Abstract

In this doctoral dissertation, I examine two strategies for slotted channel random access concerning the time-critical ad hoc network synchronization problem. The synchronization is understood by collecting a *control message* from every network agent. The agents act independently; not knowing each other a priori, they form an ad hoc network by accessing the same communication channel.

The challenging part is that all agents' synchronization is triggered simultaneously and must occur in a constrained time. The standard contention resolution techniques, such as backoff, are not really useful in this situation. Instead, each agent shall access multiple channel slots aligning to some strategy, hoping for at least one non-collision transmission. The prevailing application use cases are traffic coordination systems, Unmanned Aerial Vehicles (UAV) swarms, and intermittent sensor networks; their mission strictly depends on network synchronization within a constrained timeframe.

This study focuses primarily on the characteristics of two proposed channel random access strategies. The abstract communication model is defined where the time-constraint requirement is formalized by the finite-length communication round consisting of n slots. I assume that if two agents transmit in the same slot, there is a collision, and no message comes through. The goal is that every agent transmits successfully (without collision) in at least one slot.

The first strategy, Bernoulli trials (BT), is a default approach where every agent transmits in each slot with a predefined probability $p \in [0,1]$. Using the alternative strategy, t-Slots, every agent chooses at random exactly t out of n available slots and transmits in these slots; $t \in \{1, 2, \ldots, n\}$ is a strategy parameter.

The research hypothesis states that t-Slots behaves better than BT. The hypothesis is confirmed in two phases.

First, I analyze the restrictive case where each agent has to communicate successfully, having at least one collision-less transmission. The second case is when up to f agents may fail to communicate due to collisions. In both cases, I show that t-Slots is superior to BT in the sense of a higher probability of success and, at the same time, fewer messages sent over the shared communication channels. For both cases, I present the optimal choice of the parameters p and t that maximizes the probability of success. These values can be provided based on analytical formulas derived for both strategies. In the (complex) case of t-Slots, it was necessary to use analytical combinatorics tools.

The formulas derived for BT and t-SLOTS allowed me to provide a comprehensive comparative analysis. The examples analyzed combine the calculated results and the statistical tests I performed; the statistical results perfectly align with the calculated synchronization probabilities. Separately, for all-agents and fault-tolerant synchronization, I compare the strategies in terms of synchronization achievability, suboptimal configuration tolerance, properties of their algorithms, energy consumption, and scalability. The gathered results confirm the research hypothesis.

The implementations of the BT and t-SLOTS success probability formulas are delivered as a Python library, along with the raw statistical test data.

Keywords— mobile ad hoc networks, ad hoc initialization, network synchronization, coordination systems, traffic control, drone swarms, multiple access, random-access channels, slotted communication channels, real-time systems