DBM: Decentralized Burst Mitigation for Self-Organizing LoRa Deployments

Simon Raffeck, Stefan Geißler, Tobias Hoßfeld
University of Würzburg, Institute of Computer Science, Chair of Communication Networks
Würzburg, Germany
prename.surname@uni-wuerzburg.de

I. Introduction

Modern Internet of Things (IoT) networks are comprised of a multitude of different communication protocols and heterogeneous hardware. Especially in smart city and smart home environments these can range from long range solutions like Long Range (LoRa), Sigfox and Zigbee to more short range approaches like Bluetooth and WiFi. Providing connectivity to IoT use cases in urban and rural areas is a task predominantly taken care of by the LoRa communication protocol, paving its way to become one of the most used IoT protocols. With its simple network architecture, LoRa can achieve high transmission ranges with a comparatively small energy consumption per message.

However, based on pure-ALOHA channel access, LoRa is vulnerable to high collision rates in dense urban areas [1]. After a collision, packets are lost to the network and applications may request re-transmission, causing a significant increase in energy consumption, since using the antenna for transmissions has the highest impact on LoRa's power usage. Thus, it can be stated that reducing collision rates of LoRa will lead to increased energy efficiency when taking into account the energy consumption per successful transmission [2]. Previous research has shown that the arrival process of multiple, heterogeneous IoT devices tends to result in bursty traffic [3], hence increasing the probability for collisions, as many devices tend to transmit at the same time resulting in synchronous traffic, while the overall channel capacity would suffice if devices were to send more spread out.

To this end, this work proposes a novel approach to disperse dense transmission intervals and reduce bursty traffic patterns without the need for centralized control. Furthermore, by keeping the mechanism as close to the Long Range Wide Area Network (LoRaWAN) standard as possible the suggested mechanism can be deployed within existing networks and can even be co-deployed with other devices.

II. Background and Related Work

We provide a brief overview of the LoRa and LoRaWAN technologies. We further outline the Time Division Multiple Access (TDMA) based DESYNC algorithm [4] and highlight its impact on the proposed approach. Lastly, alternative channel access methods for LoRa are presented together with their potential benefits and drawbacks.

A. LoRa and LoRaWAN

LoRa is a chirp-spread spectrum modulated wireless communication protocol for IoT devices. Due to its high range and low energy consumption it is highly suitable for urban and rural environments [5]. It operates on the open Industrial-Science-Medical (ISM) bands at 433, 863, and 902 MHz frequencies. To manage its medium access it makes use of its own Medium Access Control (MAC) protocol LoRaWAN, employing a pure-ALOHA random access mechanism. The network is constructed as a star-of-stars topology with access points being connected to a server back-end, which authenticates the received devices and checks whether they belong to the network. In the context of this work, it is crucial to note that by design, no synchronization between devices or other management mechanisms are intended, to keep the energy consumption of devices as low as possible.

B. DESYNC TDMA

DESYNC [4] is a TDMA based approach for wireless sensor networks. Its nature-inspired approach is used to generate decentralized desynchronized networks. The approach assumes that every device is constantly listening to the frequency band and makes use of so called Fire Messages (FMs) to communicate the transmission time of each node to its respective temporal predecessor and successor. After learning the transmission times of these two, each node then adjusts its own timer into the middle of its temporal neighbors. This way the network will converge towards a desynchronized state without the need for a centralized control unit. However, the additional overhead introduced by the FMs and the energy costs of keeping the antenna powered all the time, is unsuitable for LoRa. To this end, we adapt the DESYNC mechanism to better suit the energy constraints in LoRa deployments.

C. Alternative Channel Access for LoRa

The high collision rates of random access and its impact on LoRa's performance has been subject to related work for some time. Various alternative access methods have been proposed by the research community. In [6] the authors suggest a Listen Before Talk (LBT) approach to equip devices with the ability to dynamically react to changing channel occupancy.

Figure 1: Time series of bursty periodic traffic.

To this end, devices will monitor the selected channel before each transmission and postpone its message if the channel is already used. Improving ALOHA itself by deploying a Slotted ALOHA implementation to LoRaWAN has been investigated in [2], [7]. However, the need for a centralized synchronization to manage the assigned time slots, will increase the baseline energy consumption of LoRaWAN. And lastly various Carrier Sense Multiple Access (CSMA) approaches have been implemented and tested with LoRaWAN. One of these is presented in [8], however, the additional messages needed to implement CSMA and the additional energy costs to receive and listen for these, makes CSMA a costly alternative. As opposed to previous approaches, ours does not rely on synchronization or management transmissions, and is hence in line with the vision of minimal power consumption of LoRa.

III. Self-Organizing LoRa Devices

To combat the disadvantages of alternative channel access methods, this work proposes a DESYNC inspired desynchronized channel access method called Decentralized Burst Mitigation (DBM), that aims at dispersing the transmissions occurring in a LoRa environment to avoid dense transmission periods and reduce collisions. The suggested mechanism has no need for a centralized control unit or control messages, rendering it more flexible and energy efficient. Consider the simple network traffic pattern displayed in Figure 1, where the red lines represent the transmission start of individual end-devices. Since LoRa is a wireless communication, packets can be damaged if another transmission starts while the message is still on the air. Hence, for the dense transmission slots with four transmissions very close to one another, the network is prone to collisions that need to be resolved. The bursts shown in the figure may for example occur periodically at every full hour or can be externally triggered (e.g. shift change, weather conditions, etc.), depending on the specific use cases.

A. The DBM Approach

The idea behind the DBM approach is to disperse periods with bursty transmission patterns by adapting the organization mechanism used in the original DESYNC algorithm. Here, we assume devices that attempt repeating transmissions, as occurs with periodic devices, e.g. a temperature sensor that transmits values every hour. The DBM mechanism extends standard LoRaWAN by two additional receive windows ahead of transmission, as shown in Figure 2. The red marker indicates a transmission window, the green boxes show the 4 symmetrical receive windows, two before the transmission and two after. This allows devices to sense the carrier before and after each transmission to identify if other devices attempt transmissions close to their own sending attempt without the need for constant carrier sensing or FMs, like they are used in original DESYNC. In this work, the receive window blocks are called DESYNC receive windows (DeRCW) for the DBM mechanism.

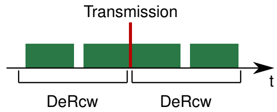

Figure 2: Transmission time slot and receive windows.

The functionality of the proposed mechanism is presented in Figure 3. Three different devices, A in green, B in blue and C in red, can be observed. The figure shows three distinct burst sequences separated by the vertical lines. The devices happen to be too close to one another regarding their transmission time slots. To avoid possible collisions, devices will change their transmission times with the help of the information gathered during the DeRCWs. The core concept of the algorithm revolves around the symmetrical receive windows, to ensure that each participant can gather information at the same time than any direct temporal neighbor and act accordingly. Conflicted devices will make use of an asymmetrical back-off procedure, or if more than one conflict persists with a jump between its two temporal neighbors. To further elaborate on the proceedings, two exemplary scenarios are described in the following sections.

B. Example Scenario

For the first scenario consider two devices within the network. This is depicted in Figure 3 on the left. Device A is too close in transmission time to device B. Each of the two will register the other device in one of its receiving windows. A hears B in its succeeding receive windows, B hears A in its preceding receive window. Each device will keep the transmission time of its temporal neighbors after hearing them. A will store the transmission time of B t_{send_B}, and B will remember t_{send_A}. Since A noticed a transmission closely following its own, it will set its transmission time to an earlier time by a set interval in a back-off procedure. B on the other hand, will not change its transmission behavior, thus, leading to an asymmetrical back-off.

A more complex scenario is created if more than two devices are involved in the collision event. This can furthermore be observed in Figure 3. To this end, the procedure for the two devices is handled as described above and the procedure continues to the second section. This section represents the next transmission cycle within the network. If A notices in this transmission cycle that it backed-off too close to another device - Device C (red) - it will move its slot into the middle of C and B. Because C will now be in the preceding receive window of A and A is in the succeeding receive window of C, A can calculate the middle of C and B using t_{send_B} and t_{send_C}. C will back-off the same way A did in the cycle before, hoping it will not cause further collisions in the next cycle. B will once again not move its transmission slot. After three cycles the devices have successfully resolved the burst period and avoid future collisions.

The reasoning behind only using an asymmetrical back-off procedure and having the successor keep its original sending

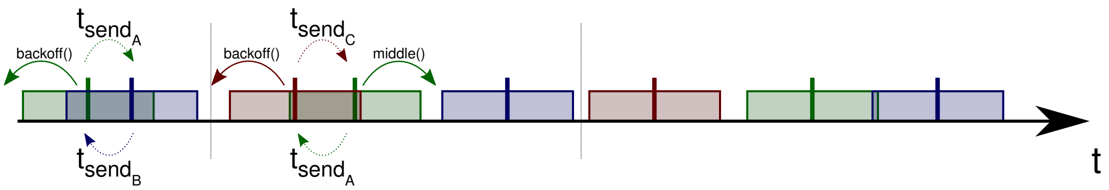

Figure 3: Behavior of three devices within a dense traffic sequence.

slot can be found in the assumption that the collision that can be observed at the time are located in the middle of a dense transmission interval. If every device participating in the collision would back-off in its respective direction, predecessors to an earlier slot and successors to a later slot, both devices could potentially cause more collisions thus negating the beneficial effects, by making devices back-off in either direction repeatedly. If a successor would back-off to a later slot and cause a collision, it would become a predecessor and hence, back-off in the direction it just came from, resetting to the original problem.

IV. Future Simulation Setup

To investigate the efficiency of the proposed mechanism, it is implemented in the process-oriented discrete event simulation framework r-simmer. This framework is chosen over more common alternatives like SimPy, due to its trajectory-based style, which makes it more suited for a later performance evaluation and application of queuing theory approaches.

The simulation is later used to test the influence of different parameters of the mechanism on its overall performance. This encompasses investigating the influence of the back-off duration on the performance. As of right now the back-off correlates with the DeRCW duration and thus, indirectly with the Time on Air (ToA) of a message. Choosing a random back-off duration or a set interval, will influence the overall behavior and must be further investigated.

Another interesting field of study is the compatibility with standard LoRaWAN devices. Due to the characteristics of the proposed mechanism, no drastic changes to the LoRaWAN MAC have been made, thus enabling the new algorithm to be deployed in conjunction with other devices. Investigating the efficiency of the presented mechanism in networks with both traditional and modified devices is crucial. To this end, standard LoRaWAN networks can be enriched with modified devices, which will then avoid collisions on their own, without need for a centralized controller. Of interest is thus, how many modified devices are needed to help reduce overall collisions, and the impact this has on the amount of cycles needed to find a steady state.

In the end, the simulation is used to holistically investigate the performance of the proposed mechanism. Not only is the performance of the modified devices of interest, but also expressing the algorithm and the resulting network as a queuing model. These findings can be used in future works to enhance the performance, especially in regards to energy efficiency as defined in [2] and optimizing energy consumption of devices and the network.

V. Discussion and Conclusion

In this work, a novel approach to LoRa's channel access was presented. Although influenced by the nature-inspired TDMA DESYNC, the mechanism does not rely on control messages or FMs to manage the time slots of participating nodes. Furthermore, like DESYNC, the network follows a decentralized approach in striving towards a desynchronized state. However, true desynchronization can not be achieved as transmission times are generally dictated by external factors such as device configuration or trigger events. Instead, the DBM mechanism attempts to reduce the collisions during dense transmission periods. Since LoRa becomes highly energy inefficient when listening to the channel all the time, devices will deploy an additional receive windows prior to each transmission to be aware of its temporal neighbors. This way each transmission is surrounded by a preceding and succeeding receive windows called DeRCW in a symmetrical fashion. This enables each participant to register each device that is too close to his own transmission slot, while also ensuring that each device that is noticed, also notices the other device within the same transmission cycle. The devices will resolve possible collisions by deploying a back-off mechanism or a jump towards the middle of its predecessor and successor, if more than one collision is detected.

This TDMA approach is investigated with the help of the r-simmer simulation framework and will be further evaluated in regards to its performance and later be expressed as a queuing model with the goal to assess the energy efficiency of single devices as well as the network as a whole. To this end, the influence of different parameters on the performance are being investigated, also with the idea of deploying a mixed network with traditional and modified devices alike in mind. Thus, answering which conditions are needed for the proposed algorithm to exceed the energy efficiency and transmission success probability of the standard LoRaWAN MAC.

For future work a more detailed investigation of the network and all its participants is of interest. This can range from considering cross traffic generated by other protocols, to applying the mechanism to other MACs or communication procedures to further analyze its performance. Another aspect of interest is the control plane and its role in choosing a suitable MAC for the currently used communication protocol. To this end a centralized aspect can be brought back into the mechanism, to sporadically evaluate the network performance and the configuration of its participants to try and optimize the network by changing the MAC and channel access of specific devices to reduce collisions or enhance energy performance.

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