Conference Paper

Network Centrality: An insight for gateway designation in real-time wireless sensor networks

Miguel Gutiérrez Gaitán*
Luís Almeida*
Alejandro Figueroa
Diego Dujovne

*CISTER Research Centre

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Miguel Gutiérrez Gaitán*, Luís Almeida*, Alejandro Figueroa, Diego Dujovne

*CISTER Research Centre

Rua Dr. António Bernardino de Almeida, 431

4200-072 Porto

Portugal

Tel.: +351.22.8340509, Fax: +351.22.8321159

E-mail: mjggt@isep.ipp.pt, lda@fe.up.pt, alejandro.figueroa@unab.cl, diego.dujovne@mail.udp.cl

https://www.cister-labs.pt

Abstract

This research explores the notion of network centrality as a criterion to designate a node as sink or gateway in real-time wireless sensor networks (WSN). Since centrality is a quantitative measure of how important a node is with respect to others in a given network, we propose to designate as gateway the node with the highest centrality measure. To this purpose, four classical centrality metrics from social network analysis are evaluated, namely, (i) degree centrality, (ii) closeness centrality, (iii) betweenness centrality, and (iv) eigenvector centrality. Simulation results under varying configurations show that using network centrality as a gateway designation criterion is, in general, an effective and promising approach to improve schedulability in WSNs.

Network Centrality: An insight for gateway designation in real-time wireless sensor networks

Miguel Gutiérrez Gaitán[1,2,3], Luís Almeida[1],
Alejandro Figueroa[3], Diego Dujovne[4]
[1]CISTER/FEUP, Universidade do Porto, Portugal - mgg@fe.up.pt;
[2]CISTER/ISEP, Politécnico do Porto, Portugal
[3]Facultad de Ingeniería, Universidad Andrés Bello, Chile.
[4]Esc. de Informática y Telecomunicaciones, Universidad Diego Portales, Chile.

Abstract
This research explores the notion of network centrality as a criterion to designate a node as sink or gateway in real-time wireless sensor networks (WSN). Since centrality is a quantitative measure of how important a node is with respect to others in a given network, we propose to designate as gateway the node with the highest centrality measure. To this purpose, four classical centrality metrics from social network analysis are evaluated, namely, (i) degree centrality, (ii) closeness centrality, (iii) betweenness centrality, and (iv) eigenvector centrality. Simulation results under varying configurations show that using network centrality as a gateway designation criterion is, in general, an effective and promising approach to improve schedulability in WSNs.

Author Keywords. Centrality, EDF, TDMA, TSCH, WSN.

1. Motivation

WSN applications that require real-time coordination and communication are numerous and long-standing, from monitoring and control for safety-critical or military, to environmental or domestic infrastructure (Stankovic et al. 2003). WSNs usually consist of a large number of wirelessly linked nodes deployed to sense and/or control a particular environment. Typically, one of the WSN nodes acts as a sink and/or gateway for the others, thus being responsible for collecting all the sensors data (e.g. measurements), often in a centralized and convergecast fashion. While designating one of these nodes as gateway may depend on many different factors, its relative position w.r.t. the rest of the nodes has a significant impact on the overall network performance. In particular, for the case of real-time WSNs, i.e. those operating under specific timing constraints (e.g. maximum end-to-end delays), this observation is highly relevant since the problem of how to judiciously assign to a node the role of a gateway has not been explored yet for real-time performance.

In this work, we address such a challenge by proposing the notion of network centrality as a criterion to designate a node as a gateway in order to improve network schedulability. More concretely, we propose to designate as gateway the node with the highest centrality measure, particularly, using conventional centrality metrics borrowed from the field of social network analysis. Since, to the best of our knowledge, no other work in the literature address this issue from the perspective of real-time networks, we compare the results of our approach against an arbitrary (random) gateway designation.

2. Performance Evaluation

For the purposes of evaluation, we consider the network and flow models as in (Gaitán et al. 2021a), specifically, assuming the network is a mesh operating under a centralized resource-management framework which uses shortest-path routing and earliest-deadline-first (EDF) scheduling. Moreover, without loss of generality, we assume the medium-access-control

(MAC) is based on a TSCH or time-synchronized channel-hopping protocol, whose predictable nature allows us to apply the supply/demand-bound based schedulability test proposed in (Gaitán and Yomsi 2018). This test, as shown in (Gaitán et al. 2020), is a state-of-the-art schedulability assessment for TSCH WSNs under EDF. As for the centrality, we consider: (i) degree, (ii) closeness, (iii) betweenness, and (iv) eigenvector centrality metrics, as commonly defined in the literature of social network analysis. These specific metrics are chosen because, as reported in (Valente et al. 2010), are deemed as near optimally correlated, which is a highly desirable feature for the purposes of benchmarking. Here, due to space restrictions, we do not further discuss the metric definitions, but we refer the reader to the fundamental expressions commonly found in the literature, e.g. in (Rodrigues 2019). We recall that in this work, we select as gateway the node with the highest centrality.

2.1. Simulation Setup

Consider 100 test cases obtained from the random generation of network topologies with fixed number of nodes, $N = 80$, and target node density of 0.1. For each topology we select one of these N nodes as sink or gateway, according to the centrality criteria above indicated. We assume the number of radio channels is fixed, i.e. $m = 16$, and the number of real-time flows is varying according to $n \in [1,10]$. Moreover, the flow periods are generated randomly within the range $[2^4, 2^7]$ slots, and the deadlines are assumed as in implicit-deadline model. The length of the interval of evaluation for the schedulability test is set as equal to the hyper-period, here $H = 2^7 = 128$ slots. Further details about this setup, as well as about other related parameters, can be found in (Gaitán et al. 2021a). As for the centrality, we refer the reader to the centrality implementations available in MATLAB[1].

2.2. Preliminary Results

Figure 1 shows the results of the schedulability ratio evaluation of the four centrality metrics chosen when compared against a random baseline. These results suggest that under varying workload conditions, the performance of a centrality-driven designation criterion is always better than or equal to the baseline. Notably, achieving up to 40% of improvement under particular settings. From all metrics, the eigenvector centrality finished with the greatest growth in performance, while the degree centrality the lowest. Yet, since the degree centrality is the simplest one, it remains preferable in terms of computational complexity. The rest of metrics performed alike to the eigenvector centrality, while not showing clear dominance from one measure above the other. Thus, leaving this research question open for further research. We note that an alternate version of these results can be found in (Gaitán et al. 2021b), specifically, with additional details in terms of the network connectivity.

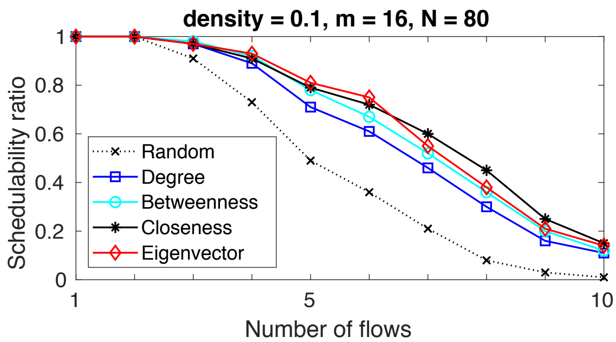

Figure 1: The schedulability ratio under varying number of flows n ∈ [1, 10].

[1] “Measure node importance - MATLAB centrality”. MathWorks. Accessed May 13, 2021. https://www.mathworks.com/help/matlab/ref/graph.centrality.html.

3. Summary & Future Work

This research proposes network centrality as a criterion for gateway designation in real-time WSNs. It reports preliminary, but promising, results for four of the most common centrality metrics in social network analysis. It further shows that any of the centrality metrics evaluated can be used to improve schedulability in real-time WSNs. Notably, achieving up to 40% of improvement w.r.t. a random baseline. More importantly, these preliminary findings offer a number of research opportunities, where we identify two as the most promising. First, to design novel methods for gateway designation in real-time WSNs motivated by the fact that arbitrary decisions are far from optimal. Second, to explore further concepts in network science that may bring additional benefits from a real-time systems perspective. We envision these two directions are not only relevant for the case of WSNs, but also for related fields such as software-defined networks (SDN) or time-sensitive-networks (TSN), where the relative sink (or controller) position, as well as further details of the structural properties of the network, have not been fully explored for real-time performance.

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