Cluster-based Routing Protocol in Wireless Sensor Networks for Tracking Livestock Movements in Mongolian Nomadic Herding

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***Abstract*— Mongolian nomadic herding is characterized by a large number of livestock and vast pastureland. In this paper, firstly, we present an architecture of wireless sensor network for tracking livestock movements considering scalability, mobility and energy efficiency. To solve the problems of scalability and energy efficiency, we adopt cluster-based wireless sensor network architecture. And a mobile sink is introduced to solve the problems of mobility and the absence of communications infrastructure. Secondly, we design a cluster-based routing protocol for the architecture by combining and tailoring two existing cluster-based routing protocols, LEACH-Mobile Enhanced (LEACH-ME) and Mobile Sink based Routing Protocol (MSRP), to allow for achieving energy efficiency, scalability and mobility. The routing protocol designed for the architecture is based on a mobility metric "remoteness" for cluster head election and the declaration of membership of a cluster for mobile sensor nodes, which ensures high success rate in data transfer between a cluster head and its sensor nodes even though nodes are moving. And the mobile sink moves in the clustered wireless sensor network to collect sensed data from cluster heads within its vicinity, which prolongs network lifetime.**

***Keywords*— clustering, animal tracking, node mobility, energy efficiency, mobile sink.**

I. INTRODUCTION

The main foundation of Mongolia's economy, livest ock husbandry plays an important role in the economy, employment and export revenues of Mongolia [1]. Nomadic herding in Mongolia is characterized by a large number of livestock and vast pastureland. Recently the open access to pastureland combined with high livestock numbers has resulted in some problems such as significant degradation of pastureland and desertification [2]. For improving the management of livestock and pasture, relating to livestock husbandry, there is a need for tracking livestock movements using an automated system.

It is difficult to achieve practical and reliable livestock tracking or monitoring with current conventional technologies due to challenges such as large grazing areas of livestock, long time periods of data sampling, and constantly varying physical environments. Wireless sensor networks bring a new level of possibilities into this area [3]. Wireless sensor network (WSN) is a highly distributed network of small, lightweight wireless sensor nodes (limited amount of energy, short communication range, low bandwidth, and limited processing and storage), deployed in large number, and monitors the environment or system by measuring physical parameters such as temperature, pressure and humidity [4].

There is a large number of works to develop automated systems for tracking or monitoring livestock using wireless sensor network technology [3], [5-8]. However, there are some problems in using the existing wireless sensor network-based systems for tracking livestock movements in the Mongolian nomadic herding which is characterized by a large number of livestock and vast pastureland. A system for Mongolian nomadic herding should be scalable to be used for a large number of livestock on the wide pastureland. And it should support mobility to cope with the frequent movement of livestock herd and herder household. It should also achieve energy efficiency to operate for a long time with limited energy resources. Besides, we should consider that it is too costly to build a new communications infrastructure on the vast pastureland.

In this paper, firstly, we present an architecture of wireless sensor network for tracking livestock movements in Mongolian nomadic herding. To solve the problems of scalability and energy efficiency, we adopt cluster-based wireless sensor network architecture. And a mobile sink is introduced to solve the problems of mobility and the absence of communications infrastructure.

Secondly, we design a cluster-based routing protocol for the architecture by combining and tailoring two existing cluster-based routing protocols, LEACH-Mobile Enhanced (LEACH-ME) and Mobile Sink based Routing Protocol (MSRP), to allow for achieving energy efficiency, scalability and mobility.

The routing protocol designed for the architecture is based on a mobility metric "remoteness" for cluster head election and the declaration of membership of a cluster for mobile sensor nodes, which ensures high success rate in data transfer between a cluster head and its sensor nodes even though nodes are moving. And the mobile sink moves in the clustered wireless sensor network to collect sensed data from cluster heads within its vicinity, which prolongs network lifetime.

The remainder of the paper is organized as follows. Related work is discussed in Section II. In Section III, we present an architecture of WSN for tracking livestock movements. We describe a cluster-based routing protocol designed for the architecture of WSN in Section IV. Finally, Section V concludes this paper.

II. RELATED WORK

Most of cluster-based routing protocols such as the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol [9] assume that nodes are stationary. However, with some applications such as animal tracking this assumption is not very realistic. Inclusion of node mobility as a new criterion for the cluster creation and maintenance adds new challenges for the clustering techniques [10]. And in recent years, contrary to static sink, mobile sink approach has attracted much research interest because of increase in its potential WSN applications and its potential to improve network performance such as energy efficiency and throughput [13]. There is a large number of current works for the development of cluster-based routing protocols for WSNs with mobility in sensor node or sink. In this section, we present a brief overview of two cluster-based routing protocols on which our routing protocol is based.

A. LEACH-Mobile-Enhanced (LEACH-ME)

LEACH-ME [11] consists of two phases: setup phase and steady state phase. In setup phase, nodes that are less mobile relative to its neighbors are elected as cluster heads (CHs) to cope with the situation of CH's going out of reach due to mobility. Each node estimates the distance to all its neighbors and calculate the mobility factor based on the "remoteness" of a node from its neighbors. Node with least mobility factor is selected as a CH, provided the energy level of that node is not below a certain threshold. New CH election is introduced after a certain number of time division multiple access (TDMA) frames. This periodicity is decided based on the active mobility of nodes. The steady state phase is same as in LEACH-Mobile [12]. A CH will send data request to its member nodes, however, packet is considered loss when the CH does not receive data from its member nodes. The membership of the sensor node under this CH will be lost. Sensor node which does not receive request from its CH realizes that it has moved out from its cluster. It then sends the join message to nearby CHs in order to join into the new cluster and avoid losing more packets.

B. Mobile Sink based Routing Protocol (MSRP)

In MSRP [13], a mobile sink moves in the clustered WSN to collect sensed data from the CHs with its vicinity. At a particular instance of time CHs in the neighborhood of the mobile sink forward their data to the sink. The rest of the nodes in the network wait for their turn to become mobile sink neighborhood. In this way, during sink movement, all the nodes in the network forward their data to the mobile sink, when mobile sink comes in their neighborhood. During data gathering the mobile sink also maintains information about the residual energy of the CHs. In deciding a new location, the mobile sink consults maintained information about the residual energy of the CHs and searches for zones with richer energy CHs.

III. ARCHITECTURE OF WIRELESS SENSOR NETWORK FOR TRACKING LIVESTOCK MOVEMENTS

In this section, we present an architecture of WSN for tracking livestock movements in Mongolian nomadic herding environment which is characterized by a large number of livestock and vast pastureland.

A. Requirements

The architecture of WSN for Mongolian nomadic herding should be scalable to be used for a large number of livestock on the wide pastureland. And it should support mobility to cope with the frequent movement of livestock herd and herder household. It should also achieve energy efficiency to operate for a long time with limited energy resources. Besides, we should consider that it is too costly to build a new communications infrastructure on the vast pastureland.

B. Architecture of WSN for Tracking Livestock Movements

To solve the problems of scalability and energy efficiency, this architecture uses cluster-based wireless sensor network architecture. Many research projects and papers have shown that clustering in wireless sensor networks makes significant improvement in energy efficiency and scalability [14].

And a mobile sink is introduced to cope with movement of herder household and the absence of communications infrastructure. A mobile sink that moves closer to sensor nodes can not only help conserve energy since data is transmitted over fewer hops thus reducing the number of transmitted packets but also handle sparse and disconnected networks better [15].

The architecture of WSN for tracking livestock movements consists of sensor nodes and a mobile sink as shown in Fig. 1. The sensor nodes mounted on livestock form clusters and cluster heads are elected for each cluster. Each sensor node chooses the most suitable cluster head. And then sensor nodes send the locations of livestock to the respective cluster heads. The cluster heads aggregate the sensed data and then wait for the mobile sink to come in its vicinity to send data to it. The mobile sink carried by a herder moves in the network and collects the locations of livestock from the cluster heads in its vicinity. When a cellular network is available, the mobile sink will upload the collected data to the server via internet. When a cellular network is not available, the mobile sink will store the collected data and then upload them to the server as soon as a cellular network becomes available.

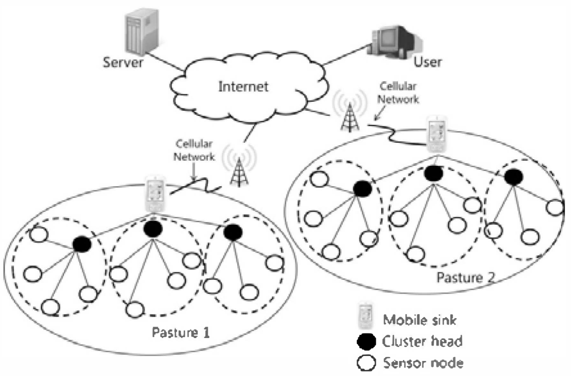

Fig. 1 Architecture of WSN for tracking livestock movements

IV. CLUSTER-BASED ROUTING PROTOCOL IN WIRELESS SENSOR NETWORK FOR TRACKING LIVESTOCK MOVEMENTS

We design a cluster-based routing protocol for the architecture by combining and tailoring two existing cluster-based routing protocols, LEACH-ME and MSRP, to allow for achieving scalability, mobility and energy efficiency. The routing protocol designed for the architecture is divided into three main phases: setup phase, steady state phase and mobile data collection phase. LEACH-ME is adopted in setup phase and steady state phase to allow for cluster formation and the actual data transfer between sensing nodes and cluster head. In mobile data collection phase, MSRP is tailored to allow for mobile sink's moving in the network and collecting sensed data from the cluster heads in its vicinity.

A. Setup Phase

In this phase cluster formation takes place. Cluster head election based on a mobility metric "remoteness" ensures high success rate in data transfer between a cluster head and its sensor nodes even though nodes are moving.

1) Cluster Head Election: To cope with the situation of cluster head's going out of reach due to mobility, the cluster heads are elected from the group of mobile nodes having minimum node mobility or they are in a group motion with the other cluster members as in the Reference Point Group Mobility (RPGM) model [16]. Each node estimates the distance to all its neighbors and calculate the mobility factor using the following equation.

$$M_i(t) = \frac{1}{N-1}\sum_{j=0}^{N-1} d_{ij}(t) \tag{1}$$

where $M_i(t)$ is the mobility factor based on the "remoteness" of node i from its neighbors, N is the number of neighbors of node i, $d_{ij}(t)$ is the distance of node i from its neighbor j at time t. A node with least mobility factor is elected as a cluster head, provided the energy level of that node is not below a certain threshold.

The cluster head calculates the average transition count of its members for the last few cycles and if that value goes beyond a threshold it introduces ACTIVE slot during which clusters are reorganized.

2) Advertisement: After a cluster head has been elected, it broadcasts an advertisement messages to the rest of the sensor nodes in the network. For these advertisement messages, cluster heads use a Carrier Sense Multiple Access with Collision Avoidance Medium Access Control (CSMA/CA MAC) protocol. All cluster heads use the same transmit energy when transmitting advertisement messages.

3) Cluster Decision: After non-cluster head sensor nodes have received advertisement messages from one or more cluster heads, sensor nodes compare the received signal strength for received advertisement messages, and decide the cluster to which it will belong. The sensor node selects cluster head with which needs the minimum amount of transmitted energy for communicating. After deciding the cluster it will belong to, the node sends registration message to inform the cluster head. This advertisement messages are transmitted to the cluster heads using CSMA/CA MAC protocol.

4) TDMA Schedule Creation: After a cluster head receives registration messages from the nodes that would like to join the cluster, the cluster head creates a TDMA schedule based on the number of nodes and assigns each node a time slot when it can transmit. This schedule is broadcasted to all the sensor nodes in the cluster.

B. Steady State Phase

In this phase, sensed data from sensor nodes are transferred to their cluster heads according to a TDMA schedule. And a cluster heads waits for the mobile sink to come in its vicinity to send the sensed data to the mobile sink. Data transfer success rate is improved by declaring membership of a cluster for mobile sensor nodes.

1) Sensor Node Side: A sensor node wakes up at the beginning of its timeslot and waits for data request message sent from the cluster head. If the sensor node receives data request message, it will send the data back to the cluster head. Otherwise it will go back to sleep mode until the next allocated time slot in the next frame. If no data request message is received once again, the sensor node assumes that it is not a member of the cluster. And then it sends the join request message to the nearby cluster heads.

2) Cluster Head Side: If the cluster head does not receive data from a sensor node during two consecutive frames, the cluster head removes the sensor node from its scheduling and it may also assign this time slot to the newly joined node in TDMA schedule. The cluster head assumes that the sensor node had moved out of the cluster. The cluster head hearing the join request message allots a time slot in its TDMA schedule and broadcasts it to all the member nodes including the new member. After receiving sensed data from all the member nodes, the cluster head waits for the mobile sink to come in its vicinity to send sensed data to it.

C. Mobile Data Collection Phase

In this phase, the mobile sink moves in the network and collects sensed data from the cluster heads in its vicinity, which prolongs network lifetime.

1) Mobile Sink Advertisement: The mobile sink broadcasts beacon message to the cluster heads in its vicinity and sets the time interval T based on the communication delay.

2) Cluster Head Registration: When the mobile sink enters the valid dissemination range of some cluster heads, a cluster head intercepts beacon message of the mobile sink and responds to the mobile sink by sending registration request to it. If the mobile sink receives the registration request from the cluster head within the time interval T the mobile sink sends an acknowledgement message to that cluster head and include the cluster head in the registered cluster head list.

3) TDMA Schedule Creation: Once all cluster heads have been registered, the mobile sink assigns the time slots to all the registered cluster heads when the registered cluster head nodes can send the sensed data to the mobile sink.

4) Data Forwarding: It involves how a cluster head should send the sensed data to the mobile sink in allocated time slot. Cluster heads send the sensed data to the mobile sink using single hop communication in an agreed TDMA time slot.

5) Sink Movement: The mobile sink moves by the Random Waypoint Mobility model [17] to collect cluster head information and sensed data from cluster heads. The mobile sink begins by staying in one location for a certain period of time and in this period the sink collects sensed data from cluster heads in its vicinity. Once this time expires the mobile sink travels towards the newly chosen destination.

V. CONCLUSION

In this paper, we presented an architecture of WSN for tracking livestock movements in Mongolian nomadic herding. And we designed a cluster-based routing protocol for the architecture. By adopting clustering schemes and introducing a mobile sink, we achieve scalability, mobility and energy efficiency which are important requirements for tracking livestock movements in Mongolian nomadic herding. When the architecture and the routing protocol designed for the architecture are implemented and deployed in Mongolian nomadic herding, it will be possible to get actual economic effects such as time and cost savings in livestock census, improvement of pasture quality through systematic pasture management, disease prevention through livestock health monitoring, and livestock protection against thieves and wolves.

In the future work, we need to evaluate the performance of the designed routing protocol by simulation based on three metrics: scalability, mobility and energy efficiency.

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