Energy-Efficient Mobile Groupcasting Protocol in Wireless Sensor Networks

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***Abstract*—The research on mobile groupcasting has been studied to deliver messages of interests to all mobile sinks that have collective mobility as a group. It provides a current geographical region of the group to a data source to support mobile sink groups in a macroscopic view of the group mobility. Several protocols have been proposed for mobile groupcasting and can be classified into two data dissemination strategies: unicasting and flooding. In aspects of energy efficiency, unicasting is good for a small number of sparse sinks, while flooding is good for a large number of dense sinks. However, since both extremes are too conservative, they are hard to support the generic case that the region is overall sparse and partially dense. In this paper, we suggests an energy-efficient mobile groupcasting protocol, which exploits both unicasting for sparse sinks and partial flooding for dense sinks in a group region. To do this, we present an analytical model to calculate an optimal combination of both a flooding subgroup for the sparse sinks and an unicasting subgroup for the dense sinks. By separating a group into a unicasting subgroup and a flooding subgroup, the proposed protocol can efficiently eliminate unnecessary flooding areas as well as duplicated transmissions. Simulation results in various environments shows that the proposed protocol has better performance than the existing protocols.**

***Keywords*—wireless sensor networks, mobile groupcasting, group communication, mobile sink group, group mobility.**

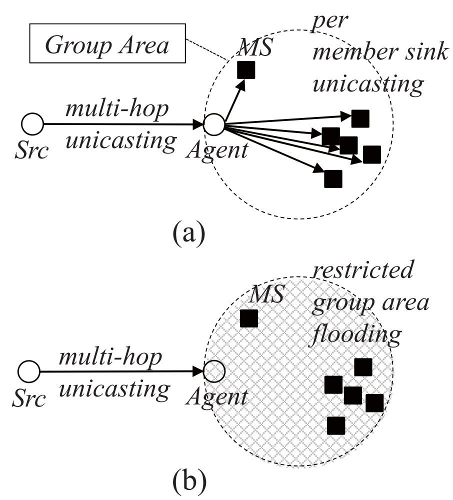

Fig. 1. (a) represents unicasting-based mobile groupcasting, while (b) represents flooding-based mobile groupcasting. Both strategies show inefficient data dissemination when they meet the generic case overall sparse and partially dense.

I. Introduction

Wireless sensor networks (WSNs) have been designed and developed for a wide variety of applications, such as environment monitorings, smart battlefields, home automations, and traffic controls etc, [1]. In an intelligent sensing systems with sensor nodes in WSNs, mobile sinks can reduce network traffic by moving over the network to gather data instead of reporting from all sensor nodes to a sink [2]. As a special type of mobile sinks such as a platoon of firefighters, solders, or even cars for cooperative driving, the concept of the mobile sink group has considered as an interesting one in the literature since it has ambivalent properties of mobility [3]. Mobile sinks in this group collect the sensed information from networks while moving, but they can share an interest, a mission, and a destination each other. That is, each mobile sink can freely move around in a microscopic view, however, they are tightly coupled and move toward the same destination as a group in a macroscopic view [4].

One can consider that the message delivery to a mobile sink group is necessary in order to share current interests, instructions, location of hazard areas, and/or accident information according to their applications. For this goal, traditional data dissemination schemes for a mobile sink cannot be directly adopted because the message delivery in disregard of their collective mobility can waste a large amount of resources of networks. For example, several multicasting protocols [5] might be adopted, however, the sink mobility might waste much energy and long delay due to frequent tree reconstruction. Geocasting [6] can reduce dissemination cost and delay for freely moving sinks, but it is effective only with mobile sinks in a static geocasting area. It may suffer from the failure of data delivery whenever each sink moves out from the geocasting area.

Recently, mobile groupcasting [7][8][9] protocols have been proposed to efficiently deliver data to the mobile sink group. By updating a current geographic region of the group to a data source, the source puts data packets on the proximate node of the group, so mobile sinks can easily get the packets from the node. As shown in Fig. 1, mobile groupcasting can be classified according to their data dissemination strategies: unicasting-based mobile groupcasting [7][8] and flooding-based mobile groupcasting [9]. As a special type of multicasting, unicasting-based schemes have proposed to share source's data with mobile sinks at the close range. One of the mobile sinks (or an agent) gets data packets from the source and relays them to other sinks by using unicasting per member sink. On the other hands, flooding-based schemes have

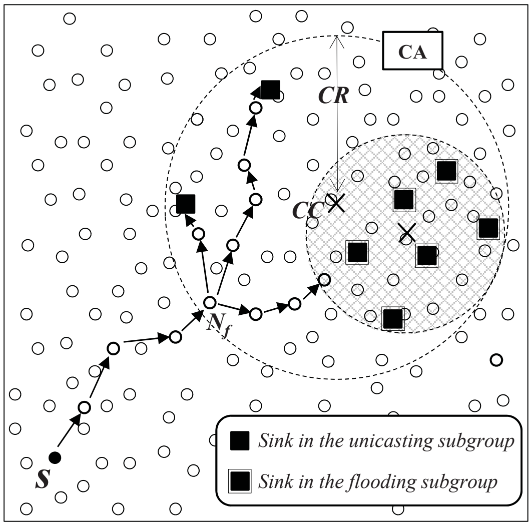

Fig. 2. An example of data dissemination in the proposed protocol

proposed to extend traditional Geocasting in order to make the static data dissemination area for a group to be dynamic, thus mobile sinks can receive data packets by using geographically restricted group area flooding.

In aspects of energy efficiency, unicasting-based schemes are effective for a small number of sparsely located sinks, while flooding-based schemes are effective for a large number of densely located sinks. Except these ideal cases, mobile sinks tend to locate in a group area which are overall sparse as well as partially dense. That is, both unicasting and flooding are hard to support such the generic case since they might lead to waste of energy of sensor nodes. For example, in Fig. 1(a), unicasting-based schemes might waste energy of sensor nodes due to duplicated transmission toward densely located sinks. On the other hands, in Fig. 1(b), flooding-based schemes might suffer from energy due to unnecessary flooding area made by a few number of sparsely located sinks. Unfortunately, this problem would become considerable in complex and practical scenarios that contain merging and/or splitting groups.

In this paper, we propose an energy-efficient mobile group-casting protocol for a mobile sink group which exploits both partial flooding for densely located sinks and unicasting for sparsely located sinks within a current group area, respectively. By eliminating the unnecessary flooding area made by a few number of sparsely located sinks in a group area, the proposed protocol could reduce communication traffic. Note that finding an optimal number of subgroups for partial flooding is extremely hard due to high computational complexity with resource-constrained sensor nodes. To enable this requirement, we try to find one partial flooding group and the other unicasting group in a mobile sink group because we observe that the unnecessary data disseminations is mainly caused by a few number of leaving node from the dense group in many scenarios. We present an analytical model to calculate an optimal combination of both a flooding subgroup for the sparse sinks and an unicasting subgroup for the dense sinks. With various analysis and simulations, our heuristic scheme show better performance regarding energy-efficiency than previous protocols, M-Geocasing and VLDD.

Algorithm 1 Pseudocode of the Subgrouping

procedure **GetSubfloodingGroup**(set M)
  $Input : n$ ▷ *the number of member sinks*
  $Input : M$ ▷ *a set of member sinks*
  $minC \leftarrow 0$;
  for $i = 1 \rightarrow n$ **do** ▷ *1 is unicasting for all members, while n is flooding for all members*
    $p \leftarrow$ **Combntns**(n, i); ▷ *select all possible combinations*
    $FGroup \leftarrow$ **Join**$(M[p])$;
    $UGroup \leftarrow$ **Leave**$(M[p])$;
    $C \leftarrow$ **CostF**$(FGroup)$ + **CostU**$(UGroup)$;
    if $mC = 0$ **or** $C < minC$ **then**
      $minC \leftarrow C$;
      $R \leftarrow FGroup$;
  $Return\ R$;

The rest of this paper is organized as follows. Section II presents the proposed protocol based on our analytical model in detail. The performance of the proposed protocol is evaluated by analysis and experimental results through simulations in Section III. Finally, Section IV concludes this paper.

II. The Proposed Protocol

A. System Model and Network Initialization

We consider that a large number of sensor nodes are deployed in an interest field. Each mobile sink can collect data from adjacent sensor nodes, and can communicate with other sinks by multi-hop communication via sensor nodes without any supporting of legacy networks such as Internet or 3G/LTE networks. Note that a group of mobile sinks moves collectively toward a destination but each member can move randomly within a certain distance. Since the distance may be predefined by applications, we initially denote AR as the radius of the group. Each mobile sink has its own $group - ID$ and $sink - ID$. Each group consists a predetermined Leader Sink (LS) and Member Sinks (MSs). The LS has responsibility to collect location information of MSs in order to get a current position of the group. We assume that every sensor nodes and sinks are aware of their own location information by using GPS devices or other localization schemes [10], so that geographic routing such as GPSR [11] would be exploited as an underlying transport protocol.

B. Obtaining the Location Information of the Group

The LS selects an adjacent sensor node as an agent node, and then the node floods a member search message within a Search Area. The Search Area (SA) can be represented as a circle with center point SC which is the current position of LS, and the radius SR which is the twice of AR. Once a MS receives the search message, it replies an acknowledgement message including its current position to the agent node. The agent node relays the collected location information to the LS. On receiving acknowledgement messages from MSs, the LS calculates the Current Area (CA) where all MSs can contain. We assume that the LS is aware of the number of member sinks *a priori*, so that the LS can increase both SA and AR at a rate when it fails to find the location information of all member sinks. The Current Area is a circle with the center point CC which is the average x-y coordinates of

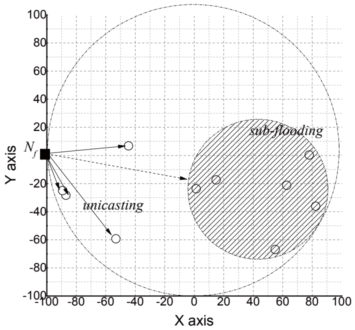

Fig. 3. An example of semi-optimal data delivery within a mobile sink group

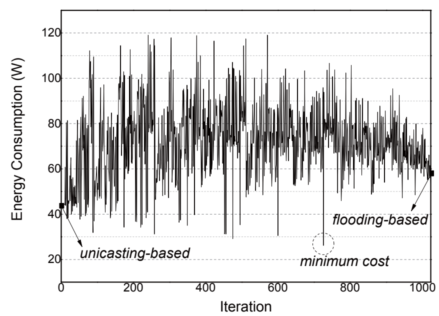

Fig. 4. All possible candidates on the case of Fig. 3

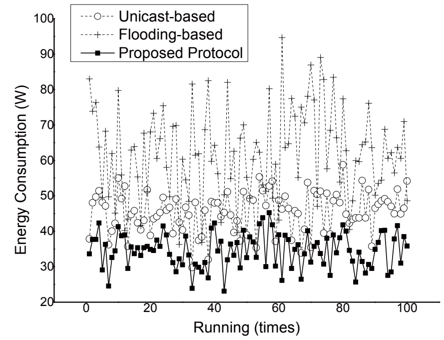

Fig. 5. 100 times repeated cost calculation by MATLAB

all member sinks, and the radius CR which is the same as AR. This loosely-fitted group area is more reliable to deliver data to mobile sinks on the edge of the group than tightly-fitted one in the most previous studies [8][9]. The LS then sends the calculated CA to sources. By exploiting location service schemes such as [10], the LS can obtain the location of sources.

C. Subgrouping

Once a source is aware of the CA of a group, the source has responsibility for separating the group into subgroups: a unicasting group and a partial flooding group. The source calculates the most cost-effective subgroup by using Algorithm 1, then it sends data packets to the sink group including CC, CR, and subgroup information. The data packet would be forwarded toward CC before the packet meets a sensor nodes located within the CA. As shown in Fig. 2, the node N_f is the first sensor node receiving the data packet among nodes within the CA. Then, the N_f stops forwarding data toward CC and performs both partial flooding and unicasting according to the subgroup information in the header of the data packet. The following is detailed description of this scheme.

For simplified calculation, we consider that N sensor nodes are uniformly distributed in a square sensor field A. That is, there are approximately $\sqrt{N}$ sensor nodes on each side. So we can get an approximate cost for flooding as follows:

$$Cost_{flooding} = m \cdot \frac{N}{A} \cdot \pi \cdot R^2, \tag{1}$$

where m represents the length of a data packet and R represents a radius of the flooding area. Also, the following is an approximate unicasting cost between the node A and B.

$$Cost_{unicasting} = m \cdot \frac{dist(a,b)}{TRR}, \tag{2}$$

where the function $dist(a,b)$ means an Euclidean distance between two nodes, a and b. TRR denotes a transmission radio range of sensor nodes. By the equation (1) and (2), we can get the partial flooding cost when a candidate group is given. For example, when a group G has n member sinks $\{G|m_1, m_2, , m_n\}$, a subgroup $\{m_1, m_2\}$ for the partial flooding and the rest subgroup $\{m_3, \ldots, m_n\}$ for unicasting may be selected. In this case, the approximate total cost would be the sum of $cost_{flooding}$ for $\{m_1, m_2\}$ and $cost_{unicasting}$ for $\{m_3, \ldots, m_n\}$.

By the combination of the all member sinks, we can get the case of the minimum costs. Note that these all mechanisms would be started on the first node N_f. However, we exploit the Center Point of a group (CC) since a source cannot know the position of N_f *a priori*. Therefore, the approximate total cost can be calculated as follows:

$$C = min\{m \cdot (\frac{dist(CC, C_{sf}) - R_{sf}}{TRR} + \frac{N}{A} \cdot \pi \cdot R_{sf}^2 \sum_{k=i}^{j} \frac{dist(N_f, MS_k)}{TRR})\}, \tag{3}$$

where C_{sf} and R_{sf} denote the average x-y coordinates and the radius of the partial flooding subgroup, respectively. R_{sf} can be determined as the distance between C_{sf} and the farthest member sink in the partial flooding group. The unicasting subgroup falls from MS_i to MS_j.

D. Data Dissemination

As stated above, the N_f, the closest node from the source within a group area, would generate a copy of the data packet and individually send them to both a partial flooding group and a unicasting group. That is, the proposed protocol need to be perform different routing mode: flooding mode and unicasting mode. For the flooding mode, the destination field for geographic routing would be filled with the center point of the area. It can be nested, however, the maximum depth is just two due to the restricted packet size of resource-constrained sensor networks. Once the packet meets a node that fulfills the area information, the node stops forwarding and generates a copy of the packet including modified header information. It then sends them individually. Fortunately, the unicasting mode is exactly the same as the traditional geographic routing such as [11]. The LS periodically updates the current area information to sources so that they can send data to a group of mobile sinks whenever they need to.

III. Experimental Results

In this section, we first analyze the energy consumption according to data delivery methods using MATLAB [12], then

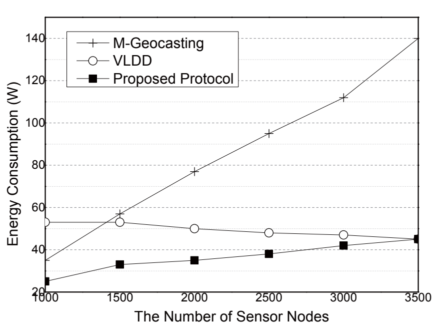

Fig. 6. The energy consumption for the number of sensor nodes

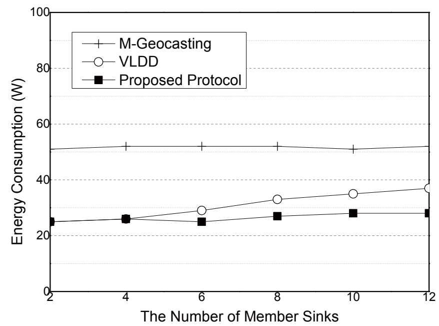

Fig. 7. The energy consumption for the number of member sinks

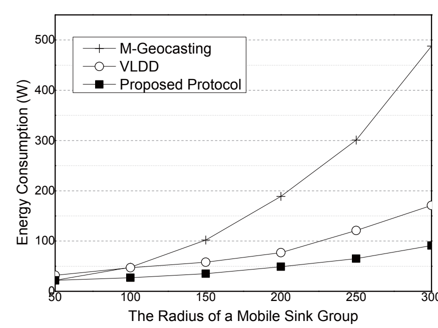

Fig. 8. The energy consumption for the radius of a mobile sink group

compare performances of the proposed protocol with respect to energy consumption and data delivery ratio with other protocols: VLDD [8] as the representative of a unicast-based mobile groupcasting and M-Geocasting [9] as the representative of a flooding-based one. These protocols are implemented in QualNet 4.0 network simulator [13]. For the large-scale scenario, 2,000 sensor nodes are randomly distributed in a 1,000 $m \times$ 1,000 m sensor fields. The model of sensor nodes is followed by the specification of MICA2 [14]. The transmission range of a sensor is 25 m. The transmitting and receiving power consumption rates are 21 mW and 15 mW, respectively. A source node is randomly selected among sensor nodes and sends a data packet of 128 bytes to a mobile sink group. The mobile sink group has 10 member sinks with the average speed of 10 m/s, and the radius of the group is 100 m. We use the Reference Point Group Model [15] as the mobility model for a mobile sink group. We use two metrics, Energy Consumption and Data Delivery Ratio to evaluate the performance of the proposed protocol. The Energy Consumption is defined as the communication (transmitting and receiving) energy the network consumes for supporting mobile sink groups. The data delivery ratio is defined as the ratio of the number of successfully received data packets at sinks of the mobile sink group to the total number of data packets generated by the. Every simulation runs 10 times in different network topology and the results are the average of the measurements.

Fig. 3, 4, and 5 show the expected energy consumption implemented by MATLAB. For simplified calculation, we assume that the center point of the group is located at (0, 0) and the first node N_f that receives data packet from a source node is located at (-100, 100). As shown in Fig. 4, the best case is at 726 iteration which corresponds to Fig. 3, among all possible data delivery of combining of unicast and sub-flooding. Fig. 5 indicates a hundred times repeated running. For each calculation, member sinks are randomly distributed. We can see that the average cost of the proposed algorithm is 24 percent reduced from the unicast-based method as well as 44.5 percent reduced from the flooding-based one.

Fig. 6, 7, and 8 show simulations implemented by QualNet network simulator. Fig. 6 shows the energy consumption for the number of sensor nodes. As the number of sensor nodes increases, M-Geocasting costs much energy than other protocols since more number of sensor nodes participate in a flooding-based data dissemination. VLDD costs more energy than M-Geocasting when low density, however, its graph slightly decreases since it could select better dissemination route that can reduce the hop counts. Since the proposed protocol can find the best case between them, it shows similar energy consumptions with M-Geocasting when low density and with VLDD when high density.

Fig. 7 shows the energy consumption for the number of sinks in a mobile sink group. Independent of the number of sinks, M-Geocasting shows the same energy consumption due to the nature of flooding-based data dissemination, while VLDD increases the energy consumption due to the requirement of additional dissemination routes. The proposed protocol basically low energy consumption because it can eliminate the unnecessary flooding area in most cases.

Fig. 8 shows the energy consumption for the radius size of the group region. As the radius increases, M-Geocasting is on the exponential increase, while VLDD is on the linear increase. The reason is that the data delivery path of VLDD is proportional to the radius of the group and the flooding cost of M-Geocasting is proportional to the number of participated sensor nodes. However, since VLDD cannot consider sinks which are closely located, it wastes energy due to individual and multiple data disseminations even though they could be merged. The proposed protocol shows better performance than VLDD since it can handle these cases.

Fig. 9 shows the average delivery ratio for the number of sensor nodes. Flooding-based M-Geocasting shows low delivery ratio in a sparse network that has a small number of sensor nodes, however, it shows high delivery ratio when dense networks. On the other hands, unicasting-based VLDD shows relatively low performance than others, which is independent of the number of sensor nodes. Actually we already know that the delivery ratio would increase as the number of nodes increases because it is much easier to find an appropriate forwarding node when high density, however, this graph shows that its influences are low where dense enough networks. We observed that multi-hop communication affects more to reduce delivery ratio. The proposed protocol shows better performance than VLDD, but lower delivery ratio than M-Geocasting. It is because that the proposed protocol exploits both unicasting and flooding in a group area. Some sinks would be received by unicasting, and the rest would be received by flooding. If we could ignore the impact to energy consumption, we can get the simple result that as the number of sinks that receives packets by flooding increases, the average delivery ratio would

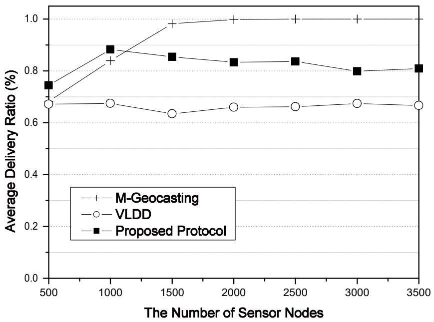

Fig. 9. The average delivery ratio for the number of sensor nodes

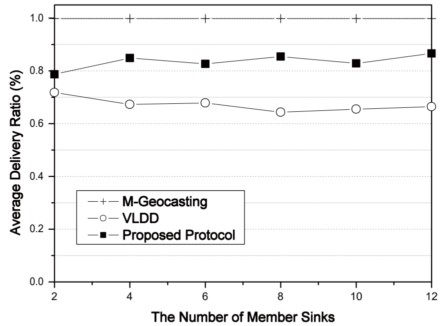

Fig. 10. The average delivery ratio for the number of member sinks

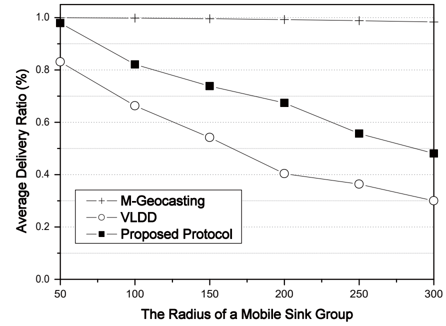

Fig. 11. The average delivery ratio for the radius of a mobile sink group

increase, and vice versa.

Fig. 10 shows the average delivery ratio for the number of member sinks. M-Geocasting shows high delivery ratio independent of the number of sinks. One thing that we have to focus on this graph is that VLDD shows lower delivery ratio as the number of sinks increases, while the proposed protocol shows higher delivery ratio. The main reason is that many sinks are meant to be a large number of hops that packets should be delivered in VLDD. However, as the number of sink increases, the ratio of sinks which are proximity to other sinks also increases, so that the proposed protocol can use flooding into such specific area.

Fig. 11 shows the average delivery ratio for the radius size of the group region. In this simulation, the number of sensor nodes and the number of member sinks remains steady, so M-Geocasting shows high delivery ratio independent of the group size, but it should pay extremely high energy for that as shown in Fig. 8. Both VLDD and the proposed protocol show lower delivery ratio as the size of the group region increases, because the distance from the initial point of the group to the sink also increases. The longer distance leads to decrease delivery ratio due to fading, more hops, and interference. In the proposed protocol, the group would become sparse as the size of the group increases, as well as the ratio of sinks increases in order to reduce redundant energy consumption, which receives packets by unicasting. That is, such decrease phenomenon is close to the number of sinks in a sink group which receives packets by unicasting, so that the difference in performance regarding delivery ratio between VLDD and the proposed protocol comes from the difference in the number of sinks proximity to others.

IV. Conclusion

In this paper, we propose an energy-efficient mobile group-casting protocol for supporting a mobile sink group in wireless sensor networks. Based on the insight that the most of mobile sink groups are overall sparse and partially dense, the proposed protocol exploits both unicasting for sparsely located sinks and partial flooding for densely located sinks. We present an analytical model to calculate an optimal combination of both a flooding subgroup for the sparse sinks and an uni-casting subgroup for the dense sinks. By using the optimal combination, the proposed protocol can eliminate unnecessary flooding areas. Our various analysis and simulation results show that the proposed protocol achieves better performance with respect to energy-efficiency than previous representative protocols, VLDD and M-Geocasting.

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