Computers and Electrical Engineering 000 (2016) 1–19

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

A dynamic Energy-aware fault tolerant routing protocol for wireless sensor networks☆

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ARTICLE INFO

Article history:
Received 25 February 2016
Revised 25 October 2016
Accepted 26 October 2016
Available online xxx

Keywords:
Network lifetime
Energy-awareness
Clusters formation
Fault tolerant
Energy de-efficiency
Wireless sensor networks

ABSTRACT

In recent decades, cluster-based schemes have emerged as viable solutions for energy conservation problem in wireless sensor networks (WSN). However, most of the existing solutions incur imbalanced energy consumption and high network overheads. In addition, existing cluster-based solutions do not optimize route discovery based on the restricted resources of sensor nodes. Moreover, most of the cluster-based solutions perform periodical re-clustering for load balancing, which results in shortening network lifetime. This research paper presents a Dynamic Energy-aware Fault Tolerant Routing (DEFTR) protocol that exploits uniform-sized network partitioning based on network size and utilizes a multi-facet routing mechanism, which takes into consideration the residual energy, and position and link quality of neighbors. Furthermore, DEFTR not only offers reliable and energy efficient data routing but also supports fault tolerance. Simulation results demonstrate that DEFTR improved the network lifetime by 20.9% and throughput by 35%, also it reduced the delay by 29% and transmission cost by 46% in comparison to the existing work.

1. Introduction

WSN comprises of an enormous number of tiny devices called sensor nodes that are spread in a physical environment for collecting required information. With the integration of information sensing, computation, and wireless communication, the sensor nodes can sense physical status, process the sensed information, and report them to the sink node or Base Station (BS) [1,2]. Due to limited resources, sensor nodes consume their energy rapidly and it is impractical or difficult to refresh their batteries. Consequently, improving energy conservation is the foremost design challenge for any sensor based network. In recent decades, the concept of hierarchical based solutions [3,4] has been widely used in the field of wireless communication for energy efficiency and routing performance. Basically, the concept behind hierarchical schemes is to group the sensor nodes in non-overlapping regions called clusters and each cluster has one leader node called Cluster Head(CH) [5]. Although different clustering schemes have been proposed, most of them generate sub-optimal clusters leading to unnecessary energy consumption and imbalanced load distribution [6,7]. In addition, most of the existing schemes perform non-optimized route discoveries, which disturb the data forwarding operations and may result in frequent route breakages

☆ This paper is for CAEE special section SI-wls7. Reviews processed and recommended for publication to the Editor-in-Chief by Guest Editor Dr. R. Varatharajan.

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http://dx.doi.org/10.1016/j.compeleceng.2016.10.017
0045-7906/

with re-transmissions. Moreover, the majority of the recent schemes support fault tolerance by performing re-clustering of the entire network field at periodic intervals, which acquires additional communication overheads and energy resources. In this paper, a dynamic energy-aware fault tolerant routing protocol is designed to address the limitations of existing energy-based routing schemes for WSNs. Unlike the majority of existing solutions, our proposed protocol generates uniformly sized clusters based on network size. By exploiting composite metrics within the bounded regions, appropriate nodes are chosen to be CHs thereby improving network lifetime. Based on a multi-facet strategy, the optimized routing paths are constructed at multi-level and a fault tolerant mechanism is developed, which result in reducing route recovery time and balancing energy consumption. The simulations for evaluating DEFTR protocol are done in Network simulator (NS-2) [8,9]. The simulation results reveal outstanding performance in terms of different evaluation metrics as compared to other state-of-the-art protocols. The remainder of this paper is structured as follows. Section 2 presents the related work. Section 3 highlights the findings of related work and contributions of proposed protocol. Section 4 illustrates the preliminaries and energy model. Section 5 presents the details of our proposed DEFTR protocol. The evaluation and validation of proposed DEFTR protocol are discussed in Section 6. Finally, Section 7 concludes the paper with some future research directions.

2. Related work

Sensor nodes of WSNs are characterized by constrained resources.During data gathering and forwarding process, the sensors limited energy has impacts on network lifetime. LEACH [10] is the first dynamic cluster-based routing approach for WSN, which uses a stochastic process. A random number is generated by each node n then it is elected as a CH if the random number is smaller than a threshold $T_n$as shown in Eq. 1, where P is the required fraction of clusters, r is the current round, G is the set of nodes that have been not selected as CH in last 1/p rounds.

$$T_n = \begin{cases} \frac{P}{1-P*\left(r \ mod \ \frac{1}{P}\right)} & if \ n \in G \\ 0 & otherwise \end{cases} \quad (1)$$

However, random selection of CHs leads to short network lifetime and sub-optimal clusters formation. To improve the performance of LEACH, different energy efficient schemes are proposed [11,12], where CHs are selected by BS based on the provided information by nodes. Nevertheless, such solutions have a scalability problem and incur further network overheads. The Multi-hop Routing with Low Energy Adaptive Clustering Hierarchy (MR-LEACH) [13] is presented for balancing the energy load and improving data delivery performance. MR-LEACH approach divides the sensors field into numerous layers and each layer is considered as a particular cluster. MR-LEACH initiated the concept of equal clustering, where any node in a particular layer can reach BS in identical hop count. However, it lacks of optimizing the end-to-end routing paths by keeping in view the scarce resources of nodes, thereby results in lower network throughput.

Chain-Chain Based Routing Protocol (CCBRP) [14] provides a hybrid scheme that incorporates the characteristics of LEACH and PEGASIS. CCBRP allocates the nodes into different chains in two different phases, which incurs high energy consumption in the large scaled region. In addition, the selection of intermediate nodes during chain construction is non-optimized which significantly decreases network lifetime and requires more re-transmissions. Different unequal cluster-based schemes [8,15,16] are developed to address the issue of a hot spot, which occurs in neighbor clusters closest to BS, as these clusters need to handle additional traffic load coming from the faraway clusters. In such schemes, unequal clusters are generated where smaller size clusters are closer to BS. Nevertheless, utilizing different size of clusters leads to uneven distribution of traffic load among CHs and has scalability problems, as the overall operation is performed in a centralized manner.Recently, fuzzy based clustering protocols are presented [17,18] for the formation of clusters and electing of CHs over the network field. As compared to probabilistic approaches, fuzzy based schemes are more energy efficient and reliable. However, such schemes have slow convergence time and are not feasible for large scale networks.

In Tree Based Clustering (TBC) [19], a logical tree is constructed inside each cluster where the associated CH is elected as the root node. TBC utilizes distance factor for the determining of nodes level inside each constructed tree. However, TBC lacks the ability to adapt to changing network conditions such as node's residual energy and quality of wireless links, which results in frequently route breakages and compromised network lifetime. An energy efficient fault tolerant clustering routing protocol [20] was proposed, which aims to execute run time recovery when CHs are unexpectedly fail. In this protocol, a Distributed Fault tolerant Clustering Routing (DFCR) algorithm is introduced to perform clustering and data routing phases. To handle the failure of CHs during data routing, DFCR searches an additional suitable CH with minimum hop counts. In addition, to deal with fault tolerance, this approach only considered permanent failures of CHs and temporary failure of sensors is overlooked.

3. Contributions of proposed DEFTR protocol

Based on the related work, it is revealed that cluster-based schemes have a great impact on saving energy and have higher network scalability. However, most of the existing clustering schemes are based on probabilistic or random selection methods that construct sub-optimal clusters. Moreover, the CH election mechanism incurs over the entire network field, which leads to degrading network lifetime and significantly increasing network overheads. Furthermore, most of existing cluster-based routing schemes do not optimize route discovery according to the restricted resources of sensor nodes and the dynamic nature of wireless communication links. In addition, due to limited and low-powered constraints of sensor

Please cite this article as: K. Haseeb et al., A dynamic Energy-aware fault tolerant routing protocol for wireless sensor networks☆, Computers and Electrical Engineering (2016), http://dx.doi.org/10.1016/j.compeleceng.2016.10.017