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An Optimized Multi-hop Routing Algorithm Based on Clonal Selection Strategy for Energy-efficient Management in Wireless Sensor Networks

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Abstract: Wireless sensor network consisting of nodes with limited battery power and wireless communications are deployed to collect useful information from the field. Gathering sensed information in an energy efficient manner is critical to operate the sensor network for a long period of time. In this paper, we have developed algorithm to dynamically adapt the network topology within the cluster to reduce the energy consumed for communication, thus extending the life of the network while achieving acceptable performance for data transmission. Experimental results show that based on the proposed algorithm, the estimated lifetime of a battery powered sensor node can be increased significantly. *Copyright © 2013 IFSA.*

Keywords: Wireless sensor networks, Power-efficient gathering in sensor information system, Base station, Cluster, Optimized clonal multi-hop routing algorithm.

1. Introduction

As world business becomes more mobile and computational applications become widely distributed, wireless networks bridge the gap by making distance and movement seamless. Wireless networks require innovative medium access techniques to share the limited broadcast bandwidth in a fair and efficient manner as computing and communications devices continue to proliferate [1, 2]. Typically, a wireless sensor node consists of sensing, computing, communication, actuation, and power components [3]. In wireless sensor network (WSNs), hundreds or thousands of small nodes that communicate through wireless channels for information sharing and cooperative processing are deployed randomly in the field.

A key feature of any wireless sensing node is to minimize the power consumed by the system. In wireless sensor network, sensors nodes are energy constrained and have a finite lifetime [4]. However, more data must be exchanged among nodes, which will result in energy consumption in communication. In order to further increase the applicability in real world applications, minimizing energy consumption and energy-efficient management are the most critical issues [5, 6]. Therefore, more research efforts are needed to investigate the scheme to jointly optimize the energy consumption on computation and communication, among which is mainly a multi-hop routing scheme, which transmits the data detected by a sensor to the destination via multiple node paths. Each node has a routing table that covers its communication range, and adjacent nodes determine which node the data should be forwarded to by considering the amount of remaining energy and the distance to the base station.

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Among the various techniques proposed for improving energy-efficiency, multi-hop routing protocol has been realized as an effective approach [7]. The purpose of this paper is to develop a new multi-hop routing protocol which performs cluster management in an energy-efficient management. We have developed a novel optimized clonal multi-hop routing algorithm (OCMRA) based on clonal selection strategy to dynamically adapt the network topology within the cluster to reduce the energy consumed for communication, thus extending the life of the network while achieving acceptable performance for data transmission. This proposed protocol improves on existing sensor PEGASIS (Power-Efficient Gathering in Sensor Information System) protocols [12] by not only creating additional opportunities to place the sensor platforms into lower power-saving modes, but also minimize power mode transition costs. We compare the proposed routing algorithm OCMRA with different well-known approaches used in the WSNs. Experimental results show that OCMRA protocols extend network lifetimes by reducing the activity of the highest energy-demanding component of the sensor platform.

The rest of this paper is organized as follows. A brief overview of the related works is presented in Section 2. A novel energy-efficient optimal model for wireless sensor network is presented in Section 3. Section 4 presents the OCMRA protocols designed to optimize energy efficiency. Experiments are given in Section 5. Finally, Section 6 summarizes the anticipated results and discusses some future research directions.

2. Related Works

WSNs can be deployed on a global scale for environmental monitoring and habitat study, over a battle field for military surveillance and reconnaissance [8]. With the progression of computer networks extending boundaries and joining distant locations, wireless sensor networks have been attracting more and more attention. There are many studies that focus on optimizing energy consumption in wireless sensor networks.

The Low-energy adaptive clustering hierarchy (LEACH) protocol presented in [9] is an elegant solution where clusters are formed to fuse data before transmitting to the base station (BS). LEACH is a cluster-based protocol that uses a passive mechanism to randomly select a cluster head node, which uses the random rotation method for electing the CH. LEACH assumes that all nodes are homogeneous and are deployed at the same time with equal energy. Its basic idea is energy-saving data aggregation/fusion to reduce the amount of data messages sent back to the base station, localized coordination for cluster setup and operation, and randomized rotation of the local base station or cluster head nodes. The cluster head gathers the cluster membership requests and builds a schedule for each node to send its data up to the cluster head to be aggregated and forwarded to the network sink. The LEACH-C [10] approach consumes less energy than the conventional LEACH algorithm does. However, the problem with the LEACH-C algorithm is about its inability of using a self-organizing approach as against its allowing a base station to intervene in the cluster selection process, which forces all nodes into communicating with a base station in every round and consume a lot of energy compared to other nodes.

Power aware clustered time division multiple access (PACT) is a novel protocol with a clustered multi-hop topology [11]. PACT utilizes the concept of passive clustering where nodes are allowed to take turns as the communication backbone. PACT uses a passive cluster head election scheme. These cluster heads then form the communication system backbone nodes. PACT classifies nodes into four status categories: cluster head, gateway, and ordinary and low energy state node. In order to reduce energy consumption within a cluster, the role between cluster heads and gateway nodes is rotated. Furthermore, the duty cycle of each node is adapted to the traffic conditions in the network where the radios are turned off during inactive periods. PEGASIS [12] is a novel improved protocol where only one node is chosen a head node which sends the fused data to the BS per round. PEGASIS protocol requires formation of chain which is achieved in two steps: first, chain construction and gathering data. Leader of each round is selected randomly. Second, randomly selecting head node also provides benefit as it is more likely for nodes to die at random locations thus providing robust network. When a node dies chain is reconstructed to bypass the dead node [12]. Energy-aware routing has received attention in the recent few years, motivated by advances in wireless mobile devices. Since the overhead of maintaining the routing table for wireless mobile networks is very high, the stability of a route becomes of a major concern [13].

Al-Karaki et al. [14] is to find the tradeoff between computational accuracy and energy requirement of the algorithm on a single node. The purpose is to maximize the computational quality for a given energy constraint. Raghunathan et al. [15] is to break down the algorithm into multiple tasks and distribute the tasks among a group of nodes, so that the energy consumption will be balanced among multiple nodes, and the overall lifetime will be prolonged. Wang and Chandrakasan [16] also investigate the energy efficiency by parallelizing computation among nodes. Shin et al. [17] proposed an optimizing algorithm for cluster formation in wireless sensor networks. However, they used only location data of all the sensor nodes and did not take into account an energy consumption model. Dhar et al. [18] proposed a distributed clustering approach using a gateway node which is intersection between clusters in wireless sensor networks. Gateway nodes are selected through potential CHs. Soro et al. [19] put forward a very efficient self-organizing CH election approach based on node density and residual energy to improve the lifetime of a network.

3. Energy-efficient Optimal Model

As mentioned before, one of the main features of WSNs is a high energy restriction, which is due to the limited battery of the sensor node, and in many cases due to the impossibility of battery replacement [20]. In this paper, many factors that influence the energy consumption in WSNs are analyzed. To estimate the lifetime of sensor node, the energy consumption model should consider the node basic operations: transmission, reception, sensing, and processing.

Define that the size of the monitoring area is A_r, the working sensor set is $N=\{n_1,n_2,...,n_n\}$ and the sensing radius set is $R=\{r_1,r_2,...,r_n\}$, where r_i is the sensing radius of node n_i. The radius of nodes is η in the distribution area of WSN, and the total of clusters is K.

The radius of each cluster R is shown as the following:

$$R=\eta/\sqrt{K} \tag{1}$$

The number of packets that entered into the *i* rings is referred to as

$$\varphi_i=\sum_{k=1}^{i} n_k \times (r_k^2 - N^2 r_k^2) \tag{2}$$

The energy consumption with transmission (E_{elec}) and energy reception (E_{amp}) are treated separately. The energy consumption E_M is given Equation (3):

$$E_M = n \times [E_{elec} \times k + E_{amp} \times k \times (\frac{R}{n})^2] + (n-1) E_{elec} \times k \tag{3}$$

$$R = n \times r \tag{4}$$

In which, k is bits, and n is the average number of nodes in the Link on the cluster radius R.

When $\frac{d(E_M)}{dr}=0$, E_M obtained the optimal value.

$$E_M = E_{amp} \times k \times \frac{R^2}{n} + (2n-1) \times E_{elec} \times k$$

$$= E_{amp} \times k \times R \times r + (\frac{2R-r}{r}) \times E_{elec} \times k$$

$$N = R\sqrt{\frac{E_{amp}}{2E_{elec}}} \tag{5}$$

The energy consumption W was measured in E_{amp} and E_{elec}. To account for energy conservation, delay optimization and other performance metrics, we define the following the total energy consumption cost function.

$$E_{total} = \frac{\lambda}{\eta^2} \times [\sum_{i=1}^{N} \eta^2 \times \alpha_i \times (2E_{elec} + E_{amp} r^n) + m \times p \times (R^2 - n^2 r^2)]$$

$$\alpha_i = \begin{cases} 1 & \text{provide forwarding services} \\ 0 & \text{otherwise} \end{cases} \tag{6}$$

4. Optimized Clonal Multi-hop Routing Algorithm

The main idea in OCMRA is for each node to receive from and transmit to close neighbors and take turns being the leader for transmission to the BS. This algorithm will distribute the energy load evenly among the sensor nodes in the network. We could have constructed a loop to ensure that all nodes have close neighbors is difficult as this problem is similar to the traveling salesman problem [21]. So, we adopt the clonal selection algorithm (CSA) to constructing the chain works well and this is done before the first round of communication. To construct the chain, we start with the furthest node from the BS. We begin with this node in order to make sure that nodes farther from the BS have close neighbors.

The structure of our algorithm is described as follows:

Step 1 (Initialization): Random deployment of the *N* homogeneous sensors in a given space and with the same energy level. Each chromosome (antibody) uses binary encoding and has size *L* equal to the number of sensor nodes in the network.

One problem solution is encoded to one sequence code, namely individual [22]. Encoding is a key step to use evolutionary algorithm. The aim is to represent a solution by a sequence code, which is an individual in population-based algorithms [23]. Each position of the chromosome represents a gene: if a chromosome position is set to 1, this implies that the node corresponding to this position is turned on in this chromosome. The population size is N, and the chromosome length is L.

Step 2 (Clone): Clone the chromosomes with the best values of the fitness function, and the clonal size is proportional to their affinity.

Clone is the process of antibody proliferation. A new population is generated by selecting the best antibodies from the population.

Step 3 (Crossover): Perform the crossover operator for the population (Fig. 1).

Step 4 (Mutation): We generate randomly an integer i for each position (j) and then swap the elements at positions i and j in the chromosome (Fig. 2).

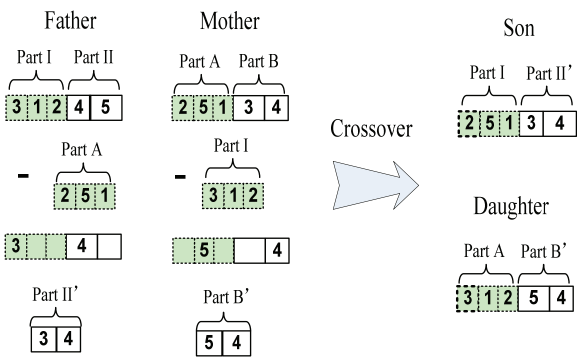

Fig. 1. Crossover operator.

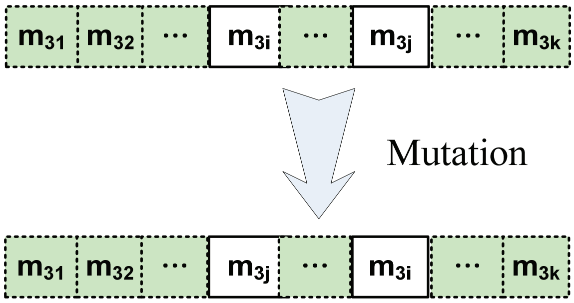

Fig. 2. Mutation operator.

Mutation operators change the value of a gene to keep the solution's diversity. Mutation prevents the search process from falling into local maxima [24]. By the above way an initial population including a number of individuals (antibodies) can be generated. Then those nodes will be organized to form a chain, which can either be accomplished by the sensor nodes themselves using a CSA algorithm starting from some node. Alternatively, the BS can compute this chain and broadcast it to all the sensor nodes.

Step 5 (Data transmission): Data transmission from the simple sensors to the CHs: consumed energy is calculated using the Eqs. (3) and (6). When the CH is chosen according to the first criterion (maximum energy), the same CHs are reelected after each transmission.

Each node will fuse its neighbor's data with its own to generate a single packet of the same length and then transmit that to its other neighbor [25]. For gathering data in each round, each node receives data from one neighbor, fuses with its own data, and transmits to the other neighbor on the chain.

Step 6 (End): Return to the step (2) until the death of all the sensors in the WSNs.

5. Experimental Validation

In this section, the effectiveness of the routing approach is validated through simulation. In the experiments the cluster consists of 100 randomly placed nodes in a 500×500 meter square area. We assume that all nodes have location information about all other nodes. Packet lengths are 10 Kbit for data packets and 2 Kbit for routing and refresh packets. Each node is assumed to have an initial energy of 0.5-2 joules and a buffer for up to 15 packets [26]. In these experiments, the proposed approach was compared with other routing approaches. The performance comparisons between OCMRA, PEGASIA and PACT are shown in Figs. 3-10.

Table 1 lists the results of the experiments involving varying the amount of initial energy to measure a sensor network's lifetime. The lifetime was measured by the round index at which the first or the last node died. When initial energy is equal 0.5 J/node, OCMRA's lifetime measured when the first node died was about 1.27 times longer than PEGASIS 's, and 1.37 times that of PACT's. When initial energy is equal 1 J/node, OCMRA's lifetime measured when the first node died was about 1.3 times longer than PEGASIS's, and 1.36 times that of PACT's. When initial energy is equal 1.5 J/node, OCMRA's lifetime measured when the first node died was about 1.36 times longer than PEGASIS 's, and 1.45 times that of PACT's. When initial energy is equal 2 J/node, OCMRA's lifetime measured when the first node died was about 1.09 times longer than PEGASIS's, and 1.28 times that of PACT's. It was observed that the performance of lifetime was highly dependent on the initial energy. Measurements based on when the final node died showed similar results. OCMRA showed the best performance among the three algorithms in every case.

Table 1. Results of a sensor network's lifetime comparison of OCMRA with other two algorithms.

Energy (J/node)	Algorithm	Round number at which the first node dies	Round number at which the last node dies
0.5	OCMRA	245	489
	PEGASIS	173	385
	PACT	168	356
1	OCMRA	475	889
	PEGASIS	356	685
	PACT	368	652
1.5	OCMRA	895	1428
	PEGASIS	668	1052
	PACT	525	985
2	OCMRA	1395	2428
	PEGASIS	1225	2235
	PACT	1084	1896

Fig. 3 shows the number of nodes alive of the three protocols. OCMRA's lifetime measured when the first node died was about 1.22 times longer than PEGASIS's, and 1.34 times better than PACT's. In the first 1250 rounds, the entire nodes were alive for OCMRA and PEGASIS protocols, but only three quarters of nodes were alive for the PACT protocol. In the 1700th round, most of the nodes died in the PACT algorithm and half of nodes were alive for PEGASIS.

Most of the nodes in the OCMRA algorithm prolonged the lifetime of networks in the same condition. Based on the proposed algorithm, the estimated lifetime of a battery powered sensor node can be significantly increased.

The simulation results for the network lifetime performance metric while varying the unicast packet rate directly follow from the comparison with the sleep percentage metric. Fig. 4 is the WSN energy/Bit comparison of OCMRA with other two algorithms. The PEGASIS and PACT protocols are unable to leverage increased network energy capacity obtained with the increasing cluster size to gain network lifetime. The PEGASIS and PACT protocols do not obtain any energy savings with the increase in nodes because all nodes incur the same message overhearing energy costs. For all algorithms the lifetime of a sensor network gradually increased as node density increased. However, the inclination of OCMRA was sharper than that of PEGASIS and PACT protocols.

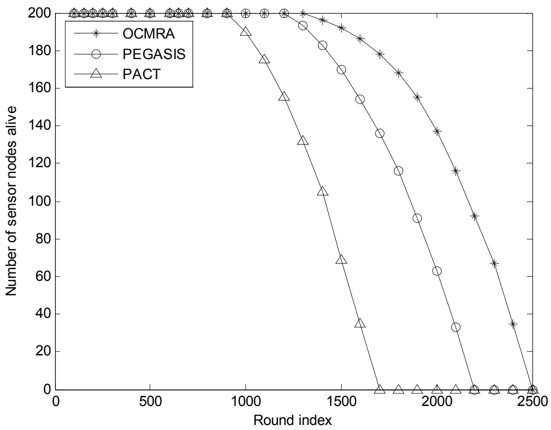

Fig. 3. Number of nodes alive comparison of OCMRA with other two algorithms.

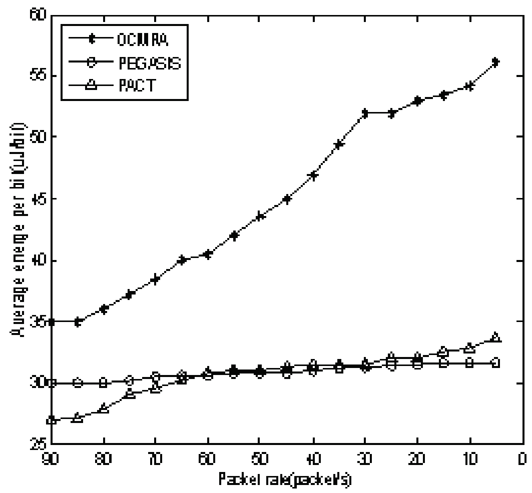

Fig. 4. WSNs energy/Bit comparison of OCMRA with other two algorithms.

A typical application in a sensor web is gathering of sensed data at a distant BS [27]. Each sensor node has power control and the ability to transmit data to any other sensor node or directly to the BS. In each round of this data-gathering application, all data from all nodes need to be collected and transmitted to the BS. Fig. 5 is the lifetime comparison of OCMRA with other two algorithms. Fig. 6 is the number of data received at the BS. Fig. 7 is the running time comparison of OCMRA with other two algorithms. Fig. 8 is number of covers comparison of OCMRA with other two algorithms. Fig. 9 is the best value of energy comparison of OCMRA with other two algorithms. Fig. 10 is the running time comparison of OCMRA with other two algorithms when different generations. Measurements based on when the last node died showed similar results. OCMRA showed the best performance among the three protocols in every case. Because any node within the vicinity of the source node which receives correctly the original data packet with the sending timer information automatically becomes a cooperative transmitting node. This experiment also showed that performance of OCMRA was not affected by the size of the network.

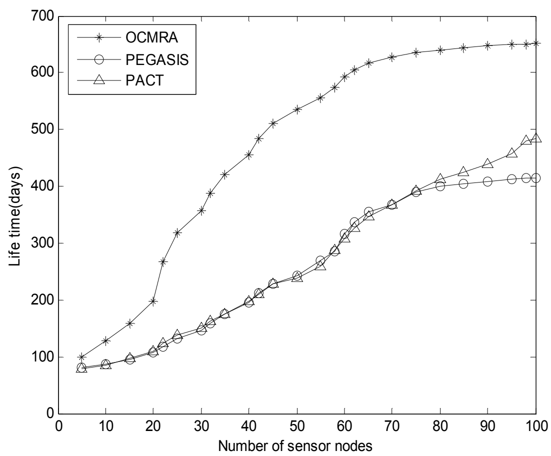

Fig. 5. Lifetime comparison of OCMRA with other two algorithms.

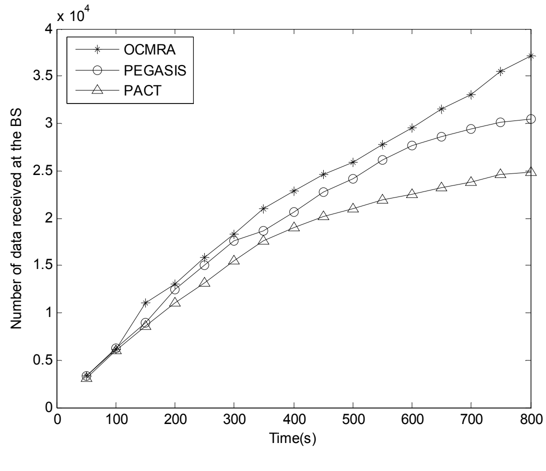

Fig. 6. Number of data received at the BS comparison of OCMRA with other two algorithms.

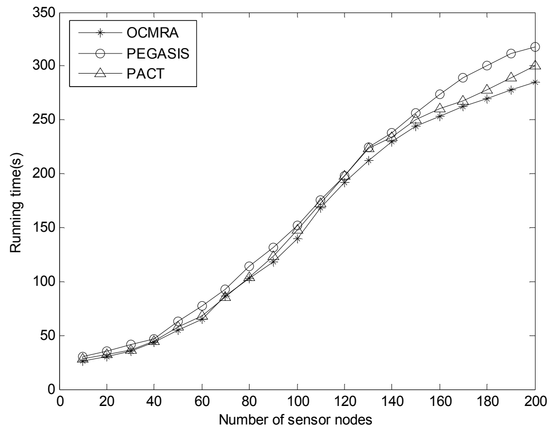

Fig. 7. Running time comparison of OCMRA with other two algorithms.

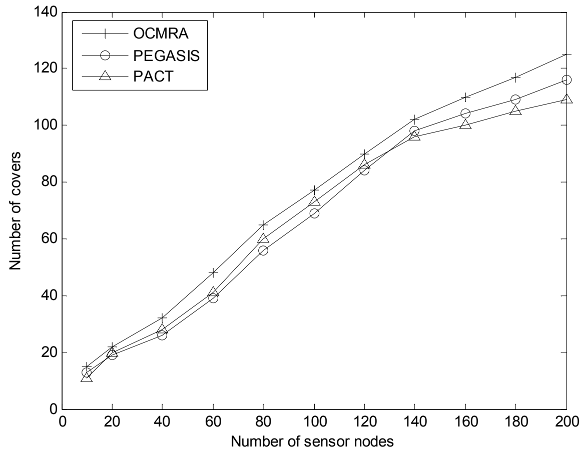

Fig. 8. Number of covers comparison of OCMRA with other two algorithms.

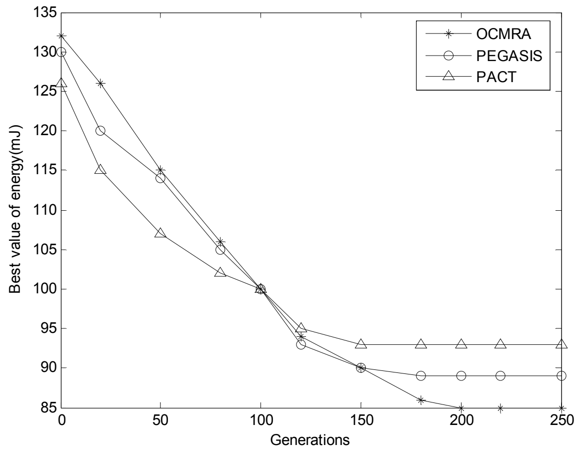

Fig. 9. Best value of energy comparison of OCMRA with other two algorithms.

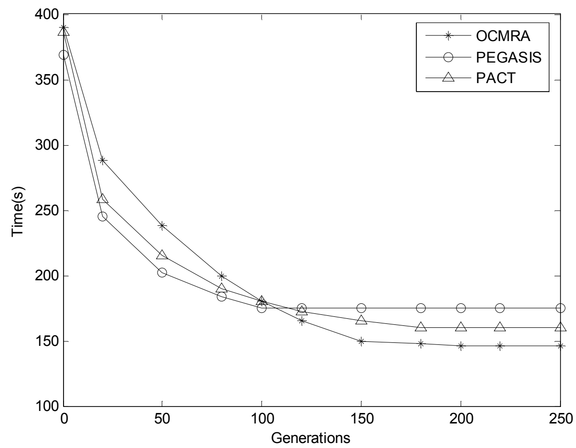

Fig. 10. Running time comparison of OCMRA with other two algorithms when different generations.

6. Conclusions and Future Work

Wireless sensor networks may consist of several to thousands of homogeneous or heterogeneous sensors that share the need to organize for data collaboration or network data collection sink routing. As technology makes the hardware smaller, WSNs research continues developing innovative, energy-saving techniques at all network protocol layers in order to engineer sensor platforms which can operate unattended for months or even years. In order to further increase the applicability in real world applications, minimizing energy consumption is one of the most critical issues in WSN, this paper presents an overview of research trends and challenges in the design and implementation of WSNs. Our focus is to improve the energy-efficiency of the systems by assuming that all such techniques are available.

WSNs are becoming an increasingly vital technology that will be used in a variety of applications such as medical, military applications, environmental monitoring, chemical/biological detection, precision agriculture, etc. The era of WSNs is highly anticipated in the near future. Future work is being performed on systems that exploit piezoelectric materials to harvest ambient strain energy for energy storage in capacitors. As new standards-based networks are released and low power systems are continually developed, we will start to see the widespread deployment of wireless sensor networks.

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