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On the optimal frame-length configuration on real passive RFID systems

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ABSTRACT

The majority of the anti-collision protocols proposed for passive RFID systems are based on frame slotted aloha (FSA). They assume a classical result in FSA-based protocols which states that the theoretical identification throughput is optimized when the number of competing tags in coverage equals the number of slots in the frame. However, this is not exact in real RFID systems, as the so-called *capture effect* is neglected. The capture effect occurs when a tag identification signal is successfully decoded from a collision slot. This paper analyzes the identification performance of real RFID systems, taking into account not only the capture effect, but also the requirements imposed by the *de facto* standard EPCglobal Class-1 Gen-2. The analysis is addressed by discrete time Markov chains. From the analysis, a set of relevant results is extracted: the frame-length values that, configured into the readers studied, guarantee the best identification performance (maximum throughput). The analytical results have been confirmed by means of simulations and by a set of measurements performed on a real passive RFID system. Results closely match the analysis predictions, which demonstrate a notable impact of the configuration on the performance.

1. Introduction

In RFID systems, the communication between readers and tags takes place in a shared communication channel. An anti-collision mechanism is required to minimize the collisions caused by simultaneous transmissions. Meanwhile, in passive RFID, the extreme simplicity of the tags is a severe constraint on the design of collision resolution methods, and complexity must rely almost exclusively on the reader.

UHF passive RFID readers available in the market implement the anti-collision protocol EPCglobal Class-1 Gen-2 (*aka* EPC-C1G2), which is based on a variation of frame slotted aloha (FSA). As depicted in Fig. 1, the reader divides the time into identification cycles (frames). Each frame is in turn divided into time slots. At the beginning of each identification cycle, the reader announces the length of the frame (K slots) with a *Query* packet. Tags in coverage receive the information and randomly select a slot in that cycle to transmit their identifier (Bueno-Delgado et al., 2009a). When the number of tags competing is much larger than the number of slots or *vice versa*, the identification delay increases and the throughput is negatively affected. The anti-collision protocols based on FSA perform optimally if $N=K$, achieving the theoretical maximum throughput $\Omega=e^{-1}\approx 0.36$. However, current readers on the market cannot perform with this maximum throughput due to the following reasons:

- EPC-C1G2 restricts the frame-length to $\{K=2^Q: Q=0,\ldots,15\}$.
- Most of commercial readers operate with a fixed frame-length per cycle, whereas a few exceptions also operate with a variable frame-length per cycle (*e.g.* Development Kit Alien 8800), but the frame adjustment is based on simple heuristics (*e.g.* Fig. 2 shows the default algorithm of EPC-C1G2). Besides, some state-of-the-art algorithms have been proposed to select K based on the *estimated* number of contenders N (see Bueno-Delgado et al., 2009b, for a discussion on these algorithms), though current readers do not implement these approaches.
- Capture effect (CE) is usually neglected in the performance analysis of passive RFID, where it is commonly assumed that transmissions in the same slot are unrecoverable, yielding to invalid conclusions (Myung and Lee, 2006; Vogt, 2002; Khandelwal et al., 2007; Cha and Kim, 2005; Floerkemeier, 2006; Floerkemeier and Wile, 2006). CE is a phenomenon associated with simultaneous transmissions in a shared channel, in which the strongest signal can be successfully demodulated. Due to this effect, in RFID a tag identification can be sometimes extracted from a collision slot (Li et al., 2009). The reader communication transceiver is able to demodulate the strongest signal if the signal-to-interference ratio (SIR) is higher than a threshold. This threshold is called capture ratio (thereafter denoted as C_r) and directly determines the

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