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Active data dissemination for mobile sink groups in wireless sensor networks

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ABSTRACT

In wireless sensor networks, a mobile sink group brings out many challenging issues with regard to data dissemination due to its twofold mobility: group mobility and individual one. All member sinks of a group should move together toward the same destination in relation to the group mobility, but each member sink can also move randomly within a certain group area in relation to the individual mobility. For supporting such groups, geocasting may decrease data delivery ratio due to continuous group area shifting by the group mobility, and multicasting may increase energy consumption due to frequent multicast tree reconstructions by the individual sink mobility. Recently, mobile geocasting protocols have been proposed, which enable a mobile sink group to periodically register its current group area information to a source and member sinks in the group to passively receive data from the source by flooding within the registered group area. However, due to the passive data dissemination, they suffer from excessive energy consumption of sensor nodes due to flooding data within the large group area and result in high data delivery failures of member sinks on edge of the group due to asynchrony between the registered group area and the actual group area. Therefore, we propose an active data dissemination protocol that exploits a local data area constructed by considering the moving direction and pattern of a mobile sink group. In the proposed protocol, a source sends data to nodes in the local data area in advance, and member sinks in the group actively receive the data from the local data area when they potentially pass it. To efficiently construct a local data area, we investigate the pattern of group mobility and classify into three major categories according to the prediction level: a regular movement, a directional movement, and a random movement. We then present three different data dissemination schemes with an efficient local data area to effectively operate for each mobility pattern. Experimental results conducted in various environments show that the proposed protocol has better performance than previous protocols in terms of the data delivery ratio and the energy consumption.

1. Introduction

Recent advances in wireless communications and electronic devices has enabled the development of low-cost sensor nodes, and furthermore, a large number of them have enabled the construction of Wireless Sensor Networks (WSNs) to sense events in interesting areas [1]. As one of the key technologies of Internet of Things (IoTs), nowadays WSNs have been receiving significant attention again due to various potential applications in environmental surveillance, military operations as well as European Smart Cities [2], In-Home Health care and climate-smart agriculture [3]. In WSNs, sensor nodes generally sense interesting events, generate sensing data about them, and forward the sensing data to sinks via wireless multi-hop communications. In many practical applications of WSNs, sinks need to receive sensing data while moving around within the sensor fields for performing their own missions.

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For example, forest rangers move within a forest to monitor it and receive data about events such as forest fires or illegal hunters. Until now, a number of routing protocols [4] have been proposed for supporting data forwarding to mobile sinks in WSNs.

In applications such as disaster areas and war zones in WSNs, the behavior of multiple mobile sinks such as firefighters and soldiers can be described as the group features in terms of their missions and mobility [5]. Thus, in a mobile sink group, sinks move together and collect data to accomplish their common missions in the sensor field. The mobility feature in a mobile sink group can be classified into two mobility type: macro and micro mobility. The macro mobility, the so-called group mobility, means that all mobile sinks in a group move toward the same direction together. This can be presented as a movement of the group itself since each member of the group has the same mission such as rescue in a target area. On the other hands, the micro mobility, the so-called individual mobility, means that each mobile sink could freely move around within a geographically restricted region called a group region. It could be referred as a random movement within the group.

Traditional groupcasting protocols [6–9] might be adopted for supporting mobile sink groups. However, they suffer from high data delivery failure and/or excessive energy consumption due to the twofold mobility features of such groups. For example, geocasting [6] as a possible solution can support a mobile sink group by using regional flooding since it allows to disseminate data of sources within a designated area such as the group area. Unless member sinks in the group move out the designated area, they can receive the data. In this case, geocasting may result in low data delivery ratio due to continuous group area shifting by the group mobility of a mobile sink group. As another solution, multicasting [7–9] can also support a mobile sink group by using multicast trees since it allows to disseminate data of sources through a multicast tree spanning and connecting all member sinks of the group. In this case, multicasting might cause high energy consumption of sensor nodes due to frequent multicast tree reconstructions by the individual sink mobility.

Recently, mobile geocasting protocols [10,11], the so-called M-Geocasting, has been proposed for supporting both the macro and micro mobility through extending traditional geocasting schemes. In M-Geocasting, a leader sink in a mobile sink group periodically calculates the current position of its group including a center point and a size of the group, and it registers them to a source. Then, the source delivers its data, i.e., missions, the number of remaining survivors, etc., to all sinks of the group within the registered group region by using regional flooding schemes such as geocasting [6]. However, M-Geocasting still remains two significant problems. The first one is the data delivery failure problem. Due to continuous movements of a mobile sink group, its registered group region and actual group region are asynchronous to each other. As a result, if some member sinks move out of the registered group region, they cannot receive data from the source by geocasting. The second problem is the excessive energy consumption that is caused by the flooding scheme for data delivery within the group region. Although the data flooding area has calculated by every reporting period, such circle-based modeling might generate unnecessary flooding area. Also, such periodic flooding may result in redundant flooding area. This trouble is worsened considerably as the size of a mobile sink group increases. As one of the improved version of M-Geocasting, [13] exploits a virtual line structure (VLS) for data storage within the group region. In this protocol, a source puts its data to VLS and each sink gets data of the source from the VLS when they need. In most cases, the VLS is very close to sinks and thus its performance could be dramatically improved, especially regarding energy-efficiency. However, [13] cannot consider the moving direction and the mobility pattern of a sink group. In the worst case, every sink requests data to backward direction comparing to its movement direction.

Therefore, to solve the high data delivery failure and the excessive energy consumption problems, we propose an active data dissemination protocol for supporting mobile sink groups in wireless sensor networks. In the proposed protocol, a source sends its data for a mobile sink group to sensor nodes in a specific area called a local data area constructed by considering the moving direction and pattern of the sink group, through which member sinks potentially pass when the group continuously moves. The sensor nodes in the local data area should keep received data during a certain amount of time, and finally, each member sink requests the data to them by one-hop communication while passing the area. That is, the proposed protocol changes the concept of the data delivery into *'Active'* from *'Passive'* of previous ones. As a result, it can reduce a large amount of energy consumption of data dissemination since the local data area is much smaller than the group area in most cases. It can also raise success ratio of data delivery to member sinks because they actively obtain data from the local data area. In the best case, the local data area can be a straight line in high-density networks. However, since this strategy requires an accurate prediction of moving direction of the group, the proposed protocol utilizes the slowly varying and continuous stream-like moving properties of a mobile sink group. Since the member sinks move freely, but they are tightly-coupled, the group of them slowly moves toward a target area or a destination like a stream. Thus, like a dam in a river, a data source conservatively sets an appropriate local data area. To simplify it, we investigate the patterns of group mobility and classify them into three major categories according to the prediction level: a regular movement, a directional movement, and a random movement. We then present three different data dissemination schemes with an efficient local data area to effectively operate for each mobility pattern. Accordingly, the proposed protocol can easily maintain a certain level of data delivery ratio given by applications. Experimental results conducted in various environments and scenarios show that the proposed protocol achieves better performance than two previous groupcasting protocols, SEAD [9] for multicasting and M-Geocasting [11] in terms of the data delivery ratio and the energy consumption.

The rest of this paper is organized as follows. Section 2 presents the related work of our protocol. We describe our protocol in detail in Section 3. Experimental results are given for evaluating the performance of our protocol in the Section 4. The Section 5 concludes this paper.

2. Related works

In wireless sensor networks (WSNs), a large number of routing protocols [14–16] have been proposed for supporting data dissemination to an individual mobile sink. For constructing an efficient unicast routing path from a source node to an individual mobile sink, they exploit virtual routing structures such as lines, circles, and clusters known beforehand to both the source nodes and the mobile sink on the network. For supporting data dissemination, an individual mobile sink constructs a routing path from itself to the virtual routing structures by periodically updating its location information to the structures. Then, a source constructs a routing path from itself to the virtual routing structures and sends its data to the mobile sink via the virtual routing structures. Thus, for a mobile sink group consisting multiple mobile sinks, these protocols should construct a unicast routing path from a source to each mobile sink via the virtual routing structures. This consumes a lot of energy for supporting a mobile sink group consisting of multiple mobile sinks.