station runs easy data processing and directs the updated info to the user using web.

If perhaps each sensor node is attached to the base station, it's referred to as Single hop network architecture. Even though long distance transmission is actually possible, the energy usage for communication is going to be considerably higher compared to computation as well as data compilation.

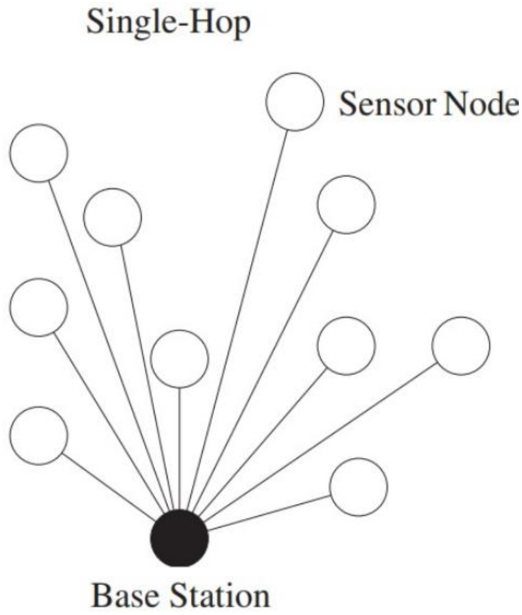

Figure 3: Single hop

Hence, Multi hop network architecture is generally worn. Rather than a single link between the sensor node as well as the base station, the information is transmitted through one or even more intermediate node.

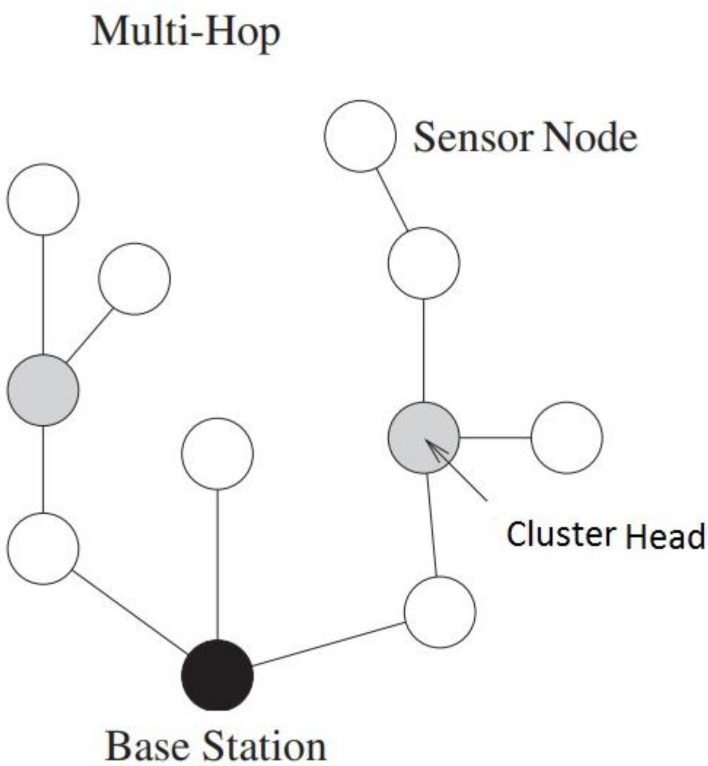

Figure 4: Multi Hop

This may be applied in 2 ways. Flat network architecture as well as Hierarchical network architecture. For flat architecture, the base station transmits commands to each of the sensor nodes but the sensor node with matching query will reply using its peer nodes through a multi hop path.

PROPOSED METHODOLOGY

Link adaptation techniques have received much research effort in the area of wireless data networks. Efforts have been made to develop algorithms that adapt MAC parameters such as frame size and data transmission rate to link quality. By adjusting the system parameters, we improve the link quality. For example, in an adaptive transmission rate system, depending on the channel quality different modulation schemes are used to obtain desired data rates. The primary objective of these ideas is to adapt to a time-varying bursty wireless channel and to meet certain level of quality-of-service (QoS) requirements imposed by certain applications, but it is difficult to track the changes of channel quality during a period of time and use this information to update a set of system parameters in a systematic way. Thus, we propose link adaptation algorithms to adapt the frame size with respect to the changing wireless channel quality.

The proposed algorithms predict an optimal frame size whenever a sensor has data to transmit based on the network parameters such as channel quality, frame length, protocol overheads, and collisions. A prediction scheme is necessary because of the time-varying and bursty nature of the wireless channel and also because the system performance is sensitive to frame size. When large frames are transmitted under a noisy channel, they accumulate bit errors which triggers retransmissions. These retransmissions consume valuable energy and degrade the energy efficiency of the entire system.

An optimal frame size is predicted using a Kalman filter approach. The Kalman filter has been widely used as a predictor and corrector technique in linear discrete-data systems. The filter keeps track of the history of the system being modeled. Based on this history, the filter predicts the future state, and then corrects the predicted value to a more accurate value using the current measurements of the system state. The MAC packages the data in a frame and transmits them over the wireless channel. For WSNs a fixed frame size is used, which if not properly set to an optimal value will result in frame errors and retransmissions. Studies have been carried out to come up with an optimal frame size depending on the application and frequency of data transmissions, but they ignored the most important factor that should influences the frame size, the channel quality. We use filtering techniques to keep track of the channel history and predict the optimal frame size given the present channel quality. The focus of this work is to improve the energy efficiency of WSNs at the MAC layer without affecting the performance. Our approach reduced energy consumption, as well as yielded better throughput.

Extended Kalman filter (EKF) is used for optimal frame size predictions. The advantages of using an optimal frame size are the following.

• When the channel is noisy the frame size is decreased, which reduces the chances of frame errors minimizing the retransmissions.

• When the channel is free of noise the frame size is increased, which improves the throughput of the sensor node. We introduce Kalman Filter and EKF in the next three subsections and discuss the optimal frame size predictor in Section III.

A. *Kalman Filter*

Link adaptation techniques adjust the system parameters in order to improve the overall network performance. If MAC parameters such as frame size and data rate are optimized depending on the link quality it will definitely improve the energy efficiency of WSNs. However, it is not easy to predict optimal values for MAC parameters by tracking the channel characteristics. It becomes necessary to develop a prediction mechanism that can predict optimal values for different system level parameters by keeping track of the network characteristics and the wireless channel quality. The problem of estimating the current state of a discrete-data system based on the past history has been of paramount importance in many fields of science, engineering, and finance. Estimation techniques called filters have been proposed to model the system under observation using a set of mathematical equations. Filtering can be defined as a technique which estimates the state of a system as a set of observations become available. Kalman filter, Weiner filter, and Particle filters are well-known filtering techniques. Due to the complexity and implementation overheads of both Weiner filter and Particle filters, Kalman filter is more widely used. Kalman filter was proposed in the year 1960 as a solution to discrete-data linear filtering problem. Since then it has been the subject of extensive research and application. The filter has the unique capability of estimating the past, present, and future states of a system even without the precise knowledge of the modeled system.

Before getting into the details of Kalman filter let us see how a general state-space model can be modeled using Kalman filter approach. The general state-space model is generally broken down into a state process and state measurement model

$$p(x_{k+1}|x_k) \qquad (1)$$

$$p\left(\frac{z_{k+1}}{x_{k+1}}\right) \qquad (2)$$

Where $x_{k+1} \in R_x^n$ denotes the states of the system at time k+1 and $z_{k+1} \in R_z^n$ the observations. The states follow a first order Markov process and the observations are assumed to be independent given the states. For example, we are interested in nonlinear, non-Gaussian system, the model can be expressed as follows:

$$x_{k+1} = f(x_k, w_{k+1}) \qquad (3)$$

$$y_{k+1} = h(u_{k+1}, x_k, v_{k+1}) \qquad (4)$$

In order to estimate any system one starts by modeling the evolution of the system and also the noise in measurements. The resulting models estimates are called time update and measurement update equations, respectively correct. The time are called process model and measurement model, and the equations that predict and the and measurement update equations are used to estimate the past, present, and future states of the system being modeled. Consider a general prediction problem with noisy data.

$$x_{k+1} = Ax_k + Bu_{k+1} + w_{k+1} \qquad (5)$$

and a measurement $z \in R^m$ given by

$$z_{k+1} = H_{k+1}x_k + v_{k+1}. \quad (6)$$

The Kalman filter estimates a process by using a form feedback control: the filter estimates the process state at any instant and obtains the feedback in the form of measurements. The equations used by Kalman filter are categorized into two types time update equations and measurement update equations. The time update equations are responsible for projecting the current state and error covariance estimates forwards to obtain the a priori estimates for the next time step. The measurement update equations are responsible for the feedback, i.e., incorporating a new measurement into the a priori estimate to obtain an improved a posteriori estimate. The time update equations can also be considered as predictor equations, while the measurement update equations can be considered as corrector equations. Hence, the final Kalman filter algorithm resembles a predictor-corrector algorithm. The equations for the time and measurement updates are given by the following equations:

$$\begin{aligned}
\hat{x}'_{k+1} &= A\hat{x}'_k + Bu_{k+1} \\
P'_{k+1} &= AP_kA^T + Q_{k+1} \qquad (7) \\
K_{k+1} &= P'_{k+1}H^T_{k+1}\left(H_{k+1}P'_{k+1}H^T_{k+1} + R_{k+1}\right)^{-1} \\
\hat{x}_{k+1} &= \hat{x}'_{k+1} + K_{k+1}\left(z_{k+1} - H_{k+1}\hat{x}'_{k+1}\right) \\
P_{k+1} &= (I - K_{k+1}H_{k+1})P'_{k+1} \qquad (8)
\end{aligned}$$

The Kalman filter, even though one of the widely used mechanisms for estimating linear systems has limitations in modeling nonlinear systems. New filtering techniques such as the EKF was proposed to overcome the limitations of Kalman filter. These schemes are efficient estimating schemes for nonlinear systems. In this paper, we propose a novel approach for optimal frame size predictions based on the EKF under the time varying, bursty wireless channel. Earlier effort in this area used a Kalman filter approach for wireless data networks. In this work, we utilize EKF approach which is proven to be more effective estimation techniques than the traditional Kalman filter.

B. Extended Kalman Filter (EKF)

The EKF is a minimum mean-square error (MMSE) estimator which allows incorporating the latest observations into a prior updating routine.The filter is based upon the principle of linearizing the measurements and evolution models. The capability of linearizing the models to incorporate nonlinear and non-Gaussian systems make EKF different from the traditional Kalman filter.

$$\begin{aligned}
x_{k+1} &= f(x_k, u_{k+1}, w_{k+1}) \\
z_{k+1} &= h(x_k, v_{k+1}) \qquad (9)
\end{aligned}$$

$$
\begin{aligned}
\hat{x}'_{k+1} &= f\left(\hat{x}'_k, 0\right) \\
P'_{k+1} &= F_{k+1} P'_k F^T_{k+1} + G_{k+1} Q_{k+1} G^T_{k+1} \qquad (10) \\
K_{k+1} &= P'_{k+1} H^T_{k+1} \left[U_{k+1} R_{k+1} U^T_{k+1} + H_{k+1} P_{k+1} H^T_{k+1}\right]^{-1} \\
\hat{x}_{k+1} &= \hat{x}'_{k+1} + K_{k+1}\left(z_{k+1} - h\left(\hat{x}'_{k+1}, 0\right)\right) \\
P_{k+1} &= P'_{k+1} - K_{k+1} H_{k+1} P'_{k+1} \qquad (11)
\end{aligned}
$$

$$
\begin{aligned}
F_{x+1} &= \frac{\partial f(x_{k+1})}{\partial x_{k+1}} \big| (x_{k+1} = \hat{x}_{k+1}) \\
G_{k+1} &= \frac{\partial f(w_{k+1})}{\partial w_{k+1}} \big| (w_{k+1} = \overline{w}) \qquad (12) \\
H_{k+1} &= \frac{\partial h(x_{k+1})}{\partial x_{k+1}} \big| (x_{k+1} = \hat{x}_{k+1}) \\
U_{k+1} &= \frac{\partial h(v_{k+1})}{\partial v_{k+1}} \big| (v_{k+1} = \overline{v}). \qquad (13)
\end{aligned}
$$

The EKF calculates the posterior mean and covariance accurately to the first-order with all higher order moments truncated.

RESULTS AND DISCUSSION

The Amount of Transmitted Data

In this experiment, we employed the same data aggregation technique and the same number of information bytes. The amount of transmitted data is determined by the number of alive nodes in the entire network, i.e., it is related to the life cycle of nodes. In this section, several tests are performed to evaluate the proposed protocol under different conditions, as displayed in Table 2. Figure 1 depicts the throughput of protocols against the simulation rounds. Since the nodes closer to the BS do not participate in cluster formation and the energy adjustment parameter is used in setting the threshold, it is obvious that the proposed IEE-LEACH protocol is superior to other protocols. Considering that the nodes closer to the BS do not participate in cluster formation, the IEE-LEACH-A improves the throughput of the network; thus, the information transmission performance of the IEE-LEACH-A protocol is better than that of the LEACH protocol. Moreover, the network throughput of the IEE-LEACH-B is larger than that of the IEE-LEACH-A, which illustrates that, in terms of improving the network throughput, the improvement by considering the energy adjustment parameter when setting the threshold is more energy-efficient than when considering the nodes closer to BS which do not participate in cluster formation.

Compared with the LEACH protocol, the IEE-LEACH increases throughput by nearly a factor of 7. Specifically, this method greatly improves the information transmission performance of the network. In addition, compared with the IEE-LEACH-B, the IEE-LEACH has an approximately 30% increase in network throughput. In terms of the amount of transmitted data, the proposed IEE-LEACH protocol sends much more data to the BS in the same round than other protocols.

Table 1. Comparison of the improvement schemes of the proposed routing protocols.

Protocol Name	Improved Details
LEACH	NULL
IEE-LEACH	Threshold setting considering the energy adjustment parameter, and closer nodes to the BS do not participate in cluster formation.
IEE-LEACH-A	Threshold setting in the same way as LEACH, but closer nodes to the BS do not participate in cluster formation.
IEE-LEACH-B	Threshold setting considering the energy adjustment parameter, but the cluster formation is the same as that of LEACH.

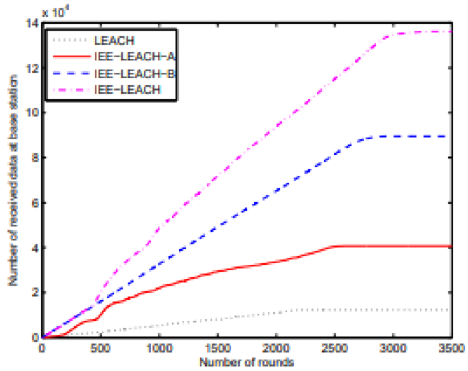

Figure 1. Comparison of data transmission.

Comparison of the Average Energy Mean Square Deviation of Nodes

After 10 rounds, we calculate the average energy mean square deviation of the remaining nodes to analyze the energy distribution in the whole network. We can obtain the optimum number of CHs depending on the analysis of the average energy mean square deviation of nodes to transmit information and increase the performance of the entire network. Figure 2 shows that the slope of the LEACH is larger than the proposed protocol before the degree of energy dispersion increases to the maximum. However, the volatility of the proposed IEE-LEACH is less than 0.1. This finding implies that the performance of the proposed IEE-LEACH protocol is better than other protocols in terms of the energy consumption. This improvement is because the proposed IEE-LEACH protocol extends the lifetime of the network by balancing the node energy

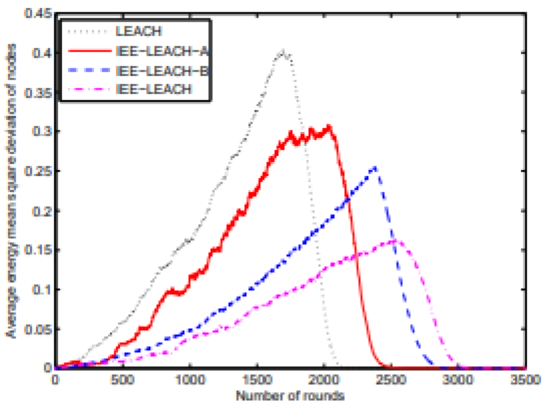

Figure 2. Comparison of average energy mean square deviation of nodes every 10 rounds.

Comparison of the Number of Cluster Heads

To demonstrate that it is necessary to consider the improvement when nodes closer to the BS do not participate in clustering formation, the simulation results of the cluster heads number for the IEE-LEACH-B and IEE-LEACH protocols are provided in this section. Unlike the LEACH and IEE-LEACH-A protocols, IEE-LEACH-B and IEE-LEACH consider the energy when selecting the CH. Thus, IEE-LEACH-B and IEE-LEACH can select the optimal number of cluster heads.

Figure 3 shows the number of cluster heads versus the number of rounds. The maximum number of cluster heads for IEE-LEACH occurs after approximately 700 rounds, and the number of cluster heads is zero after 2600 rounds. However, the maximum number of cluster heads for IEE-LEACH-B occurs in approximately 500 rounds, and the number of cluster heads is zero after 2300 rounds. We find that the number of cluster heads extends up to 2600 rounds for IEE-LEACH as compared to 2300 rounds in IEE-LEACH-B, which is due to the improvement by which the nodes closer to BS do not participate in the cluster formation. The number of cluster heads for IEE-LEACH-A and LEACH disappears after 2050 rounds and 1800 rounds, respectively. It is obvious that IEE-LEACH and IEE-LEACH-B prolong the network lifetime compared with IEE-LEACH-A and LEACH because IEE-LEACH-B and IEE-LEACH consider the energy adjustment parameter when selecting the CH. In addition, the proposed IEE-LEACH protocol generates more CHs than IEE-LEACH-B throughout the 3500 simulation rounds, which can reduce the energy consumption of the WSN nodes. Thus, the proposed scheme is efficient in terms of saving energy and extending the lifetime of the WSN.

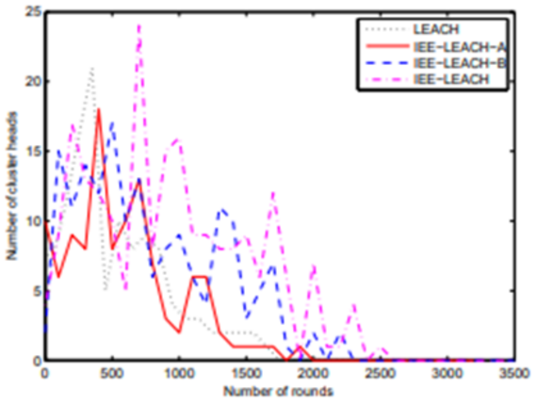

Figure 3. Comparison of the number of cluster heads.

Comparison of Total Energy Consumption of the Network

To prove that the performance of the proposed protocol is better than that of the existing protocols, the total energy consumption of the proposed protocol is compared with that of LEACH, LEACH-M, O-LEACH, LEACH-C, EE-LEACH [36] and SEEN, under the same simulation conditions. Figure 4 shows the total network energy consumption of the protocols versus the number of rounds. As shown in Figure 11, the LEACH-C protocol optimizes the cluster head selection and consumes less network energy than the LEACH protocol in the same round. The LEACH-C prolongs the network lifetime to 2723 rounds as compared to 2267 rounds of the LEACH protocol. In addition, the LEACH-M and O-LEACH prolong the network lifetime to 2775 and 2972 rounds, respectively. Because the residual energy of nodes is taken into account when selecting cluster heads and the multi-hop communication mode is applied in EE-LEACH, the EE-LEACH further prolongs the network lifetime to 3114 rounds. The proposed IEE-LEACH protocol not only considers the residual energy and initial energy of nodes when selecting cluster heads, but also considers the average energy of all nodes and the total energy of network to further optimize cluster head selection. Thus, the total network energy consumption of the IEE-LEACH protocol is less than that of the other protocols in the same round, and the proposed IEE-LEACH protocol prolongs the network lifetime to 3242 rounds. Moreover, because single hop, multi-hop and hybrid communication modes are adopted, and the nodes closer to BS than to the CH do not participate in cluster formation, the proposed IEE-LEACH protocol further extends the lifetime of the network.

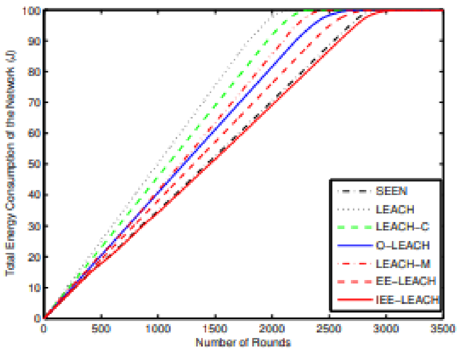

Figure 4. Comparison of total energy consumption of the network.

CONLUSION

Technological advances in low-power digital signal processors, radio frequency (RF) circuits, and micromechanical systems (MEMS) have led to the emergence of wirelessly interconnected sensor nodes. The new technological possibilities emerge when a large number of tiny intelligent wireless sensor nodes are combined. The sensor nodes are typically battery operated and, therefore, energy constrained. Hence, energy conservation is one of the foremost priorities in design of wireless sensor networks (WSNs) protocols. Limited power resources and bursty nature of the wireless channel are the biggest challenges in WSNs. Link adaptation techniques improve the link quality by adjusting medium access control (MAC) parameters such as frame size, data rate, and sleep time, thereby improving energy efficiency. In this paper, our study emphasizes optimizing WSNs by building a reliable and adaptive MAC without compromising fairness and performance. Here, we present link adaptation techniques at MAC layer to enhance energy efficiency of the sensor nodes. The proposed MAC uses a variable frame size instead of a fixed frame size for transmitting data. In order to get accurate estimations, as well as reducing the computation complexity, we utilize the extended Kalman filter to predict the optimal frame size for improving energy efficiency and goodput, while minimizing the sensor memory requirement. Next, we designed and verified different network models to evaluate and analyze the proposed link adaptation schemes. The correctness of the proposed theoretical models have been verified by conducting extensive simulations. We also prototype the proposed scheme with the MAC protocol on Berkeley Motes. Both prototype and simulation results show that the proposed algorithms improve the energy efficiency by up to 15%.

Various scenarios are taken into account for simulation by using various performance evaluation metrics. The number of nodes deployed as well as the region of deployment had been transformed in various fashion. Initially the spot was kept regular as well as the selection of nodes was transformed to assess the performance. An arbitrary changing of spot along with the number of nodes was also carried out to look at the improvements in the overall performance of the suggested solution.

The Modified LEACH algorithm demands re clustering following failure of the secondary cluster head. In comparison, event based clustering algorithm involves clusters only when there's an occasion. Hence event based EERFTDA algorithm was suggested as well as analyzed. The sink node disseminates the event of interest to the network. Thus, the nodes which identify exactly the same occasion at a period instance forms like a bunch and elect a bunch head among them. The cluster head runs fault tolerant data aggregation by eliminating the redundant and outlier data. The relay nodes are actually elected based on residual energy, to conquer the bottleneck issue. The functionality of EERFTDA is actually in contrast to DRINA algorithm for the QoS details for example delay, packet delivery ratio, accuracy and energy usage. The energy usage of EERFTDA is actually twenty % under DRINA plus it maximizes the lifetime of the network.

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