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# Evaluation Criteria for Reader-to-Reader Anti-collision Protocols

*Filippo Gandino, Renato Ferrero,  
Bartolomeo Montrucchio, Maurizio Rebaudengo  
Dipartimento di Automatica ed Informatica  
Politecnico di Torino, Italy*

*{filippo.gandino, renato.ferrero,  
bartolomeo.montrucchio, maurizio.rebaudengo}@polito.it*

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## **Abstract**

The RFID technology is affected by the RFID reader-to-reader collision problem. Several anti-collision protocols have been proposed. However, there is no accordance on the most effective criteria for performance evaluation of RFID reader-to-reader anticollision protocols. Therefore, it is not easy to reach a clear and fair comparison among different works. This work analyzes and compares the state-of-the-art criteria for performance evaluation.

## **1 Introduction**

In state-of-the-art approaches, there is no existing accordance on the most effective criteria for performance evaluation of a general RFID reader-to-reader anticollision protocol. In this work the main evaluation approaches are described, classified and analyzed, discussing their benefits and drawbacks. The list of the evaluation criteria is shown in Tab. 1. Specific criteria, not applicable to a generic reader-to-reader anticollision protocol, are not considered.

The rest of the report is organized as follows: in Sections 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11, the state-of-the-art evaluation criteria are described; in Section 12, the described criteria are discussed; finally in Section 13, some

Tab. 1: Evaluation Criteria

Paper	Throughput	Efficiency	Jain	VRT	OARWT	VAWT	TWTV	MWT	TAWT	AWTV
[1, 2]	main	main	-	-	-	-	-	-	-	-
[3, 4]	main	main	-	-	-	-	-	-	-	-
[5]	main	-	-	-	-	-	-	-	-	-
[6]	auxiliary	-	-	-	main	main	main	main	-	auxiliary
[7]	main	-	-	-	-	-	-	-	-	-
[8]	auxiliary	auxiliary	-	-	-	-	main	main	main	main
[9]	main	-	-	main	-	-	-	-	-	-
[10]	main	-	-	-	-	-	-	-	-	-
[11]	main	-	main	-	-	-	-	-	-	-
[12]	main	-	-	-	-	-	-	-	-	-
[13]	main	-	-	-	-	-	-	-	-	-

conclusions are drawn.

## 2 Throughput

Network throughput is calculated either as

1. the total number of successful query sections (SQS),
2. SQS in the unit of time ( $\frac{SQS}{time}$ ),
3. SQS in the unit of time divided by the number of readers,
4. or the sum of the time spent by each reader querying tags, divided by the number of readers and by time of the simulation.

With the assumption that each query section has the same time length, and that also the total time of each simulation is the same, all these method to calculate network throughput provide directly proportional results. However, the first metrics provides a high number that can be useful to compare different protocols, but that is difficult to evaluate for a reader; especially since it is strictly dependent by several parameters of the simulation. Even SQS in the unit of time is not so clear, although it is independent of the length of the simulation. The third result is independent of the length of the simulation and of the number of RFID readers, but it shows only the number of query sections per RFID reader and does not provides information on their length. The last metric is the most clear, since it shows the percentage of time that is spent by the readers querying tags.

The throughput is indicated as a good metric in many research studies, and it is often used to evaluate reader-to-reader anticollision protocols. In [14], Engels and Sarma state that one of the goals of reader-to-reader anti-collision protocols is to schedule all readers to communicate as often as possible. In [8], Gandino et al. used SQS as an auxiliary metric. In [1, 2],

the authors consider the requirements of real-time applications as inventory detection, so they suggest the goal of scheduling readers to communicate as often as possible. The total successful transmissions performed by a set of readers according to different configurations is used to evaluate Colorwave and to compare Colorwave and DCS. In [15] the goal of anti-collision protocols is to maximize the number of readers simultaneously communicating. Even Birari and Iyer used  $\frac{SQS}{time}$  in [3, 4], Ferrero et al. in [9], and Bueno et al. in [13]. Gandino et al. used it in [10], as the main evaluation metric, and in [6], as an auxiliary metric. In [5], Shin et al. represented the throughput as  $\frac{SQS}{time}$ , but 100 timeslots are used as unit of time. The average percentage of time spent by each reader querying tags is adopted as the main metric by Gandino et al. in [12].

The goal of using this parameter is to order the protocols according to how often they schedule readers to communicate. Using network throughput the performance of each reader has the same weight on the network evaluation. However, this metric does not consider the time distribution of the transmissions and the different contribution of each reader. Therefore, network throughput is not comprehensive for applications that require constant quality of service for the whole network.

### 3 Efficiency

Network efficiency corresponds to the percentage of successful query sections over the total number of attempted query sections (AQS). It is calculated as  $\frac{SQS}{AQS}$ . This parameter was used by Waldrop et al. in [1], in order to evaluate different configurations of DCS. Birari and Iyer [3, 4] used the network efficiency together with the network throughput. Gandino et al. [8] used this metric as an auxiliary evaluation criteria. The goal of using this parameter is to order the protocols according to how well they avoid collisions. Methods based only on network efficiency evaluate positively protocols where SQS is close to AQS, even if AQS is low. Therefore, this kind of evaluation does not seem effective, since it does not consider the throughput. Moreover, when SQS is high, the value of AQS is not so relevant.

### 4 VRT

The reader throughput corresponds to the throughput of a reader. The variance of the reader throughput (VRT) is the variance of the throughput of all the RFID readers in the network. This parameter was used by Ferrero et al. in [9]. The goal of using this parameter is to order the protocols

according to how similar are the resources given to each reader, and to how fair they are. However, this metric is dependent on the unit of measure, since multiplying all the values by a constant, VRT is multiplied by the square of that constant. In the best case, it is 0, but there is not an upper bound to VRT. Therefore, VRT can sort protocols according to their fairness level, but it does not provide a clear idea of the difference among the fairness of the evaluated protocols.

## 5 Jain's Fairness Index

The Jain's fairness index has been used to evaluate how fairly the throughput is distributed among the readers in the network. It is calculated as

$$I_{Jain} = \frac{|\sum_{i=1}^n x_i|^2}{n \sum_{i=1}^n x_i^2}.$$

Where  $x_i$  is the throughput of the  $i$ -th reader, and  $n$  is the quantity of readers. This parameter has been used by Ferrero et al. in [11]. The goal of using this parameter is to order the protocols according to how similar are the resources given to each reader, and to how fair they are. It is independent of the unit of measure, since multiplying all the values by a constant, the Jain's index does not change. If all the readers have the same throughput, it is equal to 1. In the worst case, it is equal to  $\frac{1}{n}$ . When  $k$  readers have the same throughput, and the other  $n - k$  readers have throughput equal to 0, the Jain's index is  $\frac{k}{n}$ . Therefore, the Jain's Index sorts protocols according to their fairness level, and provides an idea of the difference among the fairness of the evaluated protocols.

## 6 OARWT

The waiting time (WT) corresponds to the time span between the request and the successful query execution. The average reader waiting time (ARWT) corresponds to the average WT for all the query sections of a specific reader. ARWT of reader  $i$  is calculated as the sum of the WT of its query sections divided by SQS. The overall average reader waiting time (OARWT) corresponds to the average ARWT of all the readers in the RFID network.

This parameter has been used by Gandino et al. in [6]. The goal of using this parameter is to order the protocols according to how often they schedule readers to query tags, so in a protocol with a low OARWT, the readers communicate as soon as possible. However, in contrast to throughput, it pro-

vides a result that can directly understood. Using OARWT the performance of each reader has the same weight on the network evaluation.

## 7 VAWT

The variance of average waiting time (VAWT) corresponds to the variance of ARWT of all the readers in the RFID network. This parameter has been used by Gandino et al. in [6]. The goal of using this parameter is to order the protocols according to how similar are the resources given to each reader, and to how fair they are. A high VAWT reveals the presence of readers with bad efficiency. Using VAWT the performance of each reader has the same weight on the network evaluation.

## 8 TWTV

The total waiting time variance (TWTV) corresponds to the variance of WT of all the query sections in the RFID network. This parameter has been used by Gandino et al. in [6, 8]. The goal of using this parameter is to order the protocols according to how similar is the WT of all the query requests, and to how stable and fair the protocols are.

## 9 MWT

The maximum waiting time (MWT) corresponds to the longest WT among all the transmissions in the RFID network. This parameter has been used by Gandino et al. in [8, 6]. The goal of using this parameter is to order the protocols according to the performance of their worst case. In [14], Engels and Sarma state that one of the goals of reader-to-reader anti-collision protocols is to minimize the time span required to allow all the readers to communicate at least once. MWT represents a good metric for this goal. The value of this parameter is strongly affected by the length of the simulation, so it requires a carefully analysis in order to be fairly calculated. Moreover, it is subject to a great fluctuation, so it should be calculated as the average of many simulation executions, in order to reach a reliable result.

## 10 TAWT

The total average waiting time (TAWT) corresponds to the average WT for all the transmissions in the RFID network. This parameter has been

used by Gandino et al. in [8], as a main metric, and in [6], as an auxiliary evaluation metric. The goal of using this parameter is to order the protocols according to how often they schedule readers to query tags. A protocol with a low TWTV provides a steady performance. However, it is unfair, since it provides a higher weight to the readers that communicates more often, since each successful query section has the same weight.

## 11 AWTV

The reader waiting time variance (RWTV) corresponds to the variance of WT for all the transmissions of a specific reader. The average waiting time variance (AWTV) corresponds to the average RWTV of all the readers in the RFID network. This parameter has been proposed by Gandino et al. in [8]. The goal of this parameter is to order the protocols according to how stable is the WT of all the query requests. Using AWTV the performance of each reader has the same weight on the network evaluation.

## 12 Discussion

Throughput is a good evaluation criterion for the performance of an RFID network, since:

- it is the most employed;
- the performance of each reader has the same weight;
- when represented as the sum of the time spent by each reader querying tags, divided by the number of readers and by the time of the simulation:
  - it is independent of the length of the simulation,
  - it is independent of the quantity of readers,
  - it provides a result with fixed lower bound and upper bound,
  - it can be considered goodput (i.e., the control flow is not included).

However, it does not consider the different contribution of each reader and the distribution of the transmissions over the time. Therefore, it is not a suitable criterion for applications that require constant quality of service for the whole network. In these cases, the concept of fairness is important. The Jain's fairness index represents the best evaluation criteria for fairness, since:

- it is well established also in other fields;
- the performance of each reader has the same weight;
- it is independent of the length of the simulation;
- it provides a result with a fixed upper bound and with a lower bound;
- it is independent of the unit of measure.

So far, AWTV represents the only specific criterion used for the evaluation of the constancy of RFID reader-to-reader anticollision protocols.

### 13 Conclusions

In this work, an overview on the evaluation criteria used for RFID reader-to-reader anticollision protocols has been presented. The evaluation criteria have been discussed, and the best criteria have been identified.

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