Fast Data Collection with Interference and Life Time in Tree Based Wireless Sensor Networks

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ABSTRACT: *We investigate the following fundamental question - how fast can information be collected from a wireless sensor network organized as tree? To address this, we explore and evaluate a number of different techniques using realistic simulation models under the many-to-one communication paradigm known as converge cast. We first consider time scheduling on a single frequency channel with the aim of minimizing the number of time slots required (schedule length) to complete a converge cast. Next, we combine scheduling with transmission power control to mitigate the effects of interference, and show that while power control helps in reducing the schedule length under a single frequency, scheduling transmissions using multiple frequencies is more efficient. We give lower bounds on the schedule length when interference is completely eliminated, and propose algorithms that achieve these bounds. We also evaluate the performance of various channel assignment methods and find empirically that for moderate size networks of about 100 nodes, the use of multi-frequency scheduling can suffice to eliminate most of the interference. Then, the data collection rate no longer remains limited by interference but by the topology of the routing tree. To this end, we construct degree-constrained spanning trees and capacitated minimal spanning trees, and show significant improvement in scheduling performance over different deployment densities. Lastly, we evaluate the impact of different interference and channel models on the schedule length.*

Keywords— *Convergecast, TDMA scheduling, multiple channels, power-control, routing trees.*

I. INTRODUCTION

CONVERGECAST, namely the collection of data from a set of sensors toward a common sink over a treebased routing topology, is a fundamental operation in wireless sensor networks (WSN) [1]. 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 safety and mission-critical applications where sensor nodes are deployed to detect oil/gas leak or structural damage, the actuators and controllers need to receive data from all the sensors within a specific deadline [2], failure of which might lead to unpredictable and catastrophic events. This falls under the category of one-shot data collection. On the other hand, applications such as permafrost monitoring [3] require periodic and fast data delivery over long periods of time, which falls under the category of continuous data collection.

In this paper, we consider such applications and focus on the following fundamental question: "*How fast can data be streamed from a set of sensors to a sink over a treebased topology?*" We study two types of data collection: (i) *aggregated convergecast* where packets are aggregated at each hop, and (ii) *raw-data convergecast* where packets are individually relayed toward the sink. Aggregated con-vergecast is applicable when a strong spatial correlation exists in the data, or the goal is to collect summarized information such as the maximum sensor reading. Rawdata convergecast, on the other hand, is applicable when every sensor reading is equally important, or the correlation is minimal. We study aggregated convergecast in the context of continuous data collection, and rawdata convergecast for one-shot data collection. These two types correspond to two extreme cases of data collection. In an earlier work [4], the problem of applying different aggregation factors, i.e., data compression factors, was studied, and the latency of data collection was shown to be within the performance bounds of the two extreme cases of no data compression (raw-data convergecast) and full data compression (aggregated convergecast). For periodic traffic, it is well known that contentionfree medium access control (MAC) protocols such as TDMA (Time Division Multiple Access) are better fit for fast data collection, since they can eliminate collisions and retransmissions and provide guarantee on the completion time as opposed to contention-based protocols However, the problem of constructing conflictfree (interference-free) TDMA schedules even under the simple graph-based interference model has been proved to be NP-complete. In this work, we consider a TDMA framework and design polynomial-time heuristics to minimize the schedule length for both types of convergecast. We also find lower bounds on the achievable schedule lengths and compare the performance of ourheuristics with these bounds.

II. MOTIVATION

Existing System:

Existing work had the objective of minimizing the completion time of converge casts. However, none of the previous work discussed the effect of multi-channel scheduling together with the comparisons of different channel assignment techniques and the impact of routing trees and none considered the problems of aggregated and raw converge cast, which represent two extreme cases of data collection.

Proposed System:

Fast data collection with the goal to minimize the schedule length for aggregated converge cast has been studied by us in, and also by others in, we experimentally investigated the impact of transmission power control and multiple frequency channels on the schedule length Our present work is different from the above in that we evaluate transmission power control under realistic settings and compute lower bounds on the schedule length for tree networks with algorithms to achieve these bounds. We also compare the efficiency of different channel assignment methods and interference models, and propose schemes for constructing specific routing tree topologies that enhance the data collection rate for both aggregated and raw-data converge cast.

We start by identifying the primary limiting factors of fast data collection, which are: (i) *interference* in the wireless medium, (ii) *half-duplex* transceivers on the sen- sor nodes, and (iii) *topology* of the network. Then, we explore a number of different techniques that provide a hierarchy of successive improvements, the simplest among which is an interference-aware, minimum-length, TDMA scheduling that enables spatial reuse. To achieve further improvement, we combine transmission power control with scheduling, and use multiple frequency channels to enable more concurrent transmissions. We show that once multiple frequencies are employed along with spatial-reuse TDMA, the data collection rate often no longer remains limited by interference but by the topology of the network. Thus, in the final step, we construct network topologies with specific properties that help in further enhancing the rate. Our primary conclusion is that, combining these different techniques can provide an order of magnitude improvement for aggregated convergecast, and a factor of two improvement for raw-data convergecast, compared to single-channel TDMA scheduling on minimum-hop routing trees. Although the techniques of transmission power control and multi-channel scheduling have been well studied for eliminating interference in general wireless networks, their performances for bounding the completion of data collection in WSNs have not been explored in detail in the previous studies. The fundamental novelty of our approach lies in the extensive exploration of the efficiency of transmission power control and multichannel communication on achieving fast convergecast operations in WSNs. Besides, we evaluate the impact of routing trees on fast data collection and to the best of our knowledge this has not been the topic of previous studies. As we will discuss in Section 2, some of the existing work had the objective of minimizing the completion time of convergecasts. However, none of the previous work discussed the effect of multi-channel scheduling together with the comparisons of different channel assignment techniques and the impact of routing trees and none considered the problems of aggregated and raw convergecast, which represent two extreme cases of data collection, together. As the new concepts in this paper, we introduce polynomial-time heuristics for TDMA scheduling for both types of data collection, i.e., Algorithms 1 and 2, and prove that they do achieve the lower bound of data collection time once interference is eliminated. Besides, we elaborate on the performance of our previous work, a receiver-based channel assignment method, and compare its efficiency with other channel assignment methods and introduce heuristics for constructing optimal routing trees to further enhance data collection rate. 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. We then 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 [5] that under the idealized setting of unlimited power and continuous range, transmission power control can provide an unbounded improvement in the asymptotic capacity of aggregated convergecast. In this work, we evaluate the behavior of an optimal power control algorithm [6] under realistic settings considering 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 schedule length by $15-20\%$.

Evaluation of Channel Assignment Methods:

Using extensive simulations, we show that scheduling transmissions on different frequency channels is more effective in mitigating interference as compared to transmission power control. We evaluate the performance of three different channel assignment methods: (i) *Joint Frequency and Time Slot Scheduling* (JFTSS), (ii) *Receiver-Based Channel Assignment* (RBCA) [7], and (iii) *Tree-Based Channel Assignment (TMCP)* [8]. These methods consider the channel assignment problem at different levels: the link level, node level, or cluster level. We show that for aggregated convergecast, TMCP performs better than JFTSS and RBCA on minimum-hop routing trees, while performs worse on degree-constrained trees. For raw-data convergecast, RBCA and JFTSS perform better than TMCP, since the latter suffers from interference inside the branches due to concurrent 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 degreeconstrained 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, one simplifying assumption often made is that the frequencies are orthogonal to each other. We evaluate this assumption and show that the schedules generated may not always eliminate interference, thus causing considerable packet losses. We also evaluate and compare the two most commonly used interference models.

III. LITERATURE SURVEY

Fast data collection with the goal to minimize the schedule length for aggregated convergecast has been studied by us in and also by others.In we experimentally investigated the impact of transmission power control and multiple frequency channels on the schedule length, while the theoretical aspects were discussed where we proposed constant factor and logarithmic approximation algorithms on geometric networks (disk graphs). Raw-data convergecast has been studied where a distributed time slot assignment scheme is proposed by Gandham *et al.* to minimize the TDMA schedule length for a single channel. The problem of joint scheduling and transmission power control is studied by Moscibroda for constant and uniform traffic demands. Our present work is different from the above in that we evaluate transmission power control under realistic settings and compute lower bounds on the schedule length for tree networks with algorithms to achieve these bounds. We also compare the efficiency of different channel assignment methods and interference models, and propose schemes for constructing specific routing tree topologies that enhance the data collection rate for both aggregated and raw-data convergecast. The use of orthogonal codes to eliminate interference has been studied by Annamalai *et al.* [10], where nodes are assigned time slots from the bottom of the tree to the top such that a parent node does not transmit before it receives all the packets from its children.

This problem and the one addressed by Chen *et al.* [11] are for one-shot raw-data convergecast. In this work, since we construct degree-constrained routing topologies to enhance the data collection rate, it may not always lead to schedules that have low latency, because the number of hops in a tree goes up as its degree goes down. Therefore, if minimizing latency is also a requirement, then further optimization, such as constructing bounded-degree, bounded-diameter trees, is needed. A study along this line with the objective to minimize the maximum latency is presented by Pan and Tseng [15], where they assign a beacon period to each node in a Zigbee network during which it can receive data from all its children. For raw-data convergecast, Song *et al.* [12] presented a time-optimal, energy-efficient, packet scheduling algorithm with periodic traffic from all the nodes to the sink. Once interference is eliminated, their algorithm achieves the bound that we present here, however, they briefly mention a 3-coloring channel assignment scheme, and it is not clear whether the channels are frequencies, codes, or any other method to eliminate interference.

Moreover, they assume a simple interference model where each node has a circular transmission range and cumulative interference from concurrent multiple senders is avoided. Different from their work, we consider multiple *frequencies* and evaluate the performance of three different channel assignment methods together with evaluating the effects of transmission power control using realistic interference and channel models, i.e., physical interference model and overlapping channels and considering the impact of routing topologies. Song *et al.* [12] extended their work and proposed a TDMA based MAC protocol for high data rate WSNs in [16]. TreeMAC considers the differences in load at different levels of a routing tree and assigns time slots according to the depth, i.e. the hop count, of the nodes on the routing tree, such that nodes closer to the sink are assigned more slots than their children in order to mitigate congestion. However, TreeMAC operates on a single channel and achieves 1/3 of the maximum throughput similar to the bounds presented by Gandham *et al.* [1] since the sink can receive every 3 time slots. The problem of minimizing the schedule length for raw-data convergecast on single channel is shown to be NP-complete on general graphs by Choi *et al.* [13]. Maximizing the throughput of convergecast by finding a shortest-length, conflict-free schedule is studied by Lai *et al.* [14], where a greedy graph coloring strategy assigns time slots to the senders and prevent interference. They 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.

However, since the sink remains as the bottleneck, sending data over different paths does not reduce the schedule length. As we will show in this paper, the improvement due to the routing structure comes from using capacitated minimal spanning trees for raw-data convergecast, where the number of nodes in a subtree is no more than half the total number of nodes in the remaining subtrees. The use of multiple frequencies has been studied extensively in both cellular and ad hoc networks, however, in the domain of WSN, there exist a few studies that utilize multiple channels To this end, we evaluate the efficiency of three particular schemes that treat the channel assignment at different levels.

IV. SYSTEM ANALYSIS & DESIGN

Algorithms used:

1. BFSTIMESLOTASSIGNMENT.

2. LOCAL-TIMESLOTASSIGNMENT

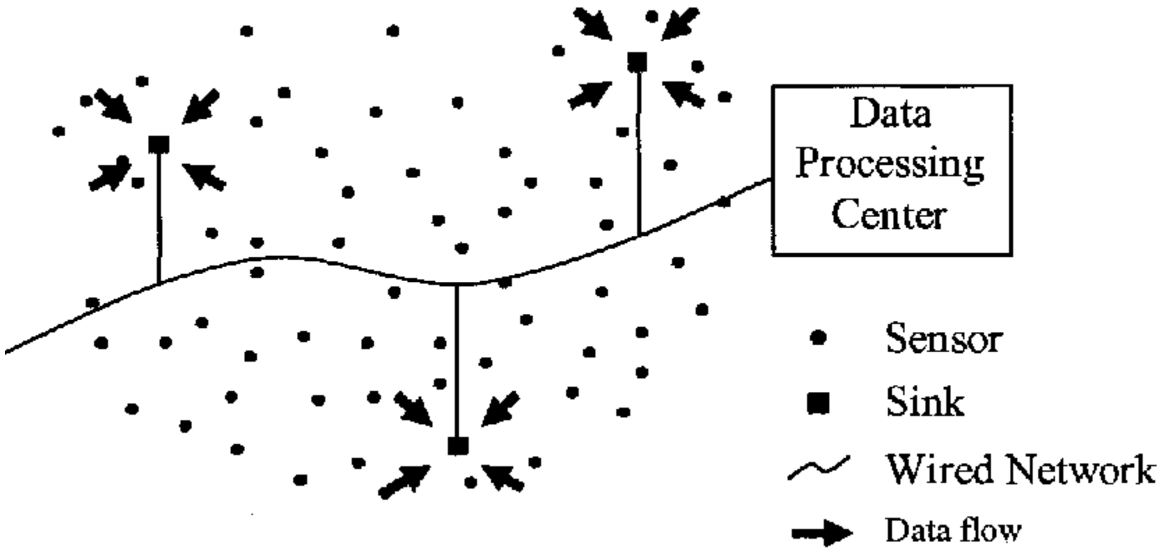
Algorithm 1 BFS-TIMESLOTASSIGNMENT

1. Input: T = (V, ET)
2. While ET _= φ do
3. e ← next edge from ET in BFS order
4. Assign minimum time slot t to edge e respecting adjacency and interfering constraints
5. ET ← ET \ {e}

6. end while

Algorithm 2 LOCAL-TIMESLOTASSIGNMENT
1. node.buffer = full
2. if {node is sink} then
3. Among the eligible top-subtrees, choose the one with the largest number of total (remaining) packets, say top-subtree i
4. Schedule link (root(i), s) respecting interfering constraint
5. else
6. if {node.buffer == empty} then
7. Choose a random child c of node whose buffer is full
8. Schedule link (c, node) respecting interfering constraint
9. c.buffer = empty
10. node.buffer = full
11. end if
12. end if

Architecture



Modules:
1. Periodic Aggregated Converge cast.
2. Transmission Power Control
3. Aggregated Data Collection
4. Raw Data Collection
5. Tree-Based Multi-Channel Protocol (TMCP)

1. Periodic Aggregated Converge cast.

Data aggregation is a commonly used technique in WSN that can eliminate redundancy and minimize the number of transmissions, thus saving energy and improving network lifetime. Aggregation can be performed in many ways, such as by suppressing duplicate messages; using data compression and packet merging techniques; or taking advantage of the correlation in the sensor readings.

We consider continuous monitoring applications where perfect aggregation is possible, i.e., each node is capable of aggregating all the packets received from its children as well as that generated by itself into a single packet before transmitting to its parent. The size of aggregated data transmitted by each node is constant and does not depend on the size of the raw sensor readings.

2. Transmission Power Control

We evaluate the impact of transmission power control, multiple channels, and routing trees on the scheduling performance for both aggregated and raw-data converge cast.. Although the techniques of transmission power control and multi-channel scheduling have been well studied for eliminating interference in general wireless networks, their performances for bounding the completion of data collection in WSNs have not been explored in detail in the previous studies. The fundamental novelty of our approach lies in the extensive exploration of the efficiency of transmission power control and multichannel communication on achieving fast converge cast operations in WSNs.

3. Aggregated Data Collection

We augment their scheme with a new set of rules and grow the tree hop by hop outwards from the sink. We assume that the nodes know their minimum-hop counts to sink.

4. Raw Data Collection

The data collection rate often no longer remains limited by interference but by the topology of the network. Thus, in the final step, we construct network topologies with specific properties that help in further enhancing the rate. Our primary conclusion is that, combining these different techniques can provide an order of magnitude improvement for aggregated converge cast, and a factor of two improvement for raw-data converge cast, compared to single-channel TDMA scheduling on minimum-hop routing trees.

5. Tree-Based Multi-Channel Protocol (TMCP)

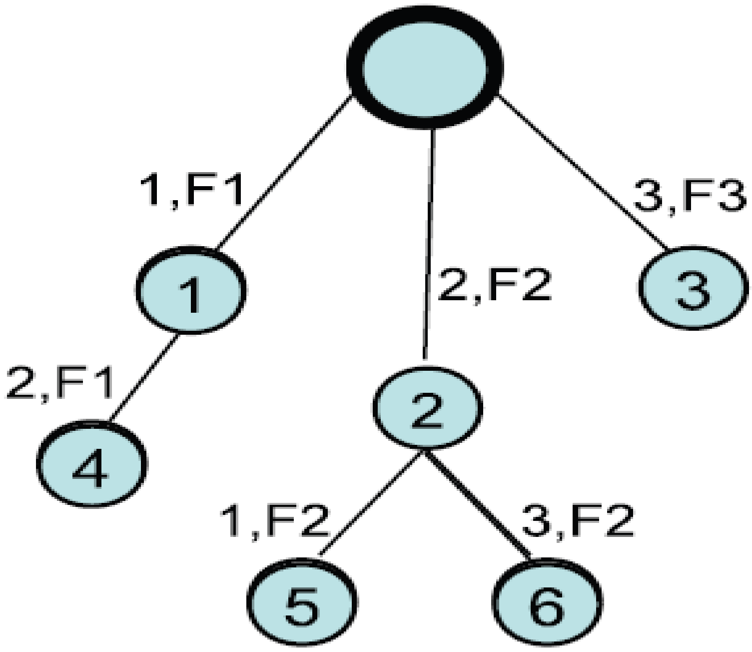
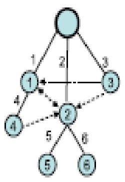


Fig: Schedule generated with TMCP

TMCP is a greedy, tree-based, multi-channel protocol for data collection applications. It partitions the network into multiple sub trees and minimizes the intra tree interference by assigning different channels to the nodes residing on different branches starting from the top to the bottom of the tree. Figure shows the same tree given in Fig. which is scheduled according to TMCP for aggregated data collection. Here, the nodes on the leftmost branch is assigned frequency F1, second branch is assigned frequency F2 and the last branch is assigned frequency F3 and after the channel assignments, time slots are assigned to the nodes with the BFS Time Slot Assignment algorithm.

Advantage

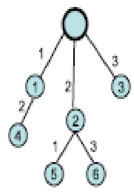
Advantage of TMCP is that it is designed to support converge cast traffic and does not require channel switching. However, contention inside the branches is not resolved since all the nodes on the same branch communicate on the same channel



(a)

	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

(b)



(c)

Fig. Aggregated convergecast and pipelining: (a) Schedule length of 6 in the presence of interfering links. (b) Node ids from which (aggregated) packets are received by their corresponding parents in each time slot over different frames. (c) Schedule length of 3 using BFS-TIMESLOTASSIGNMENT when all the interfering links are eliminated.

V. RESULTS

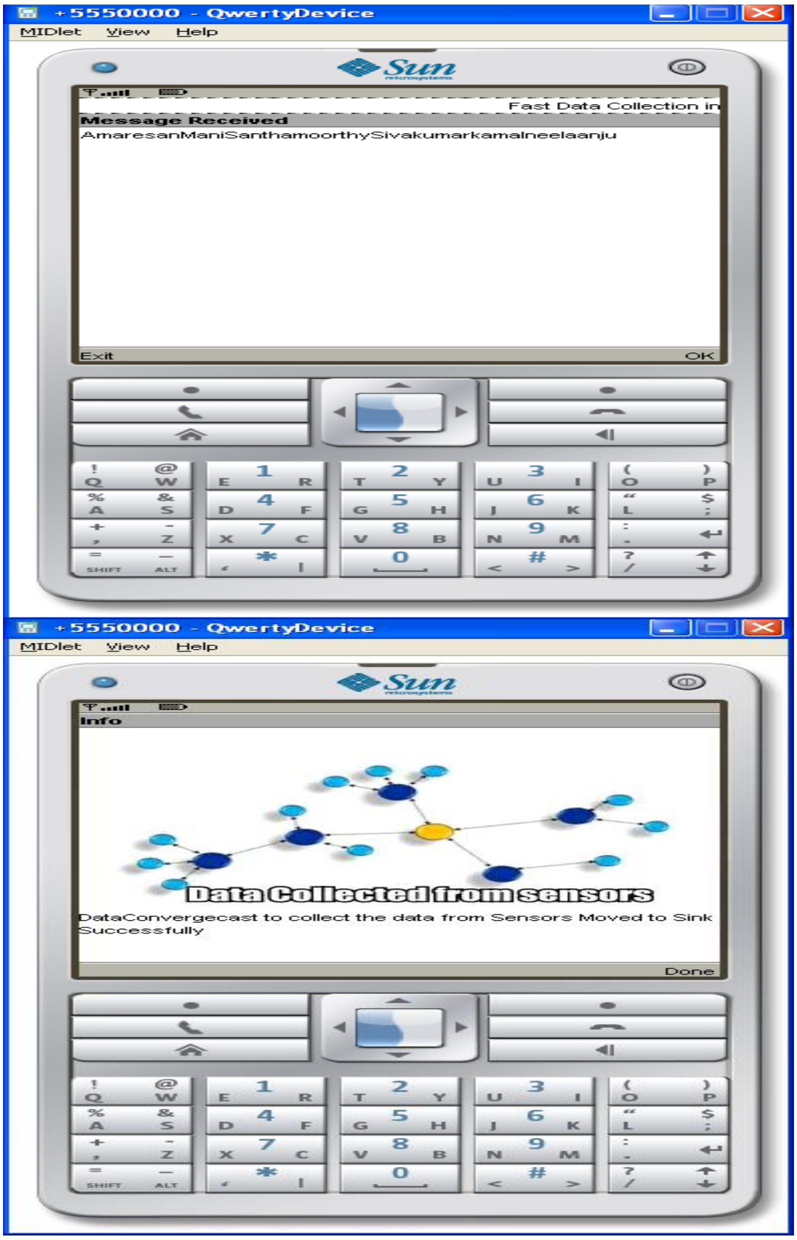


Fig: Showing Results Algorithm Implemented Screen

VI. CONCLUSION

In this paper, we studied fast converge cast in WSN where nodes communicate using a TDMA protocol to minimize the schedule length. We 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 length, 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 with half-duplex radios the achievable schedule length is lower-bounded by the maximum degree in the routing tree for aggregated converge cast, and by max $(2nk - 1, N)$ for raw-data converge cast. Using optimal converge cast scheduling algorithms, we showed that the lower bounds are achievable once a suitable routing scheme is used. Through extensive simulations, we demonstrated up to an order of magnitude reduction in the schedule length for aggregated, and a 50% reduction for raw-data converge cast. In future, we will explore scenarios with variable amounts of data and implement and evaluate the combination of the schemes considered.

ACKNOWLEDGMENT

I would like to express my sincere thanks to my Guide and my Co-Authors for their consistence support and valuable suggestions.

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