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Reliable location aware and Cluster-Tap Root based data collection protocol for large scale wireless sensor networks

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ABSTRACT

Designing a stable and energy efficient routing protocol for mobility based Wireless Sensor Networks (WSNs) is a great challenge, because frequent link changes or failures make the network topology unstable. In this paper, we propose a Cluster-Tap Root based Data Collection (CTRDC) protocol which produces a highly stable and reliable routing path for data transmission. In cluster formation phase, the Cluster Heads (CHs) are elected in a distributed manner in two levels: (i) Tentative CH (TCH) candidate selection based on node's residual energy (ii) a fuzzy logic based final CHs selection which is obtained by using node speed, number of neighbor nodes, and average connection time. This distributed CH selection ensures the two hop distance between the CHs. Besides, we introduce the tap root principle for constructing a route between the CHs and Base Station (BS), in which it uses a minimal number of sensor nodes (i.e., $O(n^2)$), whereas $O(2^n)$ nodes are involved in the tree topology and n denotes the depth of the tap root. Thus, it lessens the path setup delay, interference, collision, and also avoids the redundant searching of nodes in the same place. In addition, an effective localization method is proposed, in which all the sensor nodes are equipped with Digital Magnetic Compass (DMC). The DMC is used to measure the moving direction (azimuth) of the mobile node, thus the sensor node finds its location in the sensing area with the help of two anchor nodes. From the simulation results, it is showed that the proposed CTRDC protocol provides better performance in terms of Packet Delivery Ratio (PDR), throughput, Average Energy Consumption (AEC), Average End-to-End Delay (AEED) and control overhead as compared to MBC, OZEEP, and ES-WCA. Additionally, CTRDC adapts to mobility scenario, where the reliability, fault tolerance, scalability, and stability of the networks are enhanced, even if it gets frequent link failures.

1. Introduction

The sensor nodes are deployed in the hazardous environment for gathering event (Aslan et al., 2012), where the recharging or replacing of the battery is not possible and human monitoring system is also highly dangerous. The mobility based WSNs is broadly classified into active mobility and passive mobility. In passive mobility, the researchers attached the sensor nodes to the animals, whereas in active mobility, the sensor nodes are equipped with robot or vehicle. Most of the protocols have developed for static WSNs which are unable to support mobility based sensor network applications. As well, numerous protocols have assumed that all the sensor nodes are location-aware, and also assumed to be stationary after deployment of the sensor nodes in the sensing area. The Global Positioning System (GPS) and its assist Anchor Node (AN) are utilized by the researchers for localizing the sensor node. However, the GPS equipped devices consume more power which leads to a premature death of sensor nodes, and also gives a poor performance in indoor applications.

Most of the multipath routing protocols have not ensured the Quality of Service (QoS) in both static and mobility based WSNs. In addition, the throughput of the network decreases as the mobility of sensor node is increased (Pantazis et al., 2013). However, a high throughput of the network can be achieved by (i) increasing the bandwidth (ii) enhancing the network stability (iii) applying suitable data collection mechanism and scheduling technique. In WSNs, the multi-hop routing path can be constructed in the sensing area by either as source initiated method (on demand protocol), or receiver initiated method (hierarchical tree topology routing) (Velmani and Kaarthick, 2015). Comparatively, the receiver initiated routing is much better than source initiated routing in terms of the communication overhead, delay, and battery energy. However, the receiver initiated protocol has some constraints when it is directly applied to the mobile WSNs. This is because of the frequent radio link failures in the mobile environment leading to instability in the routing path. The mobile wireless sensor networks often create the hole problem or void area (lacking in network coverage) due to the poor radio connectivity between the sensor nodes.

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It is a crucial issue to maintain a stable network topology, because it creates a high end-to-end delay in data routing and reduces the throughput (Yan et al., 2016). Hence, the connectivity is assumed to be an important consideration in the clustering and routing design (Al-Jemeli and Hussin, 2015).

The existing WSNs protocol does not attain the following objective at the same time.

- Ensuring a reliability of mobile WSNs in an energy efficient manner.
- Ensuring a stable network topology with a minimal end-to-end delay in the packet delivery.
- Maintaining a stable connection between the sensor nodes by selecting a suitable routing algorithm which also adapts to the mobile environment.
- Minimizing the control overhead.

The network topology becomes highly dynamic in nature when the mobility is added to the sensor nodes, and it is a difficult task in finding out the stable route. Furthermore, it is not feasible to deal with more control overheads in the routing table, due to the constraints on node's on-board memory. Therefore, various types of reactive and proactive routing protocols of the mobile ad-hoc networks are not directly applied to the mobile WSNs. The reactive protocol establishes the routing path when the source node wants to send data to the destination. Thus, the existing reactive protocol is not suitable for node mobility circumstances, since it creates path setup delay and link stability problem (Rajeswari et al., 2012). In the proactive protocol, each sensor node updates their routing information at regular intervals. In mobility based WSNs, the radio links of a sensor node may often join or leave out, thereby exchanging more control packets and depletes the battery energy very quickly. In mobility based WSNs, the network stability is achieved in the following manner.

- Reducing the number of nodes involved in the data routing path.
- Reducing the end-to-end delay in packet delivery.
- Utilizing the given bandwidth efficiently instead of increasing the bandwidth size.
- Applying a reliable method for measuring the connection time between the sensor nodes.

The existing protocols (Velmani and Kaarthick, 2015; Lee and Kao, 2015; Heinzelman et al., 2002) used a distributed clustering algorithm, in which only a predefined ratio of sensor nodes were utilized to act as a CHs in each round. Thus, these protocols do not ensure the uniform distribution of the CHs to the entire network area. And thus, some sensor nodes leave out from the CHs (it means that the sensor node does not come under any CH coverage region), called an isolated node. Besides, multiple CHs exist in the same transmission region, thereby causing more link failure, more packet collision, high packet retransmission, more redundant control and data packets, hidden node problem, exposed node problem, and isolated node problem. All these result in reduced network stability and throughput.

To overcome the aforementioned problems, the design parameter selections should be taken care in both Cluster Formation (CF) and routing construction. In the proposed model, the sensor node is equipped with a magnetic compass which is used to find the moving direction of the sensor node and to achieve the node localization by finding the connection time and distance between the sensor nodes. In CTRDC, the cluster head selection is done in two phases, including tentative cluster head, and broadcasting the final CH based on the delay time. This method reduces the chance of multiple CHs to come in the same cluster head coverage region and also ensures the availability of CHs for all the sensor nodes in the targeted network area. Thus, it completely avoids the isolated node problem. In addition to this, the multi-hop data transmission is applied within the cluster, and also allow the sensor nodes to adjust their transmission power based on the distance between them, thereby reducing the interference, and data retransmission. Besides, a tap root based routing technique is introduced for constructing a multi-hop hierarchical Tap Root Topology (TRT). It is more flexible and efficient in dealing with the dynamic WSNs and also provides concurrent data communication between the CH and Cluster Member (CM) without any interference. Likewise, it ensures a collision-free data communication between the CH and BS. The proposed TRT design takes into the consideration of the residual energy, mobility, and connection time in order to achieve high network stability and energy efficiency. The aim of the proposed routing algorithm is to ensure that the data packets are being forwarded through an appropriate route, in spite of the presence of frequent link failures.

The remainder of this paper is organized as follows: section 2 illustrates a literature survey on various cluster based protocols, section 3 presents the CTRDC protocol design, section 4 reveals the localization technique, section 5 depicts mathematical analysis of CTRDC protocol, section 6 shows the simulation results and performance comparisons. Finally, the conclusion is presented.

2. Related work

2.1. Clustering mechanism

Most significant role of the clustering mechanism is to enhance the energy efficiency and extend the lifespan of the networks. Clustering is a hierarchical mechanism which divides the targeted sensing area into small group or cluster. Each cluster has a CH which is responsible for the coordination of activities inside the cluster, collecting the data from CM, performing an in-network processing, and transmitting the collected data to the BS. However, the performance of clustering mechanism in WSNs mainly depends on how the packets are routed to BS. Heinzelman et al. (2002) proposed Low Energy Adaptive Clustering Hierarchy (LEACH) protocol, in which each sensor node computes its threshold value Δ(n) by using equation (1) and also randomly generates a number between 0 and 1.

$$\Delta(n) = \begin{cases} \frac{\mu}{1-\mu\left[r \bmod \frac{1}{\mu}\right]} & \forall N_s \in G \\ 0 & otherwise \end{cases} \quad (1)$$

where, μ is the rate of the expected number of CH to the total number of deployed sensor nodes, r is the index number of current round, G is the set of sensor nodes which are ready to act as a CH, N_S is the number of deployed sensor nodes in the sensing area. If a randomly generated number is less than that of the computed threshold value, then the sensor node declares itself as a CH and broadcasts the CH awareness message to neighbor nodes. In LEACH, the CH gathers the sensed data from cluster members and then transmits the collected data to the BS directly leading to high energy consumption. The probabilistic selection of CHs in LEACH protocol does not ensure uniform distribution of CHs, and thus causing more isolated nodes.

Sleep scheduling mechanism presented in (Ahmed et al., 2016), reduced the battery energy and interferences by avoiding the idle listening of the sensor nodes. The centralized clustering mechanisms are discussed in (Hoang et al., 2013; Srivastava and Sudarshan, 2015; Sarma et al., 2016). In (Hoang et al., 2013), the BS performed a cluster using Fuzzy C Means (FCM) algorithm by considering the node location and their battery energy. The genetic algorithm based optimal number of final CH selection is proposed in (Srivastava and Sudarshan, 2015), called Optimized Zone based Energy Efficient routing protocol (OZEEP), in which the fuzzy inference system finds the CH nominee by considering the parameters such as distance, energy, mobility, and density. Energy Efficient and Reliable Routing (E^2R^2) is represented in (Sarma et al., 2016), in which the cluster formation and CH selection are achieved by the BS based on residual energy, number of neighbor nodes, and mobility. In addition to that, the deputy CH is introduced to