Poster Abstract: Algorithm for Distributed Duty Cycle Adherence in Multi-Hop RPL Networks

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ABSTRACT

Wireless Sensor Networks (WSNs) operating in unlicensed frequency bands or employing battery-less devices, require a Duty Cycle (DC) limit to ensure fair spectrum access or limit energy consumption. However, in multi-hop networks, it is up to the network protocol to ensure that all devices comply with such DC restrictions. We therefore developed a distributed DC adherence algorithm that limits the DC of all devices without introducing any additional packet overhead. This paper presents a brief description of the algorithm and evaluates its performance through simulation. Our results show that the algorithm can limit the DC of all devices to ensure no devices must switch off. Our algorithm therefore provides a solution for WSNs where nodes must operate below a DC limit.

CCS CONCEPTS

• **Computer systems organization → Sensor networks**; • **Networks → Network control algorithms**.

KEYWORDS

Duty Cycle, RPL, Wireless Sensor Networks

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1 INTRODUCTION

When deploying WSNs in unlicensed frequency bands, regularization of the available spectrum is required in order to ensure fair spectrum access and limit interference. This regularization usually consists of restricting the DC and/or transmission power of connected devices. A frequently used unlicensed band for WSNs is the 863-870 MHz band, regulated in the EU by limiting the DC to a value of 0.1 to 10 % [4]. While the details of the regulations are defined, it is left to protocol specifications to comply with these regulations. Next to adhering to imposed DC restrictions by law, energy constraints could be another motivation to limit a device's DC, especially with the increasing interest in battery-less WSNs. Since devices in such networks have access to a limited amount of energy, controlling their DC can prevent a node from being forced to switch off due to a lack of energy [3, 5].

We therefore propose a distributed DC adherence algorithm designed to be used in multi-hop WSNs employing Routing Protocol for Low-power and lossy networks (RPL). Our algorithm works in a distributed manner, only communicating with nearby nodes to restrict any additional packet overhead, which would increase the DC. RPL is a distance-vector routing protocol where nodes are organized in a Destination Oriented Directed Acyclic Graph (DODAG) structure and is regarded as the de facto routing protocol for multi-hop WSNs. Each node is assigned a rank reflecting its distance from the RPL root such that the rank of a parent is always smaller than the rank of its children. The calculation of a nodes' rank is performed by an Objective Function (OF). For this paper, we use Minimum Rank with Hysteresis OF (MRHOF) [2] as a basis. When nodes transmit a packet towards the RPL root, they send the packet to their preferred parent. This is their parent with the lowest path cost towards the root, which is directly impacted by the rank of that parent. For this paper we assumed a Multi-Point to Point (MP2P) scenario wherein multiple clients (RPL nodes) periodically send updates (data packets) to a single server (the RPL root), i.e., a common scenario for multi-hop WSNs [1].

The rest of the paper is structured as follows. Section 2 describes the implementation of the algorithm, section 3 evaluates the algorithm and section 4 concludes the paper.

2 DISTRIBUTED DC ADHERENCE ALGORITHM

This section describes the details of the DC adherence algorithm. Figure 1 depicts the state diagram, consisting out of five states of operation. Three states are alarm states in which nodes actively try to reduce their DC, with state 3 decreasing the DC more drastically than state 2 and 1. To change state, each node must compute its current DC locally and compare it to a threshold *trigDC*.

The **normal operation** state is the default state of the algorithm. If the locally computed DC does not exceed *trigDC*, nodes follow RPL without any adjustments. However, if the DC does exceed *trigDC* or if their preferred parent broadcasts a Child Support Request (CSR), they change to **alarm state 1: rerouting**. CSR is part of the alarm state 2 functionality and will therefore be explained during that state. The goal of the rerouting state is to reduce the number of packets a node has to forward upwards the DODAG in order to decrease its DC. Nodes therefore artificially increase their rank to make them less attractive to their children as preferred

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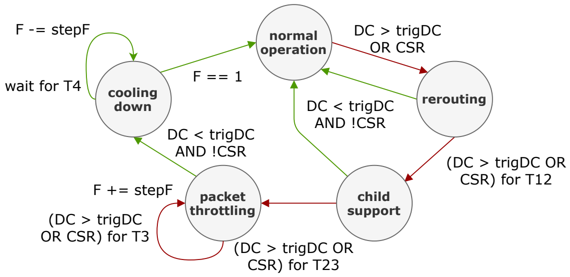

Figure 1: State diagram of the algorithm.

parent. Ideally, their children will choose a different preferred parent and the number of forwarded packets decreases as a result. If, however, this node has multiple children, only 50 % is allowed to switch preferred parent. This is to prevent all children from choosing the same new preferred parent, which might lead to a ping-pong effect where children continuously switch between two preferred parents. If a node's calculated DC drops below *trigDC*, provided its preferred parent stops broadcasting CSRs, it changes back to the normal operation state. If, however, the DC is still above *trigDC* after a duration of $T12$, the state is changed to **alarm state 2: child support**. During this state nodes ask their children for help by broadcasting a CSR, which is a bit in the currently unused *Flags* byte of a RPL DODAG Information Object (DIO) message [6]. Children who receive a CSR of their preferred parent, will change to the rerouting state. This will ideally result in less forwarding traffic for themselves and consequently less traffic for their preferred parent. As was the case for the rerouting state, nodes change back to the normal operation state as soon as their calculated DC drops below *trigDC*. Nevertheless, if the DC still exceeds *trigDC* after a duration of $T23$, nodes change to **alarm state 3: packet throttling**. Here, only a fraction F of the queued data packets will actually be transmitted. This is not valid for control packets as they are needed for the correct operation of the network protocol. The throttling starts with $F = 1 - stepF$ and decreases by *stepF* every time the calculated DC still exceeds *trigDC* for $T3$ until F reaches its minimum value of *minF*. If the calculated DC drops below *trigDC*, nodes change to the **cooling down state**. During this state, F is gradually increased again by *stepF* until $F = 1$. After that, nodes return to the normal operation state. The values for $T12$, $T23$, $T3$, $T4$, *stepF*, *minF* and *trigDC* can be used to fine-tune the algorithm to specific network needs and network requirements, but recommended values are suggested in the next section.

3 EVALUATION

To show the benefits of using the dynamic DC adherence algorithm, we performed simulations using the Cooja simulator of Contiki-NG. We simulated a multi-hop network where nine nodes periodically transmit UDP packets towards a server with a rate of 1 packet per second during a 25 min period. The maximum allowed DC is 1.3 % and the parameters of the algorithm are listed in Table 1. *trigDC* was chosen to be 1 % to provide a buffer for the 1.3 % DC limit, the timing parameters were experimentally determined to yield the best performance for the network, and *minF* was kept at 0.9 to prevent nodes from throttling too drastically. Figure 2 shows the DC for all nodes employing the algorithm and the alarm states of node 4. As a reference, we performed the same simulation without the algorithm and our results showed that three nodes would violate the DC restriction of 1.3 % by as much as 2 %. Figure 2 shows the algorithm makes sure all nodes now comply with the 1.3 % DC restriction. As a result of using the algorithm, 9.1 % of the UDP packets is being throttled. However, should the algorithm not be activated, much more packets would be lost since several nodes would be forced to shut off due to DC violations resulting in their children not being able to reconnect to the network.

Parameter	trigDC	T12	T23	T3	T4	stepF	minF
Value	1 %	5 s	5 s	1 s	1 s	0.01	0.9

Table 1: Algorithm parameters used in simulations.

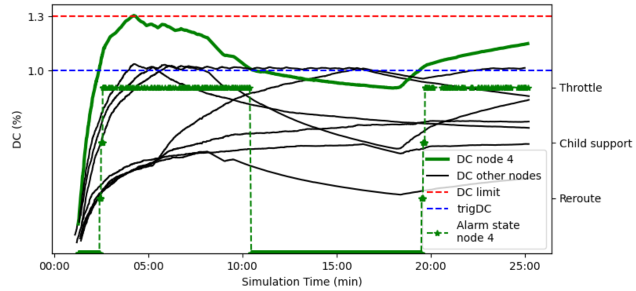

Figure 2: DC of client nodes using the DC adherence algorithm. The alarm states of node 4 are also shown.

4 CONCLUSIONS

The distributed DC adherence algorithm manages to limit the DC of devices compared to normal operation. This ensures that all devices remain operational and no devices consequently loose connectivity. The algorithm provides a solution for WSNs operating in frequency bands with DC restrictions, or in battery-less WSNs where devices cannot exceed a certain DC limit due to energy constraints.

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