[奨励講演] センサネットワークのための集約率を考慮した
GIT 経路制御の評価

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あらまし センサネットワークのための経路制御の研究では、完全集約が設定されている場合が多くみられる。そのような設定では、センサネットワークのアプリケーションを制約する。本稿では、GIT 経路制御において集約効率がエネルギー消費に及ぼす影響を検討する。われわれは、集約効率に応じて選択される最適な集約点を選択することで、どの程度のエネルギー消費を削減できるのか興味がある。本稿では、GIT を改良した AGIT（Aggregation efficiency-aware GIT）方式を提案する。また、exploratory message を抑止するための方法として、hop exploratory 方式を検討する。シミュレーション結果より、AGIT は GIT に比べてデータ転送時のエネルギー消費を削減できることを示す。

キーワード センサネットワーク、集約率、GIT 経路制御方式


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Abstract
In most research work for sensor network routings, perfect aggregation has been assumed. Such an assumption might limit the application of the wireless sensor networks. We address the impact of aggregation efficiency on energy consumption in the context of GIT routing. Our question is the extent to which energy consumption can decrease compared to the original GIT. In this paper, we propose an improved GIT: “aggregation efficiency-aware routing”, or AGIT. We also consider a suppression scheme for exploratory messages: “hop exploratory.” Our simulation results show that the AGIT saves the energy consumption of the data transmission compared to the original GIT.

Key words sensor networks, aggregation efficiency, greedy incremental tree routing
node might aggregate receiving packets that are temporally buffered, generate a new packet, and then send it to the next hop. Such a means of operation is expected to reduce the amount of transmitted data, extending remarkable power savings. An example of data-centric routing is directed diffusion (DD) [9].

In most studies, perfect aggregation has been assumed (e.g. [3, 5, 8, 9]). In this case, the most efficient data paths from sources to a sink form a Steiner tree and/or minimal spanning tree. This fact encourages research of heuristic distributed algorithms such as Greedy Incremental Tree (GIT) [8] and the Nearest Neighbor Tree (NNT) [9]. However, perfect aggregation is not universal and possibly limits applications of sensor networks, as mentioned above. Unfortunately, we do not have sufficient insight into the influence of the diversity of the aggregation to sensor network routing. In this work, we address the impact of aggregation efficiency on the energy consumption in the context of the GIT routing [8]. The original GIT is a heuristic algorithm as find a Steiner tree on a hop-count basis. Our questions are how the most efficient incremental aggregation point changes according to aggregation efficiency and how much energy consumption can decrease compared to the original GIT. We improve the GIT routing algorithm to find a more efficient aggregation point according to aggregation efficiency. In this paper, we call the improved GIT "aggregation efficiency-aware GIT (AGIT)."

This paper is organized as follows: In Section 2, we propose AGIT. Section 3 shows some simulation results. Finally, we present conclusions in Section 4.

2. Aggregation Efficiency-Aware GIT

2.1 Suppression of Exploratory Messages

In the DD, which is the basis of GIT routing, exploratory messages are distributed widely according to the nodes’ gradients because interests do not contain any information about a sink. As a result, the gradients are set in many directions. (See Section 2.2.2 in [7].)

To some extent, GIT-like routing necessarily distributes exploratory messages in order to determine the aggregation point for the existing path tree. Results of our analysis showed, however, that the aggregation point becomes nearer to the sink than the foot of the perpendicular from the additional source to the existing path in the case of $\frac{1}{2} < c$. Because since the aggregation point becomes nearer to the sink, the path tree will become similar to that of "opportunistic routing," where data from different sources can be opportunistically aggregated at intermediate nodes along the established path.

In AGIT, we consider the following scheme to suppress the excessive exploratory messages: "hop-exploratory." In the following, we assume that each node can know the hop-count from the sink through interest dissemination. Each node caches the hop-count from the sink for each interest as "own-hop." To do so, we also assume that each interest has a random identifier to be distinguished from the others.

2.1.1 Hop-Exploratory

In addition to the field previous-hop, each exploratory message contains the additional field "hop" to store the hop count from the source that initiated the exploratory message. Whenever a source initiates the exploratory message with both previous-hop and hop set to own-hop. When the node receives the exploratory message with previous-hop, it retransmits the exploratory messages with previous-hop set to own-hop and with hop decremented by one if

$$own-hop \leq previous-hop \text{ and } hop > 0.$$  \hspace{1cm} (1)

2.2 Adjustment of the Incremental Cost Message Phase

The above aggregation scheme involves some adjustments of the incremental cost message phase because the source nodes on the existing path tree might not receive the exploratory messages. Consequently, the incremental cost message is issued in such a case. We take the following approach to overcome this problem. The intermediate nodes from the sources on the existing path tree can initiate the incremental cost message. In order to suppress the multiple incremental cost messages, the more distant intermediate node from the sink issues the incremental cost message earlier. To do so, each intermediate node sets up an incremental cost message timer as

$$t_i = (\max \text{ hop} - own-hop) \times \delta,$$  \hspace{1cm} (2)

where max hop and \( \delta \) respectively denote the predefined network diameter and the timer granularity. The intermediate node issues the exploratory message if its timer expires before receiving another exploratory message; otherwise it suspends the issue.

2.3 Finding of Optimal Aggregation Point

In the following, we assume that linear aggregation is employed, whereby a packet has size $L_{packet} = L_{header} + L_{payload}$ where $L_{header}$ is the header length and $L_{payload}$ is the payload length in bytes. Furthermore, we assume that all sources send their data packet at the same rate. The procedure shown here can be extended easily to function in different cases.

In AGIT, the incremental cost message contains an additional field to store the hopcount $H$ from an intermediate aggregation point. Whenever the source and/or the intermediate nodes issue a new incremental cost message, they set $H = 1$. The intermediate nodes receiving the incremental cost message execute the following:

$$d(E \leq C + H \cdot d) \rightarrow C = E, \quad H = 1,$$

else

$$H = H + 1.$$  \hspace{1cm} (3)

where $d = L_{payload}/L_{packet}$. Recall that $E$ denotes the additional cost (hop-count) from the source joining to the existing path tree to the current node.

In (3), $C + H \cdot d$ represents the net increase of power consumption from the source nodes to the current node when using the current intermediate aggregation point. If this value is greater than or equal to the value of $E$, the current node is more optimal than the intermediate aggregation point. In such a case, the current node substitutes for the intermediate aggregation point, so that it sets $C = E$ and $H = 1$. Otherwise, it increments the value of $H$ by one.

Figure 1 shows the search procedure of the optimal aggregation point. Here we assume that the packet length is one and the payload length is 0.6.

The overhead of AGIT compared to the original GIT merely comprises the hop-count field to store $H$; it can be negligible.

3. Simulation

3.1 Model and Assumption

We implemented the original GIT and the AGIT on a self-developed event-driven simulator engine.

-34-
In this simulator, 500 sensor nodes are deployed randomly in a 50 x 50 m$^2$ field. The transmission range is 5 m. One sink is located at (45, 45) in the two-dimensional coordinate. The number of sources is varied from two to nine; they are arranged randomly in the field. The packet has a 36-byte header. The payload length is varied as 4, 30, 108 and 216 bytes.

We implemented two schemes of the dissemination of the exploratory messages: "traditional exploratory", and "hop exploratory." The traditional exploratory scheme is the original one described in [7]. We implemented the ideal media access control (MAC) on our simulator, where no collisions occur.

Assuming the case by which the pass loss coefficient of $n = 2$, we modeled the energy consumption for transmission and reception of the packet of length $l$ bits with distance $R$ m. $E_{tx}$ and $E_{rx}$ as follows:

$$E_{tx} = (\alpha_{tx} + \beta \times R^2) \times l,$$

$$E_{rx} = \alpha_{rx} \times l,$$

where $\alpha_{tx}$ and $\alpha_{rx}$ respectively denote the energy consumptions of the transmission circuit and the reception circuit, expressed as nanojoules per bit, and $\beta$ denotes the radiation energy in appropriate units (nJ/bit/m$^2$). In simulation experiments, we use $\alpha_{tx} = 50$ nJ/bit, $\alpha_{rx} = 300$ nJ/bit, and $\beta = 1.6$ nJ/bit/m$^2$.

3.2 Simulation Results

To evaluate how much the AGIT saves energy compared to the original GIT routing and opportunistic routing, we introduce the following metric, "gain", $G$:

$$G = \frac{\min(E_{git}, E_{hop})}{\max(E_{git}, E_{hop})} \times 100,$$

where $E_{git}$, $E_{hop}$, and $E_{hop}$ denote the energy consumption for data packet transmission on the path tree in the case of the GIT, the AGIT, and the opportunistic routing, respectively.

Figures 2 and 3 show the characteristics of gain as a function of the number of sources for different payload lengths.

Figure 2 shows the results of the traditional exploratory scheme. In this case, the exploratory messages are distributed network-wide. In the case of the small payload, 4 bytes, the gain is quite low because the aggregation ratio of the linear aggregation is almost identical that of the perfect aggregation. However, in the case of the medium payload, 36 bytes, which is the same as the header, the gain increases concomitant with the number of sources. This tendency is more remarkable in the case of the large payload, 108 bytes. However, in the case of too large payload, 216 bytes, the path tree will become similar to that of the opportunistic routing. Therefore, the gains decrease.

Figure 3 shows results of the hop exploratory scheme. From this figure, we can see that the AGIT routing is still more efficient than GIT routing and opportunistic routing, but the values of gain are decreased in comparison to those of the traditional exploratory scheme because the spread area of the exploratory messages is smaller than the traditional exploratory scheme.

The gain values are smaller than the expected values obtained from analysis. For analysis, we assume a dense network. However, in the simulation, the nodes are deployed in a discrete fashion. For that reason, the range of choices for the optimal aggregation point in the simulation is smaller than that for the analysis.

In Figs. 2 and 3, the gain fluctuates especially for the cases of 36-byte and 108-byte payloads, even though the average value for each case is led from 50 trials. This is because the variance of gain in this case is relatively large compared to the other cases.

Figures 2 and 3 show the gain in the data transmission phase. From this viewpoint, the traditional exploration is preferable. However, it includes the most overhead to construct the path tree. For that reason, we investigate the amount of the overhead. Figure 4 shows the total energy consumption of the entire network between the issue of the interest and the completion of the receptions of one data packet from every source. This figure indicates that the traditional exploratory scheme has a more overhead than the others. A trade-off exists between the gain of the data transmission phase and the overhead of the path tree construction phase. The answer to the problem depends on the applications: more precisely, it depends on how long the data transmission phase lasts.

4. Conclusions

This paper presented the aggregation efficiency-aware GIT (AGIT), and also described analyzes incorporating the suppression scheme for exploratory messages: hop exploratory. The AGIT routing can construct a more efficient path tree than the original GIT. The improvement becomes more remarkable as the payload packet length becomes larger and/or more sources exist. Our simulation results demonstrate that the AGIT achieves up to 8% of the gain for the energy consumption of the data transmission compared to the original GIT. Our simulation results also emphasize that the suppression scheme, hop exploratory, reduces energy consumption up to 40%.

These suppression schemes might limit the flexibility of path findings but weaken the fault tolerance. Evaluation of the issues is left for future works.

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Fig. 2. Gains by nodes on the path tree in the case of the traditional exploratory scheme.

Fig. 3. Gains by nodes on the path tree in the case of the hop exploratory scheme.

Fig. 4. Total energy consumption in whole network until the reception of the data packets from all sources.

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