Optimized Transmission Power Control of Interrogators for Collision Arbitration in UHF RFID Systems

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***Abstract*— The emergence of UHF RFID as one of the dominant technology trends has posed numerous unique challenges to researchers. This letter presents a novel, theoretically-grounded collision arbitration protocol, called TPC-CA, which optimally controls transmission power of RFID interrogators and thereby reducing redundant interrogator collisions.**

***Index Terms*— UHF RFID systems, collision arbitration, transmission power control.**

I. Introduction

UHF RFID systems is non-contact technology that identifies objects which have transponders with interrogators [1]. Therefore, correct identification of objects is the most important factor in UHF RFID [1]-[3]. This letter focuses on collision arbitration of the signals from interrogators toward a transponder, called 'collision arbitration of interrogators'. Collision arbitration schemes of interrogators can be classified into three categories. The first category is a scheduling-based method, such as Colorwave [1]. The second one is a learning-based method such as HiQ [2]. The last one is a clustering-based method. The proposed scheme in this letter is based upon clustering. We propose an optimized transmission power control scheme for collision arbitration in RFID interrogators, which optimally regulates the interrogation range by controlling transmission power in such a way that the probability of collision of interrogators is reduced.

II. Transmission Power Control for Collision Arbitration (TPC-CA) in UHF RFID Interrogators

If interrogation ranges are larger than optimal ones, collisions can be increased. On the other hand, smaller ranges result in a situation that the field of transponders is not completely covered. The TPC-CA controls transmission power to regulate each interrogation area to minimize collisions. The field of transponders also must be covered by the interrogation areas. This condition is called 'guarantee of perfect coverage' and is verified in appendix I.

Manuscript received August 18, 2006; revised October 20, 2006. The associate editor coordinating the review of this letter and approving it for publication was Dr. Luiz Dasilva. This work was supported by ITRC Project supervised by ITTA-2005 (C1090-0501-0019).

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Digital Object Identifier 10.1109/LCOMM.2007.061322.

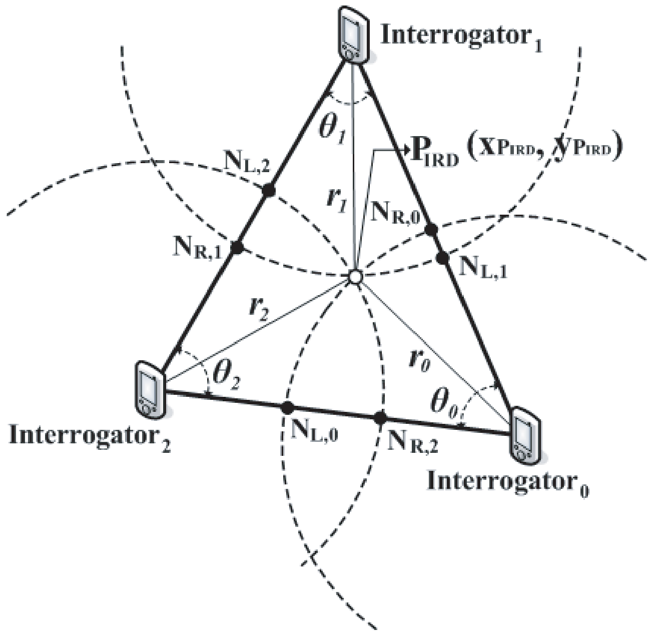

Fig. 1. System model for TPC-CA.

A. Friis Free-Space Formulation

Friis free-space formulation is generally used in modelling of antenna design [4]. The interrogator range r_k can be obtained as follows

$$r_k = \frac{\lambda}{2\pi}\sqrt{\frac{P_t(k)G_tG_r}{P_{th}} \cdot \frac{R_cR_a}{\mid Z_c + Z_a \mid^2}} \tag{1}$$

λ and P_{th} denote wavelength and minimum threshold power, respectively. Z_c and Z_a are chip and antenna impedances. R_c and R_a are chip and antenna resistance. G_t and G_r mean the gain of transmitting and receiving antennas, respectively. The values are constants. Therefore, the variable which can be adjusted is $P_t(k)$, i.e., transmission power of interrogator$_k$.

B. Transmission Power Control for Collision Arbitration (TPC-CA)

TPC-CA consists of network topology configuration (NTC) phase, interrogation area regulation (IAR) phase, and iteration phase. The iteration policy and the whole procedure of a TPC-CA algorithm are presented in Algorithm 1. As shown in Algorithm 1, NTP phase and IAR phase are operated periodically. However, if many events are identified, the policy operates the phases. We assume that the positions of interrogators are known to an RFID server a priori.

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Algorithm 1 TPC-CA Algorithm

```
loop
  //Expire timer: t
  Initialize(t); //t=0;
  t- -; //Reducing the expire time
  if (event == IDENTIFIED) then
    //If event is occurred in the RFID network field
    numEvt = numEvt + 1; //numEvt: recognition counter
    if (numEvt > Threshold) then
      //Threshold: threshold for number of identification
      //Operate TPC-CA scheme
      Initialize(numEvt); //numEvt=0;
      Function Call: NTC Phase
      Function Call: IAR Phase
    end if
    if (t==0) then
      When expire timer is expired
      //Operate TPC-CA scheme
      Initialize(numEvt); //numEvt=0;
      Function Call: NTC Phase
      Function Call: IAR Phase
    end if
  end if
end loop
```

1) NTC Phase: The interrogators construct triangles to determine the 'Point for Interrogation Range Decision (P_{IRD})' to minimize the overlapping areas. $Delaunay$ triangulation [5] is used to guarantee the construction of approximate equilateral triangles.

2) IAR Phase: The interrogation ranges can be dynamically controlled by using the P_{IRD} as a pivot. Then, balanced power consumption among the interrogators can be achieved. Because of mobility with respect to interrogators, the positions may change. Therefore, this phase also is operated under iteration policy. Overlapping area can be obtained by extracting a triangle from the summation of three sectors. The area of each sector can be calculated by $S = \frac{1}{2} \cdot \theta_k \cdot r_k^2$. Finally, the objective function is

$$\textbf{minimize: } f = \frac{1}{2}\sum_{k=0}^{2} r_k^2\theta_k - S_{triangle} \quad (2)$$

$$\text{s.t. } r_k^2 = (x_{P_{IRD}} - x_k)^2 + (y_{P_{IRD}} - y_k)^2$$

Eq. (2) gives the optimal interrogator ranges, i.e., r_k. By Eq. (1), the optimal transmission power of each interrogator can be derived as follows

$$P_t(k) = \frac{4\pi^2}{\lambda^2} \cdot \frac{P_{th} \cdot \mid Z_c + Z_a \mid^2}{G_t G_r R_c R_a} \cdot r_k^2 \quad (3)$$

Because the boundaries of coverage areas of three interrogators must meet at one point, i.e., P_{IRD}, the constraints can be given as follows. If there is a unique solution, the size of triangle can be obtained as the summation of three triangles.

$$\Delta I_0 I_1 I_2 = \Delta I_0 I_1 P_{IRD} + \Delta I_1 I_2 P_{IRD} + \Delta I_2 I_0 P_{IRD} \quad (4)$$

I_k denotes the interrogator$_k$ for brevity. By satisfying Eq. (3) and Eq. (4), we can obtain the optimal transmission power of each interrogator.

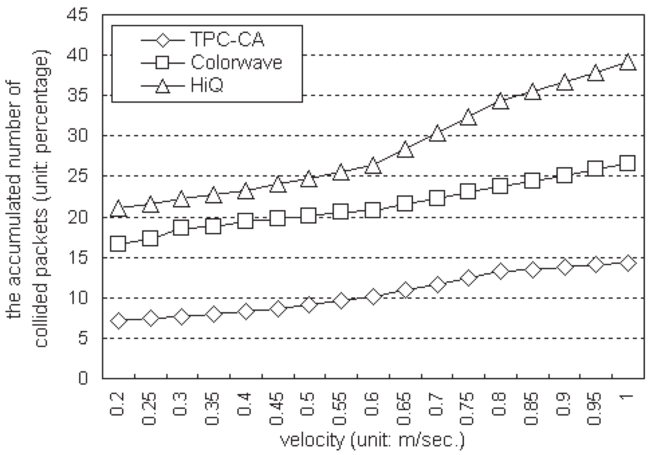

Fig. 2. The accumulated number of collided packets.

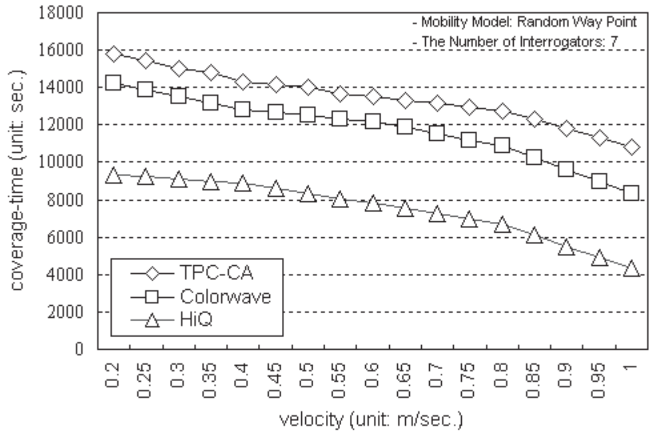

Fig. 3. Coverage-time with various velocities.

III. Performance Results

We study the effectiveness and accuracy of our protocol in mobile RFID networks by performance evaluation. Random way point model is used for mobility model in the simulation. Also seven random deployed interrogators are used.

A. The Accumulated Number of Collided Packets

Fig. 2 shows the novelty of TPC-CA compared to other well-known RFID anti-collision protocols. Note the accumulated number of collided tags in TPC-CA is almost 2.5 times less than that in HiQ and about half of that in Colorwave. HiQ cannot learn the position of each interrogator due to the mobility of interrogators and Colorwave does not support mobile RFID interrogators, whereas TPC-CA can support mobility on interrogators.

B. Coverage-Time

The coverage-time is defined as the time until one of interrogators runs out of energy such that it yields incomplete coverage. Fig. 3 shows the improvement of coverage-time performance under our protocol compared with HiQ and Colorwave.

IV. Conclusion

A novel collision arbitration scheme for UHF RFID is proposed in this letter. TPC-CA optimally controls the transmission power of interrogators for regulating the areas, and as a result it reduces collision well enough.

Appendix I
Guarantee of Perfect Coverage

The guarantee of perfect coverage in TPC-CA is verified in Appendix I.

Lemma 1: The transponders are perfectly covered by the interrogators.

Proof 1: In Fig. 1, we set up one point between $N_{L,(k+2)mod3}$ and $N_{R,(k+1)mod3}$ named β_k, where k=0, 1, and 2.

$$\beta_k = \rho \cdot N_{L,(k+2)mod3} + (1-\rho) \cdot N_{(k+1)mod3} \quad (5)$$

$$0 \le \rho \le 1$$

Under this setting,

$$\textbf{Sector } I_k N_{R,k} N_{L,k} \ge \Box\beta_{(k+1)mod3} P_{IRD} \beta_{(k+2)mod3} I_k \quad (6)$$

The meaning of '$\ge$' is not 'larger than or equal to' in this letter. '$\ge$' means 'cover'. On the other hand, the triangle is geometrical summation of three rectangles, i.e., $\Box\beta_1 P_{IRD}\beta_2 I_0$, $\Box\beta_1 P_{IRD}\beta_0 I_2$, and $\Box\beta_0 P_{IRD}\beta_2 I_1$. Therefore, we derive that the three regions, parts of three clusters, can totally cover the triangle.

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