Extending Network Lifetime by Time-Constrained Data Aggregation in Wireless Sensor Networks

K. B. Ashwini and G. T. Raju

Abstract The most important challenge in wireless sensor network is to reduce the energy consumption of each node and increase the network lifetime. Many networking schemes are used to minimize the amount of data transmission by data aggregation. Three main factors affecting the lifetime of sensor nodes are as follows: (1) the consumed energy for sending data from the leaves to the sink, (2) queuing delay during aggregation, and (3) the tree's delay, which is equal to the tree's depth, should be considered. We analyze the optimal time allotted for intermediate node data aggregation and optimal delay at each higher aggregation node. The adaptive scheme then dynamically adjusts the time constrain at the sensor node.

Keywords Data aggregation · Wireless sensor networks (WSN)

1 Introduction

Recent advances in technology have made wireless sensors compact and inexpensive. Networks formed from such sensors are known as wireless sensor networks and are used in a wide range of applications such as environmental surveillance, military operation, and other domains. The wireless sensor network consists of groups of nodes, which captures and transmits the data to the base station. The base station has continuous power supply, while the nodes are battery-powered. If a sensor node runs

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out of power, its coverage is lost. The network lifetime of a wireless sensor network is determined by the time duration before the first node fails in the network [1]. Therefore, it is very important to manage the sensor nodes in an energy-efficient way to extend the lifetime of the sensor network [2].

To increase the network lifetime, the number of packet transmission between the sensor node and the sink must be decreased. Data aggregation is a technique used to combine the information from the sensor nodes surrounding the event and send the information to the end point, which thereby reduces congestion [3]. Wireless sensor networks offer different methods of data gathering in distributed system architectures and dynamic access via wireless connectivity.

2 Related Work

Different aggregation algorithms have been implemented to prolong the network lifetime and energy-aware optimization in wireless sensor network. In [4], data-centric routing is compared with traditional end-to-end routing schemes. The author examines the impact of source–destination placement and communication network density on the energy, cost, and delay associated with data aggregation. In [1], online data aggregation problem in sensor network is considered where the author shows the problem to be NP complete and propose several heuristic algorithms in terms of network lifetime delivered. In [2], the optimal precision in network lifetime is analyzed and an adaptive scheme that dynamically adjusts the precision constraints at the sensor nodes is proposed. In [5], to increase the network lifetime, an energy-aware algorithm is proposed for constructing the aggregation tree; it considers both the energy and distance parameters to construct the tree. In [6], the problem of constructing efficient trees to send aggregated information to the sink is analyzed. In [7], data gathering protocols are presented that efficiently collect data.

3 System Model and Problem Definition

Consider a connected graph G with N nodes (v_1, $v_2 \ldots v_n$) powered by batteries with non-replenishable energy $E(i)$ and a base station $v0$ connected to an unlimited power supply with energy $E(o)$. The nodes monitor the environment and periodically report to the base station. Each sensor node generates one B-bit message per time stamp. The messages from all sensors are collected at each time stamp and aggregated at the intermediate sensor into a single outgoing message of size B-bit and sent to the base station. The amount of time required to send or receive one bit of data is αs and αr.

Consider Fig. 1a where node 4 has to aggregate the data collected by the children nodes 1, 2, and 3 and forward that to node 5. In Fig. 1b, four columns are

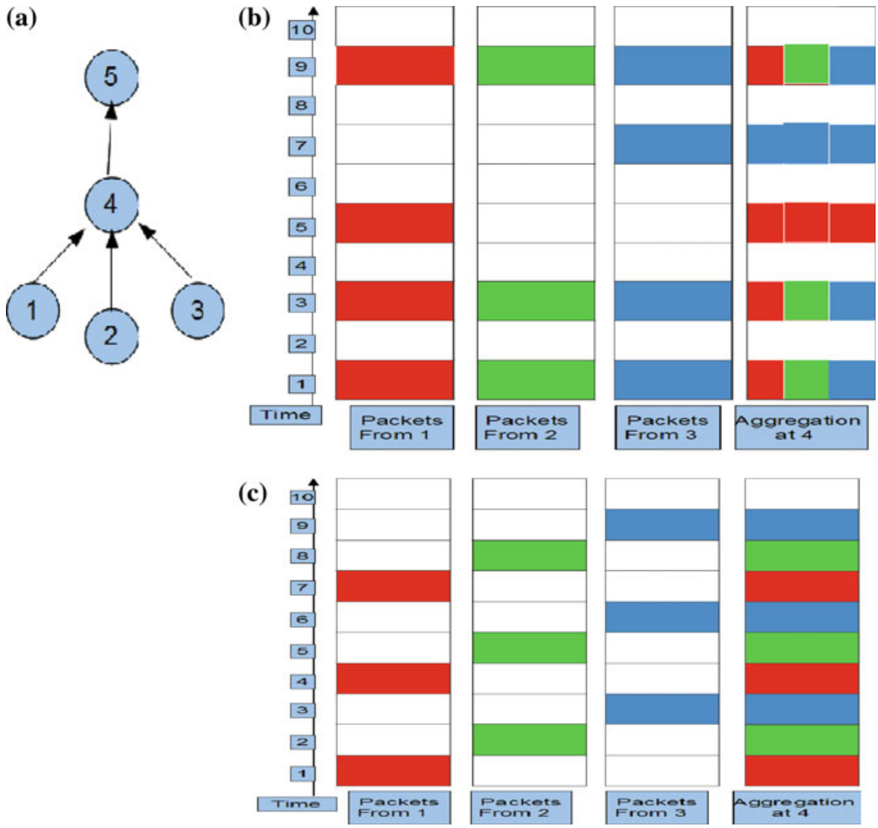

Fig. 1 Case 1: an example of data aggregation constraint

displayed where the first three represents the queues which store the packets coming from nodes 1, 2, and 3. The last column stores the aggregated packets of 1, 2, and 3. The vertical axis denotes the time when the data packet is collected. Data collected at the same time usually contain the information about the same event. In this paper, we consider that data aggregation is done only on data collected at the same time. Suppose a packet coming from node 1 at time stamp 5 has no packets at that time stamp from nodes 2 and 3, the aggregation node just forwards packet from node 1.

If the tree T has a lifetime $L(T)$
Data aggregation is required to maximize the network lifetime (A) max $L(T)$ such that T € $A(G)$
where $A(G)$ is the set of data gathering trees in G.
Let $C(T,i)$ be the number of children for node v_i in T. B is the energy required by v_i to aggregate the data received from all children. During each time stamp node v_i receives B-bit message from each child. The energy consumption of node v_i for

each time stamp after aggregating the received message and transmitting B-bit message to its parent is $\alpha r\, B\, C(T,i) + \alpha t$, its lifetime is $L(T,i) = Ei\text{-}(\alpha r\, B\, C\,(T,i) + \alpha t)$.

In Fig. 1c, node 2 postpones all its data collection by one slot, similarly with node 3. Data aggregation cannot be done, since all the packets are collected at different time stamps. As a result, the number of packets in queue 4 is the summation of packets of queues 1, 2, and 3's. To keep the network stable and to prevent the queue of node 4 from overflow, it has to transmit faster than the aggregate rate of nodes 1, 2, and 3. This example reveals that as the transmission rate of an aggregation node increases, the energy consumption increases and in turn the network lifetime decreases.

Consider Fig. 2a where nodes 0, 1, and 2 work as source nodes. Nodes 1 and 2 are directly connected to the aggregation node 4, whereas node 0 depends on the intermediate node 3 to transfer the data to aggregator 4. Suppose at a particular time t_1, as shown in Fig. 2b, nodes 1 and 2 have delivered some data to 4, whereas there is a delay in the arrival of data from node 0.

1. At that time if node 4 has to wait till time t_2, to receiving the data from node 0 and then aggregate as shown in Fig 2b at time t_2 the delay increases.
2. At time t_1, if node 4 delivers packets, it has to do the same job again after receiving packet from node 0, which results in the increased network traffic and decreased network lifetime.

4 Solution and Implementation

Data aggregation aims to combine responses from multiple sensors into a single message. By reducing the number of message transmission in the network, the energy consumption can be reduced and the network lifetime is increased. In practice, this is complicated by the fact that not every node has a response ready at exactly the same time as in Fig. 1.

A: Time Approximation Algorithm for data aggregation at intermediate nodes.

Let each aggregation node estimate and report to the base station, the number of children for the aggregation node v_n, the minimum time required to receive B-bit message from one child, and the maximum time required to receive B-bit message from at least $v_{n/2}$ nodes. The base station optimizes time allocation for the aggregation node to extend network lifetime. Optimal Time Allocation Algorithm

Input: Aggregation node *va* with the number of children v_1, v_2, v_3
Output: B-bit message from the aggregation node.

1. for time = min to max
2. B-bit message = aggregated result of any two children of node v_a
3. min = min +1

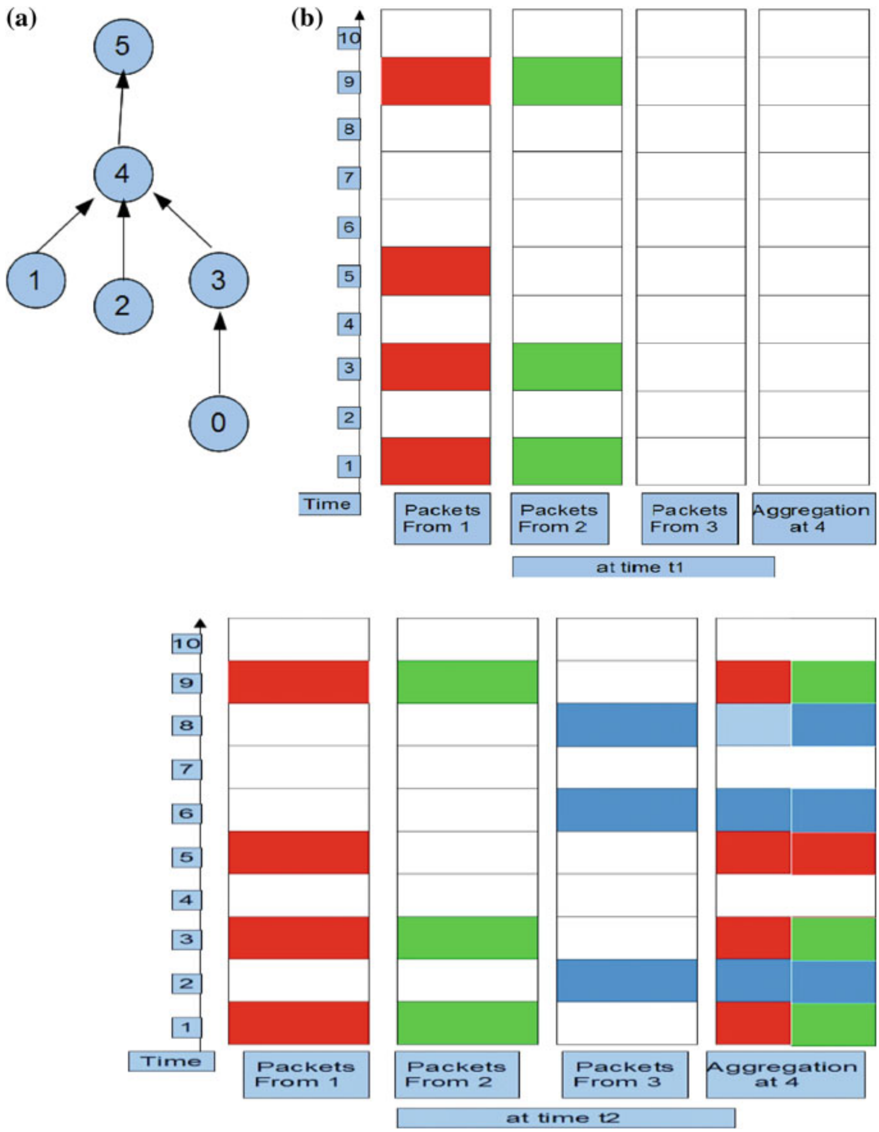

Fig. 2 Case 2: an example of data availability constraint

4. end for
5. Send B-bit message generated by the aggregator to its parent.

B: Time Approximation Algorithm for data aggregation Tree

In an unbalanced network as in Fig. 2, the response time will vary depending on the difference in tree levels of the responding nodes.

1. The leaf nodes respond as soon as the event occurs and send the sensed data to the aggregator.
2. The aggregator waits for a specific time before aggregating the response received and sends the result to the parent.
3. The process continues till the sink receives a single B-bit message.
4. This also allows the sink to recalculate a more appropriate time for the next query if necessary.

5 Conclusion

In this paper, we identify the unique challenges faced during data aggregation in wireless sensor networks. We analyzed the importance of time when aggregating data in WSN and formulated this problem as network utility maximization problem. We also proposed as algorithm to be implemented to solve the problem. In future work, we plan to implement several algorithms to determine the optimal time to be allocated for data aggregation.

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