Enhancing the Data Collection to Reduced Interference in Tree Based Ad-Hoc Sensor Network

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Abstract- In the wireless sensor networks the energy of the nodes present in the network is limited. Due to the low manufacturing costs of sensor nodes, they can be deployed in large numbers and having more challenges in routing, topology and data management protocols. These challenges are complicated by severe energy constraints and the inherently unreliable nature of wireless communications which have yielded work in increasing network efficiency. What is the fastest rate at which we can collect a stream of aggregated data from a set of wireless sensors organized as a tree? We explore a hierarchy of techniques using realistic simulation models to address this question. We begin by considering TDMA scheduling on a single channel, reducing the original problem to minimizing the number of time slots needed to schedule each link of the aggregation tree. The second technique is to combine the scheduling with transmission power control to reduce the effects of interference. To better cope with interference, we then study the impact of utilizing multiple frequency channels by introducing a simple receiver-based frequency and time scheduling approach. We find that for networks of about a hundred nodes, the use of multi-frequency scheduling can suffice to eliminate most of the interference. The data collection rate then becomes limited not by interference, but by the maximum degree of the routing tree. Therefore we consider finally how the data collection rate can be further enhanced by the use of degree-constrained routing trees. Considering deployments at different densities, we show that these enhancements can improve the streaming aggregated data collection by as much as 10 times compared to the baseline of single-channel data collection over non-degree constrained routing trees. Addition to our primary conclusion, in the frequency scheduling domain we evaluate the impact of different interference models on the scheduling performance and give topology-specific bounds on time slot and frequency channel requirements.

I. Introduction

Wireless Sensor Networks have been used for many applications such as military, home, industries etc. This paper proposes a mechanism that allows identifying the relay node and transfers data to the mobile sink. Periodic collection of aggregated data from sensors to a common sink over a tree topology is a fundamental operation in wireless sensor networks (WSN). In many such applications, it is of interest to maximize the rate at which the sink can receive aggregated data from the network [1]. For instance, it has been noted that in networked structural health monitoring more than 500 samples per second are required to efficiently detect damages [2]. Time division multiple access (TDMA) scheduling is a natural solution for such periodic data collection applications [3], [4]. Consider a repeated frame of k time slots in which each link of the data gathering tree is scheduled once. In steady state (once a pipeline is established), the sink will receive aggregated information from all nodes in the network once per frame, i.e. once every k slots. In this framework, maximizing the data collection rate corresponds exactly to minimizing the frame length. This is the
focus of our work. We explore a number of techniques in order to address the basic question: “how fast can aggregated data be streamed to the sink”? These techniques provide a hierarchy of successive improvements. The simplest approach is to do some form of interference-aware minimum frame-length TDMA-scheduling that enables spatial reuse. The second step is to combine the scheduling with transmission power control. The third step is to consider the use of multiple frequency channels. We show that once multiple frequencies are employed along with spatial-reuse TDMA, the aggregated data collection rate often becomes no longer interference-limited, but rather topology limited. Thus, the final step to enhance the rate of periodic aggregated data collection is to use an appropriate degree constrained tree topology. Our primary conclusion is that combining these techniques can provide an order of magnitude improvement in the rate compared to the simple approach of TDMA scheduling on a single channel with minimum-hop routing trees. We evaluate different design choices using simulations that use realistic channel models and radio parameters typical of WSN radio devices. The following are some of the key contributions and findings of this work:

• Evaluation of power control in a realistic setting: Moscibroda [1] has shown in a recent theoretical study that under idealized settings (unlimited power, continuous range) power control mechanisms can provide unbounded improvements in the asymptotic capacity of aggregated data collection. We employ the optimal power control algorithm proposed by El Batt and Ephremides [5] in a practical setting taking into account the limited discrete power levels available in today's radios. We find that for moderate size networks of 100 nodes, power control can reduce the number of time slots by 15-20 percent.

• Comparison of interference models: In the literature, there are two common approaches to model interference. The 1While we do not focus on minimizing energy usage directly, we note that the formulation we explore provides energy efficiency in two ways: aggregation reduces the total data transmitted, and the TDMA scheduling can eliminate collisions in addition to permitting nodes to go into sleep mode during inactive slots. Furthermore, for applications with a fixed data rate, minimizing the schedule length allows for a longer sleep period in each cycle. Therefore they propose to use some nodes for just relaying the other nodes traffic without any sensing and the other technique is cooperation. In [2] proposed a novel data collection method called as maximum amount shortest path, which increases the network throughput as well as conserves energy by optimizing the assignment of sensor nodes. Maximum amount shortest path is formulated as an integer linear programming problem solved with the help of genetic algorithm. A two-tier communication protocol based on the zone partition is designed to implement the maximum amount shortest path scheme. They developed a practically distributed approximate algorithm to solve the maximum amount shortest path problem. In mobile data collector, many mobile data collectors are used to collect the sensed data from fixed sensors. According to sink mobility pattern, we can classify it into random, predictable and controlled mobility. In [9] random mobility, mobile data collectors move in a random path inside the sensor field and implement the technique for collecting data from fixed sensors. But random mobility does not guarantee the collection of data from all sensors nodes and need a high delay for the data delivery. protocol model is a graph theoretic approach with the assumption that a message is correctly received if no other sender transmits at the same time in close proximity. The advantage of this approach is that it enables the use of simple graph-coloring based scheduling algorithms. On the other hand, the protocol model may fail in practice since interference is not a binary
phenomenon [6]. The model can also be pessimistic in the sense that two nearby communications can simultaneously take place if the interference level is tolerable. A richer model that can capture the interference from multiple senders is the physical model also named as SINR (signal to interference and noise ratio) model. We evaluate the impact of both models on the scheduling performance. We find that the use of the graph based model fails most in sparse network deployments with higher path loss exponents, but even then only about 12 percent of nodes are scheduled incorrectly. This suggests that graph-based scheduling design followed by SINR-based validation and repair maybe an acceptable compromise in practice. • Receiver-based frequency-time scheduling: In order to use multiple frequency channels, we introduce a simple receiver-based frequency-time scheduling mechanism suitable for aggregation trees in WSN. The basic idea of our scheme is to associate frequencies with receivers rather than transmitters, and to allocate frequencies greedily (with reuse) to minimize interference. • Bounds on time and frequency requirements: We provide topology-specific bounds on the schedule length and frequency channel requirements. These bounds can be quite useful in characterizing fundamental performance since they can be determined readily from in-network interference measurements for a given routing topology. • Impact of adjacent channel interference: One simplifying assumption often made about frequency channels is that the transmissions on different frequencies are orthogonal, or in other words interference-free. However, assumption of perfect orthogonal channels may fail in practice because of interference from adjacent channels. We find that the practical impact of this simplifying assumption depends upon the particular radio platform employed, as well as the density of deployment. • Identification of connectivity bottleneck: On a tree topology whenever there are multiple senders (children) assigned to the same receiver (parent), each of these senders have to be allocated a different time slot since a single half-duplex transceiver can receive from only one node at a time. When the interference limitation can be eliminated or mitigated to a large extent using multiple channels and power control, we find that the maximum degree on the tree becomes the bottleneck for scheduling performance, especially in denser deployments. • Routing enhancements: We investigate a degree constrained routing tree construction mechanism, which turns out to be more useful. Simulations describes that combining a simple degree constrained tree construction.

II. RELATED WORK

In order to alleviate interference and contention, various TDMA based MAC protocols and hybrid CSMA/TDMA techniques to Collecting data is the basic operation in wireless sensor networks. Collecting those data in a well-organized manner is more critical when compared to the performance of sensor networks. Each sensor will measure the values at regular time intervals and it will send that to sink node. The total collection of data is called as snapshot. Here the sensor network is a Time Division Multiple Access based network. In the past, the data collection capacity is based on large scale random networks, though most of the sensors are not deployed uniformly and the available sensors will not be as huge as in theory. For this purpose we have to know about the capacity of data collection in a network. The capacity of data collection shows how the sink collects data from sensor nodes quickly by considering its interference conditions. The upper and lower bounds for data collection capacity are constructed based on the protocol interference and disk graph models. A simple BFS tree based method is used to achieve the collection capacity which matches the upper bound.
networks the packets generated by each and every node have to reach the sink. This many – one communication is known as converge cast. A Time Division Multiple Access schedule is used which minimizes the total time required to complete the converge cast. A simple version of problem is considered where every node generates exactly one packet. Yin Zhang constructed a distributed scheduling algorithm for the tree networks that requires at most \(3nk - 1\) time slots for converge cast, where \(nk\) corresponds to the maximum number of nodes in any sub tree and \(N\) represents the number of nodes in network. The Distributed scheduling algorithm requires at most \(3N\) time slots in any network. The proposed simulation shows that the number of time slots required is about \(1.5 N\). Two bounds are required for the packets to be buffered at the node during converge cast. Sleep schedules for nodes are considered for conserve energy. It reduces the energy consumption by at least 50% Breadth first search tree is considered for converge cast scheduling. The problem of minimizing the schedule length for raw-data converge cast on single channel is shown to be NP-complete on general graphs. Maximizing the throughput of converge cast by finding a shortest-length, conflict-free schedule is studied, where a greedy graph coloring strategy assigns time slots to the senders and prevents interference and also discussed the impact of routing trees on the schedule length and proposed a routing scheme called disjoint strips to transmit data over different shortest paths. Though the sink remains as the restricted access, sending data over different paths does not reduce the schedule length. The improvement due to the routing structure comes from using capacitated minimal spanning trees for raw-data converge cast, where the number of nodes in a sub tree is no additional than half the total number of nodes in the remaining sub trees.

III. Joint Scheduling and Power Control
El Batt et al. [5] introduced a cross layer method for joint scheduling and power control in wireless multi-hop networks. They proposed an optimal distributed algorithm to improve the throughput capacity of wireless networks. The aim is to find a TDMA schedule which can support as many transmissions as possible in each time slot. We use their algorithm to investigate the impact of power control on the scheduling performance. The solution is composed of 2 phases: scheduling and power control. It is to be executed at the beginning of each time slot in order to cope with excessive interference levels. The scheduling phase searches for a transmission schedule which is defined to be valid if no node is to transmit and receive simultaneously and no node is to receive from more than one neighbor at the same time. Power control phase iteratively searches for an admissible schedule which means that a set of transmission powers is available to satisfy the SINR (signal to interference and noise ratio) constraints for all links in the given valid schedule. In each iteration nodes adjust their transmission powers as follows:

\[
P_{\text{new}} = \frac{\beta}{\text{SINR}} * P_{\text{current}}
\]

where \(P_{\text{new}}\) is the new transmission power level in the next iteration, \(P_{\text{current}}\) is the current transmission power level and \(\beta\) is the SINR threshold. If the maximum number of iterations is reached and still there are nodes which cannot meet the SINR constraints, i.e., if the valid scenario is not admissible, the scheduling algorithm excludes the link with the minimum SINR. The power control algorithm is repeated until an admissible transmission scenario is found. Then, the nodes start transmission using the computed transmission powers in the current slot.

IV. Frequency and Time Scheduling
The use of multiple frequency channels is an efficient way to improve the capacity of wireless networks. Simultaneous
transmissions on different frequencies (if the frequencies are not orthogonal, different frequencies may also be conflicting. We use non-conflicting frequencies and different frequencies interchangeably in the text) can take place without interference in the same spatial neighborhood. In this section we introduce a simple scheduling method which separately assigns the time slots and frequencies on a tree topology. Motivation for this proposal is as follows: • Intersecting links, which are defined as the links with a common destination, cannot transmit on the same time slot since they have to wait for each other's transmission. Assigning non-conflicting frequencies to these nodes does not improve the situation, either. Then the receiver should be assigned a frequency and the senders' interfering links should not get the same time slot and frequency. Since our aim is to minimize the number of time slots, the best option then is to assign the same time slot on non-conflicting frequencies.

V. Routing Strategies, Parent Selection
In the previous sections we have discussed the methods to cope with interference. Other than interference, connectivity may also limit the performance of scheduling. Consider the nodes that select the same parent. They have to wait for each others’ transmission which simply increases the length of a schedule. In this section we investigate the methods that can adjust the degree of connectivity on a tree topology. One option would be to construct balanced trees. We compared the scheduling performance on minimum-hop balanced and unbalanced trees. However, no improvement is observed with balanced trees since the sink node often remains the high-degree bottleneck (due to the space limitations we cannot represent the results in this paper). To avoid the bottlenecks, there should be a limitation on the number of children per parent. Thus, we explore scheduling on degree constrained tree topologies.

VI. Orthogonal Frequencies vs. Interfering Frequencies
In the current literature on multi-channel protocols, mostly either it is assumed that the channels are perfectly orthogonal (interference-free) or the use of overlapping channels is simply avoided. Assumption of perfect orthogonal channels fails in practice since radio signals are not bound to a single point in the spectrum but are distributed around a mid frequency so that channel overlap/interference is observed between adjacent bands. On the other hand, the use of only orthogonal channels cannot utilize the spectrum efficiently. For instance, the 802.11b standards define 11 channels of which only three are orthogonal. Careful use of not only 3 channels but all 11 channels by controlling the interference can significantly improve the system performance [7]. Interference between overlapping channels is influenced by the transmission power, distance between transmitters, channel spacing and transceiver characteristics [8]. We compare the impact of orthogonal frequencies and interfering frequencies on the scheduling performance for two different transceiver platforms. Moreover, we investigate the correctness of schedules generated with the orthogonal frequencies assumption.

VII. Evolution
A closely related study by Gandham et al. [13] focuses on finding a TDMA schedule that minimizes the total time required to complete a convergecast in WSN. The aim is to guarantee a bound on convergecast latency. They propose a scheduling algorithm that requires at most $3N$ time slots where $N$ is the number of nodes in the network. Although, they address the same problem as ours, we focus on methods that can reduce the schedule length by
eliminating the limitations due to interference and connectivity where they are interested in showing the bounds on the schedule length with different network organizations. Minimum frame length scheduling for TDMA wireless networks is also studied by Das et al. [14]. They develop mixed integer linear programming models for solving the problem optimally but their focus is only on power control and they consider the availability of sectored antennas. Joint scheduling and transmission power control is a well studied method [1], [5], [15], [16] to increase the throughput by limiting the interference effects in wireless networks. Moscibroda theoretically proves that non-linear power control mechanisms can significantly help to minimize the scheduling complexity and also improve the capacity of WSN even in the worst case [1]. However, we show that in a practical setting where the nodes have limited discrete transmission power levels it may not be always possible to overcome the excessive interference. The use of multiple frequency channels is an efficient way to improve the capacity of wireless networks [17], [18], [19]. If the number of frequencies is sufficient and frequencies are assigned properly, the excessive levels of interference can be eliminated. Different than the previous work, we introduce a simple frequency and time scheduling method. Instead of assigning frequencies to the links or nodes we consider a receiver based frequency assignment which is suitable for aggregated data collection on a tree topology. There exist studies evaluating the performance of graph based and SINR based interference models [6], [20]. Grönkvist et al. [6] report that the graph based models may result in serious interference since the model does not consider the accumulated interference. Our observations confirm the already reported results and we further give implications on which topologies the graph based models may not be accurate according to the density of the network and the path loss metric.

VIII. Conclusion

The proposed MAC layer solution makes use of burst transmissions with low-overhead local advertisements to avoid contention during the burst-periods. Using extensive simulations, we observe that our proposed approach can achieve up to two times higher throughput and four times higher energy efficiency than CSMA in static event scenarios, with an increasing performance gap as the network gets overloaded. We have explored a number of techniques to enhance the aggregated data collection over a tree topology in WSN. Our initial approach was to use interference-aware minimum frame-length TDMA-scheduling that enables spatial reuse. The second step was to combine the scheduling with transmission power control. Although the well studied transmission power control method helped to overcome interference and reduce schedule length, it was found to be not always the best solution in a practical setting due to the limitations on the power settings of the nodes. The next step was to consider the use of multiple frequency channels. With the extensive simulations we found that for networks of about a hundred nodes, the use of multi-frequency scheduling can suffice to eliminate most of the interference. Then, data collection rate was no longer interference-limited, but rather topology-limited. Thus, our final approach was to use an appropriate degree-constrained tree construction. Simulation results showed that, combining the last two techniques can provide an order of magnitude improvement compared to the simple approach of scheduling on a single channel with minimum-hop routing trees.

References


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