ENERGY EFFICIENT TDMA SCHEDULE FOR DATA AGGREGATION IN TREE BASED WIRELESS SENSOR NETWORKS

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ABSTRACT— *We study the following fundamental question - how quick can information be composed from a wireless sensor network structured as tree? In wireless sensor networks the collection of data from a set of sensors toward a frequent sink over a tree based routing topology is a primary operations. It is important to provide an assurance on the delivery time as well as increase the rate of such data collection in many applications. We first consider the time scheduling on a single frequency channel with the aim of minimizing the number of time slots required (schedule length) to complete a convergecast. Next, we combines scheduling with transmission power control to mitigate the effects of interference, and show that while power controls helps in reducing the schedule length under single frequency and scheduling transmissions using multiple frequencies is more efficient. We are given lower bounds on the schedule length when interference is completely eliminated and propose algorithms achieve this bounds. We also evaluates the performance of various channel assignment methods are find empirically that for moderate size networks of about 100 nodes, then the use of multi-frequency scheduling can suffice to eliminate most of the interference. Finally, we evaluate the impact of different interference and channel models on the schedule length.*

1. INTRODUCTION

Convergecast is the collection of data from a set of sensors toward a common sink over a tree- based routing topology is a fundamental operation in wireless sensor networks (WSN). In many applications, it is crucial to provide a guarantee on the delivery time as well as increase the rate of such data collection. For instance, in mission-critical and safety applications where sensor nodes are deployed to detect oil/gas leak or structural damage. The actuators and controllers needs to receive data from all the sensors within a specific deadline and failure of which might lead to unpredictable and catastrophic events. On the other hand, applications such as permafrost monitoring require periodic and fast data delivery over long periods of time which falls under the category of continuous data collection. A wireless sensor consists of a small processor, memory, power, sensing and transceiver units. Additionally, sensor can have location finding system, mobilizer and a power generator which are application dependent sub-units. The size and weight of a sensor limits the processing capability, amount of memory and the amount of power that it can store. A Major part of Power consumed by a sensor is used to run the transceiver circuitry. As, the transmission range of a sensor increases the power consumed by the transceiver also increases. Since they have limited transmission range sensors together form a multi-hop radio network to accomplish communication amongst themselves.

Many sensor applications require broadcasting and/or convergecasting. Broadcasting is the process of information dissemination from a node in the network to all other nodes in the network. Retinal prosthesis of is one such application. Convergecast is the aggregation of data collected at each node in the network towards a central node in the network. A convergecast is usually preceded by a broadcast or both can occur in an interleaved manner. An example of this communication pattern is the environment monitoring application in which sensors embedded near the area of interest collect and transmit data to an external monitoring station in response to a query (which is broadcast) by the monitoring station.

Collisions occur in a wireless network when multiple nodes simultaneously transmit to the same node over the same channel or a receiver is in the transmission range of another communication taking place over the same channel. Such collisions waste resources (e.g. bandwidth and energy) as well as increases data latency and hence they are undesirable. For broadcast and convergecast to work in a collision-free manner, we have to construct a tree and allocate a schedule that specifies for each node in the network the time-slots in which it will receive data from other nodes and the time-slot(s) in which it will send data to other node(s). This schedule is assigned for a particular duration of time and it gets repeated for each such time duration. This form of allocating timeslots and avoiding collision is called TDMA channel allocation.

For periodic traffic, it is well known that contention- free medium access control (MAC) protocols such as TDMA (Time Division Multiple Access) are better fit for fast data collection, they can eliminate collisions and retransmissions and provide guarantee on the completion time as opposed to contention-based proto-cols. However, the problem of constructing conflict-free (interference-free) TDMA schedules even under the simple graph-based interference model has been proved to be NP-complete. In this work, we consider TDMA framework and design polynomial-time heuristics to minimize the schedule length for both types of convergecast. And also find lower bounds on the achievable schedule lengths and compare the performance of our heuristics with these bounds.

We start by identifying the primary limiting factors of fast data collection, they are (i) *interference* in the wireless medium (ii) *half-duplex* transceivers on the sensor nodes and (iii) *topology* of the network. We explore, the number of different techniques that provide a hierarchy of successive improvements, among which is an interference-aware, minimum-length and TDMA scheduling that enables spatial reuse. To achieve further improvement, we combines the transmission power control with scheduling and use multiple frequency channels to enable more concurrent transmissions.

We show that once, the multiple frequencies are employed along with spatial-reuse TDMA, then the data collection rate often no longer remains limited by interference but by the topology of the network. In the final step, we construct network topologies with specific properties that help in further enhancing rate. Our conclusion is that, combining these different techniques can provide an order of magnitude improvement for aggregated convergecast, and factor of two improvement for raw-data convergecast compared to single-channel TDMA scheduling on minimum-hop routing trees.

2. ALLIED WORK

As the new concepts in this paper, we introduce the polynomial-time heuristics for TDMA scheduling for both types of data collection that is Algorithms 1 and 2. And also prove that, they do achieve the lower bound of data collection time once interference is eliminated. Besides, we elaborate performance of our previous work, a receiver-based channel assignment method, and com-pare its efficiency with other channel assignment methods and introduce heuristics for constructing optimal routing trees to further enhance data collection rate. Then the following lists our key findings and contributions:

Bounds on Convergecast Scheduling:

We show that if all interfering links are eliminated, the schedule length for aggregated convergecast is lower bounded by the maximum node degree in the routing tree and for raw-data convergecast by max(2nk − 1,N), where nk is the maximum number of nodes on any branch in the tree and N is the number of source nodes. Then we introduce optimal time slot assignment schemes under this scenario which achieve these lower bounds.

Evaluation of Power Control under Realistic Setting:

It was shown recently that under the idealized setting of unlimited power continuous range and transmission power control can provide an unbounded improvement in the asymptotic capacity of aggregated convergecast. In this work, we evaluates the behavior of an optimal power control algorithm under realistic settings considering the limited discrete power levels available in today’s radios. And we find that for moderate size networks of 100 nodes power control can reduce the schedule length by 15 − 20%.

Evaluation of Channel Assignment Methods:

Using extensive simulations, we show that, the scheduling transmissions on different frequency channels is more effective in mitigating interference as com- pared to transmission power control. We evaluates the performance of three different channel assignment methods: (i) Joint Frequency and Time Slot Scheduling (JFTSS) (ii) Receiver-Based Channel Assignment (RBCA) and (iii) Tree-Based Channel Assignment (TMCP). These methods consider the channel assignment problem at different levels: the link level, node level and cluster level. We show that aggregated convergecast TMCP performs better than JFTSS and RBCA on minimum-hop routing trees, For raw-data convergecast, RBCA and JFTSS perform better than TMCP. Since, latter suffers from interference inside the branches due to con- current transmissions on the same channel.

Impact of Routing Trees:

We investigate the effect of network topology on the schedule length and show that for aggregated convergecast the performance can be improved by up to 10 times on degree- constrained trees using multiple frequencies as compared to that on minimum-hop trees using a single frequency. For raw-data convergecast, multi-channel scheduling on capacitated minimal spanning trees can reduce the schedule length by 50%**.**

Impact of Channel Models and Interference:

Under the setting of multiple frequencies, simplifying assumption often made is that the frequencies are orthogonal. We evaluate this assumption and show that the schedules generated may not always eliminate interference, that causing considerable packet

losses. We also compare and evaluate the two most commonly used interference models: (i) the graph-based protocol model and (ii) the SINR (Signal-to-Interference-plus-Noise Ratio) based physical model.

TDMA Scheduling Of Convergecasts

In this section, we first focus on periodic aggregated convergecast and then on one-shot raw-data convergecast. Our objective is calculate the minimum achievable schedule lengths using an interference-aware TDMA protocol. First we consider the case where the nodes communicate on the same channel using a constant transmission power, and discuss improvements using transmission power control and multiple frequencies in the next section.

Periodic Aggregated Convergecast:

In this section, we consider the scheduling problem where packets are aggregated. Data aggregation is a commonly used to technique in WSN, can eliminate redundancy and minimize the number of transmissions. Thus the saving energy and improving network lifetime. Aggregations can be performed in many ways, by suppressing duplicate messages, using data compression, packet merging techniques and taking advantage of the correlation in the sensor readings.

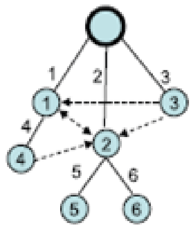


Fig 1.(a) Schedule length of 6 in the presence of interfering links

	Frame 1						Frame 2					
	S1	S2	S3	S4	S5	S6	S1	S2	S3	S4	S5	S6
s	1	2	3	-	-	-	{1,4}	{2,5,6}	3	-	-	-
1	-	-	-	4	-	-	-	-	-	4	-	-
2	-	-	-	-	5	6	-	-	-	-	5	6

Fig 1.(b) Node ids from which (aggregated) packets are received by their corresponding parents in each time slot over different frames

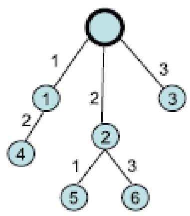


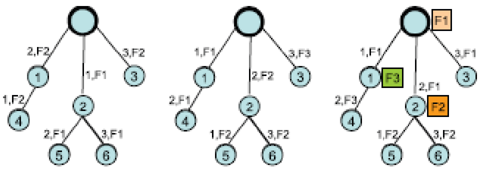
Fig 1.(c) Schedule length of 3 using BFS-TIME SLOTASSIGNMENT when all the interfering links are eliminated

One-Shot Raw-Data Convergecast:

In this section, we consider one-shot data collection where every sensor reading is equally important, and aggregation may not be desirable or even possible. Each of the packets has to be individually scheduled at each hop en route to the sink. Before, we focus on minimizing the schedule length. In the case of periodic aggregated convergecast where a pipelining takes place and each of the tree edges is scheduled only once within each frame. Here the edges could be scheduled multiple times and there is no pipelining.

3. MULTI-CHANNEL SCHEDULING

Multi-channel communication is an efficient method to eliminate interference by enabling concurrent transmissions over different frequencies. Although typical WSN radios operates on a limited bandwidth and their operating frequencies can be adjusted, thus allowing faster data delivery and concurrent transmissions. In this section, we explains three channel assignment methods that consider the problem at different levels allowing us to study their pros and cons for both types of convergecast. These methods consider the channels assignment problem at different levels: the link level (JFTSS), node level (RBCA), or cluster level (TMCP).



(a) (b) (c)

Fig. 4: Scheduling with multi-channels for aggregated convergecast:
(a) Schedule generated with JFTSS. (b) Schedule generated with TMCP. (c) Schedule generated with RBCA.

4. CONCLUSIONS

In this paper, we studied fast convergecast in WSN where nodes communicate using a TDMA protocol to minimize the schedule length. Addressed the fundamental limitations due to interference and half-duplex transceivers on the nodes and explored techniques to overcome the same. We found that while transmission power control helps in reducing the schedule lengths, multiple channels are more effective. We also observed that node-based (RBCA) and link-based (JFTSS) channel assignment schemes are more efficient in terms of eliminating interference as compared to assigning different channels on different branches of the tree (TMCP).

Once interference is completely eliminated, we proved that half-duplex radios the achievable schedule length is lower-bounded by the maximum degree in the routing tree for aggregated convergecast, and by $\max(2nk - 1, N)$ for raw-data convergecast. Using optimal convergecast scheduling algorithms, we showed the lower bounds are achievable once a suitable routing scheme is used. We demonstrated up to an order of magnitude reduction in the schedule length for aggregated, and a 50% reduction for raw-data convergecast. In future, we will explore scenarios with variable amounts of data and implement and evaluate the combination of the schemes considered.

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