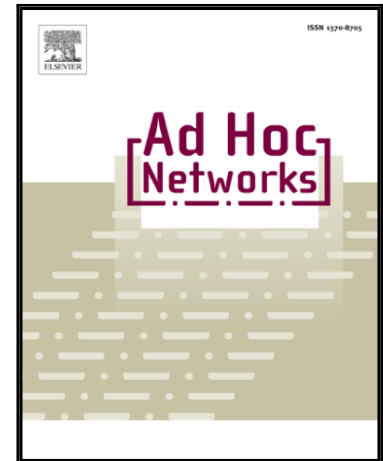


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LEEF: Latency and Energy Efficient Federation of Disjoint Wireless Sensor Segments

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Abstract- In hostile environments where explosives and natural calamities probably occur, wireless sensor networks (WSNs) are susceptible to multiple collocated failures and could be partitioned into disjoint segments. Federating the segments would be essential for restoring connectivity and enabling data sharing in the network. The federation may be achieved by populating relay nodes and providing perpetual inter-segment paths. In this paper, we tackle the federation problem while considering constrained relay availability, i.e., a limited number (k) of mobile relays to provide intermittent inter-segment connectivity that makes the problem more challenging. We propose LEEF, a novel algorithm for achieving energy-efficient federation with low inter-segment data delivery latency. LEEF strives to group the segments into k clusters in a star topology where a cluster at the center of the area serves as a hub between each pair of segment-clusters. Each cluster is served by a distinct mobile relay. In addition, LEEF opts to equalize the energy consumed by the k mobile relays due to travel and wireless communication. We analyze the properties of LEEF mathematically and validate its performance through extensive simulation experiments.

Keywords- Wireless sensor networks, Network partitioning, Topology repair, Federation, Mobile data carrier, Intermittent connectivity.

I. INTRODUCTION

Recently WSNs have attracted increased interest due to their numerous civil, scientific and military applications. In WSNs, a large set of sensors are deployed to form a mesh topology and coordinate their actions to carry out a common task [1]. Thus the inter-sensor connectivity has a significant influence on the effectiveness of WSNs and should be sustained all the time. Moreover, a WSN often operates in harsh environments and may suffer from major damage which results in the simultaneous failure of multiple collocated nodes, and causes the network to become partitioned into disjoint segments. For example, in a battlefield, some nodes in the deployment area may be attacked by explosives and get destroyed. Restoring the connectivity among segments is essential for enabling full network operation. Another scenario is when autonomous networks are to be federated to aggregate their capabilities and accomplish a common task such as search-and-rescue, military situation awareness, criminal hunting, etc.

Federating a set of disjoint segments or standalone networks has recently received growing attention from the research community. Most published solutions exploit the deployment of stationary relay nodes and formulate the federation problem as finding the locations of the least relay count to form a stable inter-segment topology [2]. In other words, a connected topology is formed by populating

sufficient relays to provide stable inter-segment data paths. However, resource scarcity makes the federation problem more challenging. In this paper, we consider the situation where the relay count is not sufficient to form a perpetual topology. Instead, multiple mobile data carriers (MDCs) are employed to form intermittent communication links among the segments. Particularly, we solve the federation problem when the MDC count is so constrained that it is not feasible to assign an MDC to each link in a minimum spanning tree of the segments.

Given the MDC availability constraint, each MDC has to serve more than two segments. We thus ought to divide the set of the segments S_T into multiple groups or clusters. This is mapped into a set cover problem which is NP-hard. Therefore, we pursue heuristics. We consider two objectives while clustering S_T : (i) *minimizing the maximum inter-segment communication delay* incurred due to the lack of stable connectivity, i.e., use of the intermittent links, which will be affected by the intra-cluster topology, i.e., a tour path of each MDC in a cluster and the inter-MDC communication; (ii) *prolonging the lifetime of the formed network* by balancing the energy consumed by the MDCs for touring in each cluster and uploading/downloading data over wireless links. The second objective incurs higher computation complexity in forming the MDC tours; yet, it is essential in order to extend the lifespan of MDCs in serving the federated network and to avoid premature depletion of the energy supply of any of them. We propose a novel algorithm for Latency and Energy Efficient Federation (LEEF) by forming a star inter-cluster topology where the energy consumption overhead in touring and data transporting is balanced among the k MDCs. LEEF consists of two phases.

In the 1st phase, LEEF reviews the layout of segments with respect to the MDC communication range, R , by modeling the damaged area as a grid based on square-cells whose side is $R/\sqrt{2}$ in length. Then, LEEF tries to find a set, CS_T , of the fewest cells which if visited, the MDCs will reach all segments. Modeling the geographical area as a cell-based grid results in a revised layout which is different depending on a value of R . LEEF focuses on federating cells in CS_T without considering R . In the next step, LEEF groups the cells of CS_T into k virtual clusters (VCs) with VC_k serving as a *hub-virtual cluster* that is formed by placing an MDC at the center of the damaged area, G around which $(k-1)$ virtual clusters are found. The resulting topology of VCs is thus star-shaped. During the

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