A Fair Adaptive Data Rate Algorithm for LoRaWAN

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Abstract
LoRaWAN exhibits several characteristics that can lead to an unfair distribution of the Data Extracted Rate (DER) among nodes. Firstly, the capture effect leads to a strong signal suppressing a weaker signal at the gateway and secondly, the spreading codes used are not perfectly orthogonal, causing packet loss if an interfering signal is strong enough. In these conditions, nodes experiencing higher attenuation are less likely to see their packets received correctly. We develop FADR, a Fair Adaptive Data Rate algorithm for LoRaWAN that exploits the different Spreading Factors (SFs) and Transmission Powers (TPs) settings available in LoRa to achieve a fair Data Extraction Rate among all nodes while at the same time avoiding excessively high TPs. Simulations show that FADR, in highly congested cells, achieves 300% higher fairness than the minimum airtime allocation approach and 22% higher fairness than Brecht’s approach, while consuming almost 22% lower energy.

1 Introduction
Depending on the specific radio communication conditions, a LoRaWAN gateway can decode one, all, or none of the colliding packets transmitted by multiple nodes. When two signals using the same spreading factor (SF) arrive at the same time, with one signal stronger than the other by a certain threshold, the capture effect causes the stronger signal to drown the weaker. This was verified experimentally by [1]. Even when the signals use different spreading factors, this effect can still be observed, because the spreading codes are not perfectly orthogonal. However, if the power difference is below the Co-channel Interference Rejection (CIR) threshold, both signals will be decoded, whereas with the capture effect, none will. Croce et al. measured the CIR for LoRa in [2]. Furthermore, the SF allocation is affecting the probability of collision as each SF has a different airtime, e.g. using a lower SF leads to a shorter airtime which results in a lower probability of collision.

As LoRaWAN is based on Aloha, it is supposed to be a fair MAC protocol. However, the above effects introduce unfairness, favouring transmissions from nodes closer to the gateway and by those that use lower spreading factors. The impact of these issues was validated experimentally, with all nodes allocated the same transmission power level (TP), and the SFs allocated uniformly, in the order of distance from the gateway. Figure 1a shows Jain’s fairness index, ζ = (Σn=1 DE Ri)2 / n Σn=1 DE R2 i , where DER denotes the Data Extraction Rate. When all the issues are considered the fairness decreases drastically with increasing network size. Even without capture effect and with perfectly orthogonal spreading codes, the fairness of Aloha decreases as well, due to the different collision probabilities of the SFs.

Figure 1b shows the DER and as expected the capture effect favours the nodes closest to the gateway, which is reflected in the overall DER of the system. However, considering the imperfect orthogonality effect, the overall DER is lower than Aloha. Here, we propose an approach to remedy this. Our proposal, FADR, a Fair Adaptive Data Rate algorithm for LoRaWAN, computes the optimal combination of SFs and TPs settings to achieve a fair DER among all nodes.

2 The FADR Algorithm
The FADR algorithm manages the allocation of SFs and TPs to the nodes. For SF allocation we use the optimal SF distribution for fair collision probability, determined in [3]. However, while the authors in [3] apply this to the entire network, based on distance from the gateway, we propose to assign it over regions. To this extent, the nodes are first ordered based on RSSI and divided into groups of 50 to over-
Evaluation and Results

The allocation of transmission power levels is shown in algorithm 1. The algorithm allocates the lowest TPs that can mitigate the capture effect and the imperfect orthogonality of spreading codes. FADR assumes that all nodes are initiated simultaneously and then randomizes the assignment of spreading codes. The algorithm allocates the lowest TPs that can mitigate the capture effect and the imperfect orthogonality of spreading codes. FADR assumes that all nodes are initiated simultaneously and then randomizes the assignment of spreading codes.

Algorithm 1 FADR - Power Allocation Algorithm

1: Input List of nodes \( N \), corresponding RSSI, power levels PowLevels, matrix of CIR
2: Output \( \forall n \in N, \text{Pow}[n] \in \text{PowLevels} \)
3: Sort \( N \) by RSSI
4: \( \text{RSSI}_0 = \min(\text{RSSI}), \text{RSSI}_m = \max(\text{RSSI}), \text{CIR}_m = \min(\text{CIR}) \)
5: \( \text{Pow}_0 = \arg \min_{n} \text{PowLevels} \cdot \text{pow}(0) \)
6: \( \text{Pow}_{\text{CIR}} = \arg \max_{n} \text{PowLevels} \cdot |\text{RSSI}_n - \text{RSSI}_0| \leq \text{CIR}_m \)
7: \( \text{PowLevels} = \left[ \begin{array}{c} 0 \quad \text{PowLevels.index} \left( \text{Pow}_{\text{CIR}} \right) \end{array} \right] \)
8: \( \text{RSSI}_0 = \min(\text{RSSI}_m + \text{Pow}_m), \text{RSSI}_m = \max(\text{RSSI}_m + \text{Pow}_m) \)
9: \( \text{Pow} \left( \text{RSSI}_m + \text{Pow}_m, \text{RSSI}_m + \text{Pow}_m \right) \)
10: \( i_0 = \arg \max_{n \in \text{PowLevels.index}} \left( \text{RSSI}[n] + \text{Pow}_m \right) \leq |\text{RSSI}_m| \)
11: \( \text{Pow}[n] = \text{Pow}_{\text{CIR}} \)
12: \( \text{pow} \left( n \right) = \arg \max_{n \in \text{PowLevels.index}} \left( \text{RSSI}[n] + \text{Pow}_m \right) \leq |\text{RSSI}_m| \)
13: \( \text{Pow}[n] = \text{Pow}_{\text{CIR}} \)
14: \( \text{idx} = i_0 + 1 \)
15: for all \( p \in \text{PowLevels} \) do
16: if \( |\text{RSSI}[\text{idx}] + p - \text{RSSI}_m| \leq \text{CIR}_m \) and \( |\text{RSSI}[\text{idx}] + p - \text{RSSI}_m - \text{Pow}_m| \leq \text{CIR}_m \) then
17: \( i_k = \arg \max_{n \in \text{PowLevels.index}} \left( \text{RSSI}[n] + p - \text{RSSI}_m - \text{Pow}_m \right) \leq |\text{RSSI}_m| \)
18: \( \text{Pow}[n] = p_0 j \in [\text{idx}, i_k], \text{idx} = i_k \)
19: end if
20: end for

4 Conclusions

We propose FADR to achieve a fair data extraction rate in LoRa/LoRaWAN by exploiting optimal combinations of spreading factors and transmission power levels and at the same time maintain node lifetime by not using excessively high transmission power levels. Simulations show that FADR, in a highly congested cell, achieves 300% higher fairness than the minimum airtime allocation approach and 22% higher fairness than Brechts approach, which is one of the state-of-art approaches, targeting the same problem with almost 22% lower network energy consumption. For future work, we will implement FADR in a real LoRa deployment.

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