RFID MAC Performance Evaluation Based on ISO/IEC 18000-6 Type C

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***Abstract*— This paper evaluates a new RFID reservation MAC protocol that utilizes tree based collision avoidance. Performance evaluation is conducted for tag read latency and read efficiency as a function of link parameters defined in ISO/IEC 18000-6 Type C standard.**

***Index Terms*— Anti-collision scheme, ISO 18000-6 Type C, tree splitting algorithm, thoughput, mean read latency.**

I. Introduction

RADIO Frequency Identification (RFID) is increasingly the technology of choice for automated object identification. The random multiple access protocols in RFID can be largely classified into two categories: tree based and framed Aloha based collision arbitrations. *The International Organization for Standard/the International Electrotechnical Commission (ISO/IEC) 18000-6 Type C* (ISOC)[1] standard uses framed Aloha based reservation MAC for the uplink(UL). A 16-bit tag identifier called *random number 16*(RN16) is used for *collision resolution* (CR) by tags wishing to reserve a subsequent (data) slot for backscattering its EPC data to the reader as shown in Fig. 1. Given an unknown number of tags, the MAC efficiency is limited by the collisions due to multiple simultaneous transmissions by tags within the same slot. There exists no definitive study to date of the actual ISOC MAC performance in real systems deployment by considered all link time overheads (in both up and downlinks) and *reservation mode*. We introduce *a new tree structured anti-collision scheme* called *breadth-first-search m-ary splitting algorithm* (BMSA)[4], where *m* is the splitting factor, for CR, and examine resulting improvements in MAC efficiency vis-à-vis standard ISOC protocol and previous tree walk schemes [2][6][7] based on *depth-first-search m-ary splitting algorithm*(DMSA).

II. Anti-Collision Protocols

A. Baseline Framed Aloha in ISOC

In ISOC the reader issues a query (*Query* or *QueryAdjust*) command that contains the Q parameter (0∼15) for use by tags; a tag randomly selects a value between [0, 2^Q-1] and loads it onto its slot counter. The tag slot counter is only decremented when it receives a *QueryRep* command from the reader and backscatters its RN16 packet when count reaches zero. The reader monitors each RN16 slot for status: *idle*, *collision* or *success*, and either issues an *Ack* command on detecting success or a *QueryRep* command on detecting idle or collision. The *Ack* command reflects the same RN16 data back to the successful tag thereby confirming its reservation to backscatter its EPC data within an exclusive time slot(*Timeslot2*) as shown in Fig. 1. $T_1(T_2)$ is the *guard space*(GS) time between reader transmission and tag response(tag response and reader command). The reader can control the probability of collision in each frame by adjusting Q value. During the tag inventory process the reader emits *continuous wave*(CW) signal by which tags can harvest energy for UL backscatter. Hence each CR can be divided into *three link time components*: reader-to-tag broadcast (downlink, DL), tag-to-reader backscatter(UL), and GS. Since the maximal throughput(t_f) in framed Aloha is approximately 1/*e*[5], *e* RN16(*Timeslot1*) slot times on average yield one successful EPC data read(*Timeslot2*). We assume that the length of *Timeslot1* is identical regardless of whether the time slot is empty or not. Let $\overline{l_{IB,DL}}$, $\overline{l_{IB,UL}}$, and $\overline{l_{IB,GS}}$ denote the mean link times for DL, UL, and GS, respectively, in a CR of the *ISOC Baseline*(IB). Then we have

$$\begin{aligned} \overline{l_{IB,DL}} &= \{F_S + L_{QueryRep}(1-t_f)\}/t_f + L_{Ack} \\ \overline{l_{IB,UL}} &= (P_{UL} + L_{RN16})/t_f \\ \overline{l_{IB,GS}} &= (T_1 + T_2)/t_f \end{aligned} \quad (1)$$

where F_S, P_{UL}, and L_X are DL Frame-Sync, UL preamble, and the link duration for packet *X*, respectively. Thus the mean length for a CR in framed Aloha $\overline{C_{IB}} = \overline{l_{IB,DL}} + \overline{l_{IB,UL}} + \overline{l_{IB,GS}}$.

B. BMSA vs. DMSA

So far DMSA type tree based anti-collision algorithms have been proposed for RFID MAC[2][6][7]. The *ISO 18000-6 Type B*[2] and [6] are special cases of DMSA with m = 2. Recently [7] introduced a *hybrid* anti-collision scheme where tree structure is embedded into a (m-ary with $m \geq 2$) TDMA time frame in order to control tag collisions more effectively. However in DMSA, the reader immediately splits any slot where a collision is detected and continues querying tags until all subsequent collisions are resolved. The shortcoming of this method is due to the exhaustive depth-first nature of the search implying that tags need to listen to *every* slot in CR interval to learn (from the reader command) its retransmission slot. Since the maximal throughput of binary tree(m = 2) walk(t_b) is approx. 0.43, this method on average, requires 1/t_b *Timeslot1*'s to transfer one EPC data packet. So by substituting t_b for t_f in (1) we can get corresponding $\overline{l_{DM,DL}}$, $\overline{l_{DM,UL}}$ and

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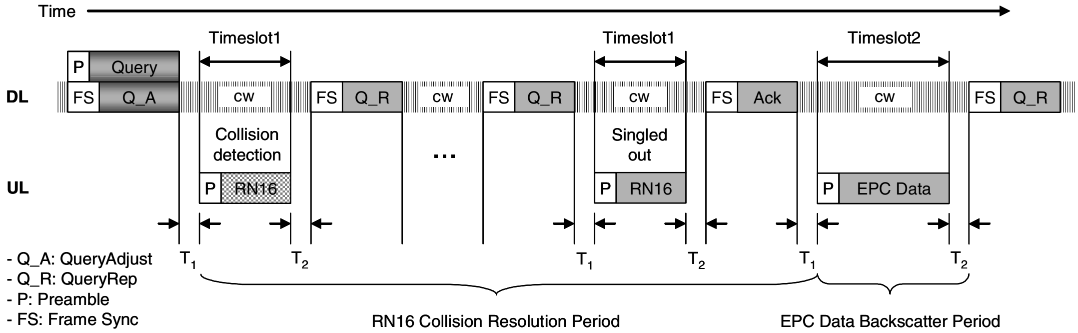


Fig. 1. Link time in ISO/IEC 18000-6 Type C (ISOC baseline)

$\overline{l_{DM,GS}}$ in a CR of DMSA. We assume that tags are equipped with a program counter to carry out depth-first-search tree protocol step according to a slot based reader feedback. Thus the mean CR length for one tag read in DMSA $\overline{C_{DM}} = \overline{l_{DM,DL}} + \overline{l_{DM,UL}} + \overline{l_{DM,GS}}$. The CR traversal in BMSA on the other hand, follows that of pure framed Aloha while preserving m-ary tree structure as shown by the sequence in Fig. 2. After each round of CR demarcated by a single query command, the reader broadcasts the results of each RN16 slot(*Timeslot1*) within the previous frame via the *access result map*(ARM). To support reservation mode, *Timeslot2* precedes *Timeslot1* if any successful tag exits in the previous frame. The advantages of BMSA is that it greatly reduces reader-tag communication time by eliminating slot-based reader commands and corresponding GS times during a CR as in ISOC and DMSA. Consider the example in Fig. 2 where the first query command carries Q = 3(8 slots) and default ARM. After the CR in first round(r = 0), the reader issues the second query command containing first round ARM, indicating that two RN16 packets backscattered at 3^{rd} and 5^{th} slots were successfully received. Consequently the tags that chose the 3^{rd} and 5^{th} slots have reservation to backscatter its EPC data before the next CR begins (indicated by dotted arrows to slot 9 & 10). All collided tags in second round(r = 1) thereafter enter CR in third round(r = 2); contention is managed by limiting the collided tags to only contend within the mutually exclusive slot groups resulting from splitting(solid arrows). The tag read process in BMSA is summarized as follows:

1) *Initialization*(r = 0):
   - Reader: set Q (0∼15) and broadcast a query command.
   - Tag: set timer to $\alpha(P_{UL} + L_{RN16} + T_2)$, where α is slot index chosen by *rand*[0, 2^Q-1], and *rand*[A, B] is a random value in the range [A, B], inclusive.
2) $r \geq 1$:
   - Reader: broadcasts ARM with the outcome of all slots in (r-1)th round and sets r^{th} round UL frame length(L_f^r) to $\beta(P_{UL} + L_{EPC\_Data} + T_2) + \gamma m(P_{UL} + L_{RN16} + T_2)$, where $\beta(\gamma)$ is the total number of success(collision) slots.
   - Tag: upon receiving a feedback notifying success, sets timer to $\delta(P_{UL} + L_{EPC\_Data} + T_2)$, where δ is the number of successes that occurred prior to the slot chosen by the tag in the (r-1)th round.
   - Tag: upon receiving feedback notifying collision, sets timer to $\beta(P_{UL} + L_{EPC\_Data} + T_2) + \eta(P_{UL} + L_{RN16} + T_2)$, where η is the slot index in the r^{th} round by *rand*[θm, $(\theta + 1)m$-1], and θ is the number of collisions that occurred prior to the slot chosen by the tag in the (r-1)th round.
3) Backscatter RN16 or EPC data packet when the timer expires.

Once an inventory process starts, 2) and 3) alternate until no further collision is detected in the frame, thereby ending the session. Because a tag obtains the values β, γ, δ, and θ from ARM, and knows the DL/UL data rates for use in the command, it is able to calculate L_f^r ($r \geq 1$) and its slot access time in terms of *Timeslot1* and *Timeslot2* within the L_f^r. Therefore only $2/t_b$ bits (2-bit per slot feedback) in ARM are required to read one EPC data in DL as follows.

$$\begin{aligned} \overline{l_{BM,DL}} &= L_{2/t_b} \\ \overline{l_{BM,UL}} &= (P_{UL} + L_{RN16})/t_b \\ \overline{l_{BM,GS}} &= T_2/t_b \end{aligned} \quad (2)$$

In our analysis, we assume that 1) all tags use identical EPC data size, 2) T_2 is the guard space between two consecutive UL packets, 3) ARM is piggybacked by each query command, and

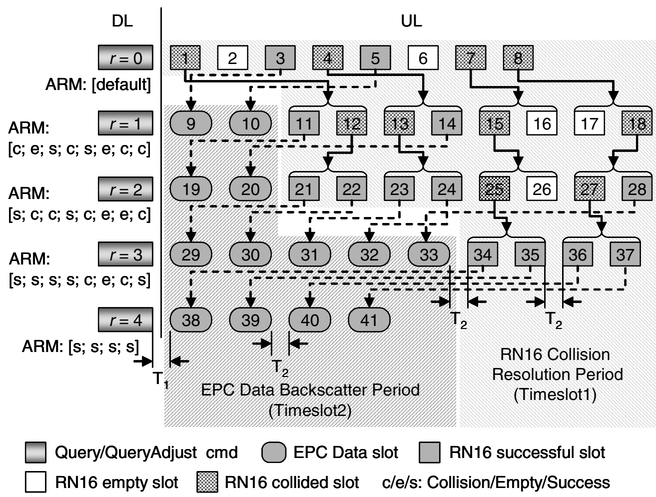
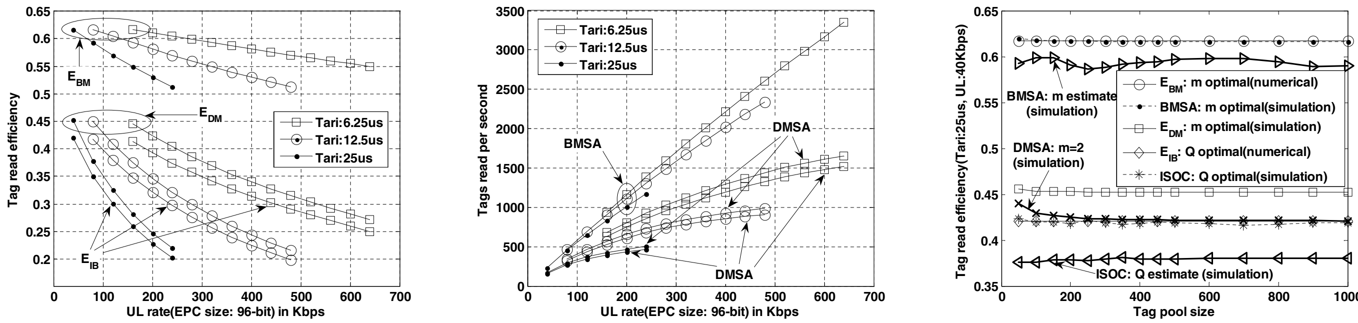


Fig. 2. Collision resolution process in BMSA (m = 2)



(a) Read efficiency(ideal) by (3) (b) Tag read rate(ideal) (c) Backlogged tag estimation

Fig. 3. Performance comparison: Proposed(BMSA) vs. ISO/IEC 18000-6 Type B(DMSA) vs. ISO/IEC 18000-6 Type C(ISOC baseline)

4) *Access* process, which may follow after *Inventory* process, is not considered. The mean CR length for one tag read in BMSA $\overline{C_{BM}} = \overline{l_{BM,DL}} + \overline{l_{BM,UL}} + \overline{l_{BM,GS}}$.

III. Performance Evaluation

The parameters for computations are as follows consistent with ISOC standard[1]:

- DL rate: *Data-0* reference time interval(*Tari*) - (6.25μs, 12.5μs, 25μs) and *Data-1* reference time interval - 2.0*Tari*. Thus DL rate = (106667bps, 53333bps, 26667bps) corresponding to *Tari* rate.
- UL rate: (160$\sim$640)Kbps for 6.25μs *Tari*, (80$\sim$320)Kbps for 12.5μs *Tari*, and (40$\sim$160)Kbps for 25μs *Tari*.
- EPC data: 96 bits(48bits(min.) $\sim$ 544bits(max.))
- T_1: max[RT_{cal}, 10*T_{pri}], where RT_{cal} (reader-to-tag calibration symbol time) equals *Tari* plus *Data-1* reference time interval, and T_{pri} is tag-to-reader link period defined by 1/UL rate.
- T_2: 5T_{pri} (3T_{pri}(min.) $\sim$ 20T_{pri}(max.))
- *FS*: delimiter(12.5μs) + *Tari* + RT_{cal}
- UL *Preamble*: FM0 without a pilot tone

We assume that the channel or air interface is perfect, i.e. no packet losses occur due to background noise. Then the tag read efficiency for ISOC baseline(E_{IB}), DMSA(E_{DM}) and BMSA(E_{BM}) can be defined by the ratio of L_{EPC_Data} to the total elapsed time for one tag read as

$$E_Y = \frac{1}{[1 + \{\frac{(\overline{C_Y} + T_2)}{L_{EPC\_Data}}\}]} \quad (3)$$

where, *Y* is one of {*IB*, *DM*, *BM*}. The numerical results in Fig. 3(a) and (b) indicate the theoretical maximum performance in framed Aloha and BMSA that can be attained under the assumption that the reader knows the size of tag population. The simulation results in Fig. 3(c) illustrate performance achieved when *Tari* = 25μs and UL rate is 40Kbps with backlogged tag estimation; the choice of *Q* in ISOC follows the appendix D in [1] and *m* in BMSA is estimated as the ratio of the number of collided slots to the entire frame length as in [4]. To achieve maximum E_Y, it is desirable for the reader to set the lowest UL rate allowed in each *Tari* as shown in Fig. 3(a). We see that E_{BM} is higher and more stable against the increase of UL rate than E_{DM} and E_{IB} for a given EPC data size. As a result when *Tari* = 12.5μs and UL rate = 480Kbps in Fig. 3(b), the tag read rate in BMSA(2,341 tags/sec) is nearly 2.4 and 2.6 times higher than that in DMSA(990 tags/sec) and ISOC baseline(910 tags/sec)[1], respectively. We also note in Fig. 3(c) that the read efficiency (0.59), which is practically achievable via tag estimation in BMSA is much higher than those for optimal cases in DMSA(0.45) and ISOC(0.42). The performance degradation (relative to the ideal) due to tag estimation in BMSA(5%) is less than that in ISOC(10%).

IV. Conclusions

We introduced a novel anti-collision scheme called BMSA and conducted performance evaluations taking all airtime components in ISOC standard into consideration. The proposed scheme yields improved tag read efficiency and latency of approximately 37%$\sim$140% and 50%$\sim$160% when compared to DMSA and ISOC baseline, respectively, for a typical EPC data size(96 bits) in ideal scenario depending on *Tari* and UL rate. The performance gain in BMSA arises from two factors: a) the feedback information broadcast by the reader in ARM (greatly reduces $\overline{l_{BM,DL}}$ and consequently $\overline{l_{BM,GL}}$), and b) the tree splitting within a frame structure that helps reduce $\overline{l_{BM,UL}}$. Further, our approach is more robust to tag estimation.

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