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“Reader Talks First” vs. “Tag Talks First” RFID protocols

A White Paper
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1 SUMMARY

This paper discusses the advantages and disadvantages of "Reader Talks First" (RTF) versus "Tag Talks First" (TTF) RFID protocols for passive tags. It comes to the conclusion that there is enough merit in TTF protocols to reopen the debate on whether an ISO standard protocol should be RTF or TTF.

The highest priority is for a standard that would allow co-existence, if not inter-operability. This can be achieved by specifying a wake-up standard for RTF tags and a maximum duty cycle for categories of TTF tags.

2 BACKGROUND

Most passive tags in use today use TTF protocols. With short-range, single-read tags, typically operating at 125 kHz or 13.56 MHz, TTF or RTF was never an issue. However, with the newer long-range UHF tags, it is possible to fit several tagged items into a reader beam, and multi-read becomes a necessity. With the expected growth in the RFID market, comes the (nightmarish) scenario of large numbers of tags and readers from different manufacturers sharing the same physical and frequency space.

Picture a truck with pallets of goods. In this scenario the truck, the driver, the tyres, the pallets and the goods could all be tagged with long-range UHF tags, almost certainly from different manufacturers. The different tags in this scenario have different primary functions. The tags on the goods might have a product identification (EPC) function, while the tyre and pallet tags might have an item identification purpose for supply chain management and authentication. The truck tag might be used for a combination of auto tolling, fleet management and access control, with at least one of the requirements that it must be read at high speeds. The goods tags might have extraordinary cost pressures, while the pallet tags might require Read/Write functionality.

Inherent in multi-read protocols is an anti-collision algorithm. This is used to identify the tags present and to set up a one-to-one communication channel between tag and reader. Both during the anti-collision phase and later during other data exchanges between tag and reader, transmissions by other tags and readers can interfere with the process.

The term "Tag pollution" has been coined for the scenario where tags from different manufacturers all clamour for attention, and in the process jam each other and interfere with the anti-collision algorithm. Lately, a new concern has arisen, namely that of "Reader pollution". In scenarios where several readers, possibly from different manufacturers, have to operate in proximity, there is a real risk that the readers would interfere with each other and with tag transmissions. Examples are warehouses with several docking bays next to each other and production lines where tags are read at several points along the manufacturing process.

What is required, and required soon, is a "Non-proliferation Treaty" – some standard or agreement that would allow for the orderly exploitation of long-range passive tags and readers. Other standards can follow later, e.g. standards that address data formats and content. ISO 18000-6 attempts to do both, and as such it is a complex standard. Standardisation efforts nevertheless deserve the support of tag manufacturers and users.

The current ISO 18000-6 proposal specifies an RTF tag. However, it has apparently become somewhat bogged down in political and licensing issues. There is also a growing realisation that the current proposal is too complex and costly to implement, and that it might be time to re-open the debate.

3 READER TALKS FIRST

The basic idea behind RTF is that tags remain quiet until specifically addressed or commanded by a reader, i.e. tags are "woken up" by a specific command. The mere presence of a signal from a reader, such as a CW power beam should not wake the tag. This means that tags from different manufacturers and executing different (anti-collision) protocols can co-exist – only a subset will be woken up at any one time, while the rest would not interfere with the anti-collision protocol and other communication between reader and tag.

To achieve co-existence, at least a wake-up command standard is necessary for RTF tags. For inter-operability, additional standards would be required. A wake-up standard would unfortunately also have to specify some additional parameters, such as modulation techniques and baud rate.

4 TAG TALKS FIRST

A TTF tag announces itself to the reader by transmitting an ID when it detects the presence of a reader. In passive tags the reader is detected by the fact that the tag powers up when it enters the reader beam. Once the reader has received the ID, it can command the tag to switch off or otherwise communicate on a one-to-one basis with the tag.

It is important that the initial ID announcement takes place in a manner that allows for multiple tags to be in the beam simultaneously. In currently available products the ID is transmitted in a pseudo-random manner with an average duty cycle that is low enough to allow for the detection of large numbers of tags, while still fast enough to achieve a reasonable throughput rate. Duty cycles of 1:500 are suitable for most supply chain applications and allow for the detection of several hundred tags simultaneously. Various licensed and unlicensed techniques exist for accelerating the anti-collision process, all with their own advantages and disadvantages.

TTF tags easily co-exist with other TTF tags, mainly because of the inherent redundancy in their protocols, but a standard should try and ensure that applications use the minimum required duty cycle. **Only a maximum duty cycle needs to be specified to ensure co-existence for TTF tags**.

5 COMPARISON

5.1 Complexity

RTF tags have to contain at the very minimum some kind of receiver / detector and a command interpreter. In reality, current RTF designs execute complex anti-collision protocols, adding to the size of the silicon die and increasing the cost.

Read-only TTF tags can be extremely simple without compromising performance, resulting in very small silicon die and very low cost tags. One current design achieves such a read-only device in less than 0.5 mm^2 silicon in a 0.5 μm CMOS process. Similarly the reader design can be relatively simple, with no need for any form of synchronisation or command capability.

5.2 Reliability and robustness

As mentioned before, TTF tag protocols are inherently robust, due to the fact that the ID is typically transmitted repeatedly. While noise and other reader and tag transmissions can result in the loss of some ID transmissions and thereby slowing the process down, the protocol still typically survives. TTF protocols are immune to dynamically varying tag populations. RTF protocols on the other hand are much more easily jammed and might for instance not survive in the presence of TTF tags or other RTF readers. RTF protocol performance will also suffer with dynamically varying tag populations/.

5.3 Anti-collision algorithms

The most basic TTF anti-collision protocol does not require any commands from reader to tag. An example of such a protocol is the so-called “Free-running” protocol, where tags just transmit their IDs at pseudo-random times. The reader only listens and builds up a list of IDs present. The two main drawbacks of this protocol is its tendency to saturate at high tag populations and the fact that it is non-deterministic, i.e. the reader can only detect all tags with a probability that approaches unity. In practice this probability can be made arbitrarily close to unity by just waiting long enough. The saturation effect can be largely offset by using higher baud rates. This is always possible as there is no spectrum limitation on the tag back-scatter signal. Current TTF RFID tag designs operating at 64 kbit/s or even 256 kbit/s can easily handle more than 100 tags simultaneously and can handle small numbers of tags at very high speeds (in excess of 140 km/h).

When reading large numbers of tags simultaneously, RTF protocols can be made much faster than TTF protocols, at least in theory. Typical RTF anti-collision protocols are based on various forms of deterministic and non-deterministic binary search algorithms. Unfortunately the protocols are finally limited by bandwidth considerations and poll rates.

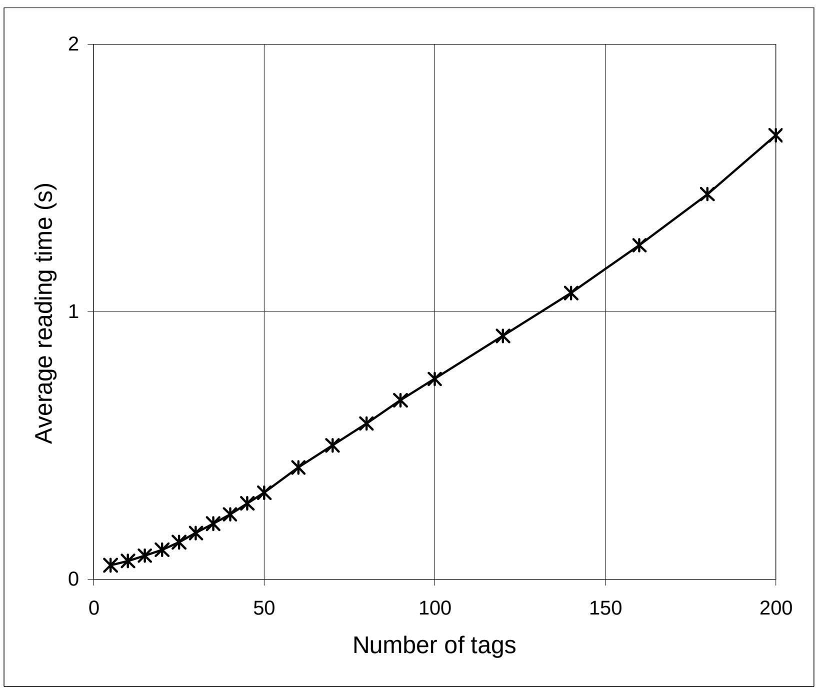


Figure 1: *Average reading time for a basic read-only TTF protocol with a 1:500 duty cycle running at 256 kbit/s.*

5.4 Bandwidth

RTF protocols require larger reader bandwidths than a basic read-only TTF protocol. ISO 18000-6 specifies 200 kHz channels, while some read-only RTF tag products require even more. In comparison, even a high performance “Free-running” TTF protocol can operate in a single 12.5 kHz channel. This is an important consideration for Europe and countries outside of the USA.

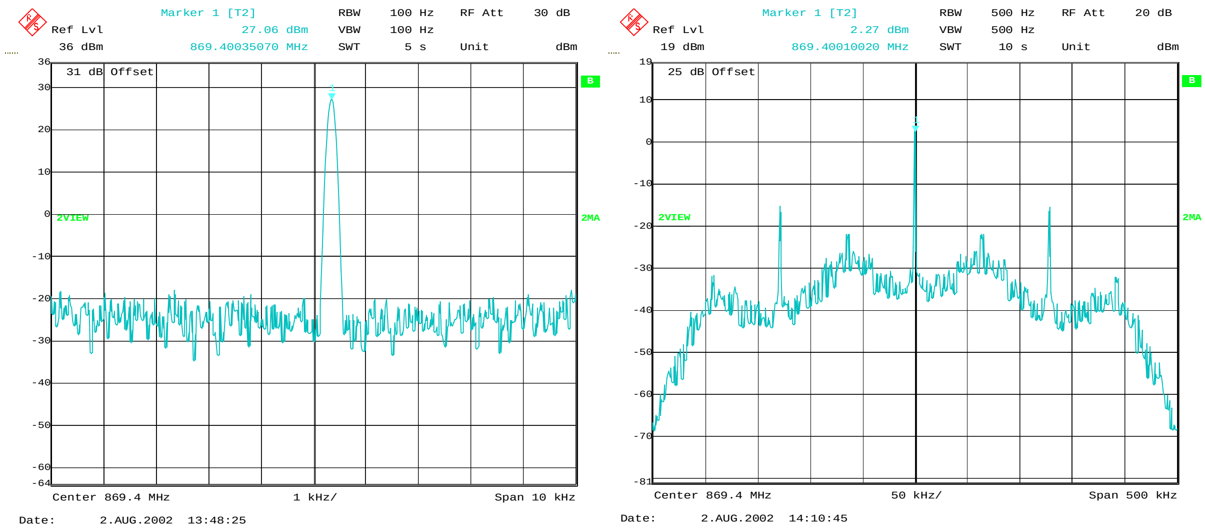


Figure 3: *Reader (left) and backscatter (right) spectra for a read-only 64kbit/s TTF protocol. Note that the backscatter spectrum was measured at the tag with a 10 dB coupler. In practice the backscatter signal is very weak (< -60 dB at 1 m).*

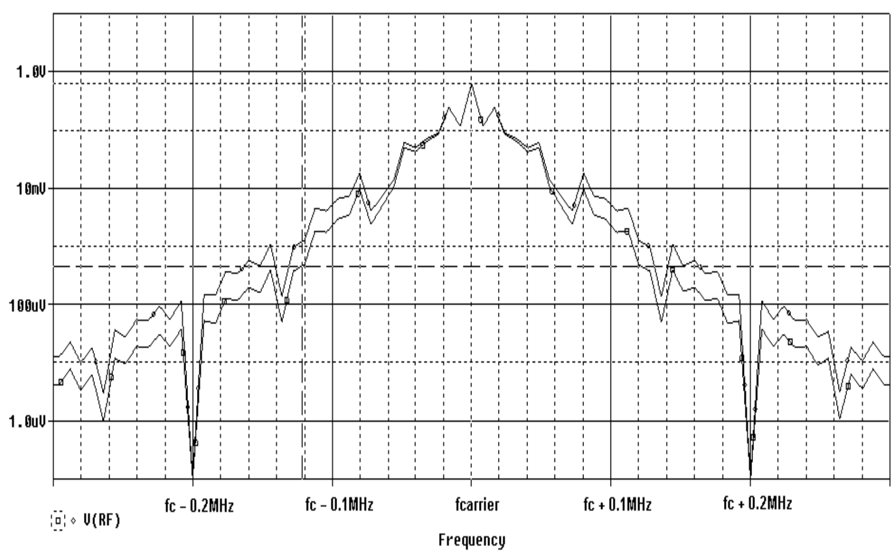


Figure 2: *Typical RTF forward link spectrum (Courtesy Matrics)*

5.5 Multiple readers in proximity

Read-only TTF readers can be operated at a single frequency in close proximity. At high baud rates the data spectrum is sufficiently far away from the carrier to make it possible to filter out difference components and inter-modulation products from other reader carriers in the vicinity. This interference can be suppressed by more than 40 dB with a high-pass or band-pass filter.

RTF readers, on the other hand, cannot easily co-exist with other readers in the same channel and will have at least 40 dB higher levels of interference, compared to TTF systems. With 6dB of path loss for every doubling in distance, this implies that RTF readers will always have to be placed at least 100 times further apart than TTF readers. See Appendix A for a detailed analysis of the problem.

Frequency hopping and frequency agility is proposed in ISO 18000-6 to counter the problem. Unfortunately such measures increase the reader complexity and only solve part of the problem. Tags typically have quite large bandwidths (as much as 50 MHz to 100 MHz) and will detect commands from readers in all the channels.

5.6 Presence detection

An important drawback of RTF protocols is that the reader must first detect the presence of tags by some other means before it can initiate communications. Alternatively, communication must be initiated by some other means, such as manual initiation by an operator. These first two options defeat the object of RFID, namely automatic identification. A third option is for the reader to poll continuously for tags, by repeatedly transmitting wake-up commands and even possibly cycling through various wake-up alternatives.

In the case of dynamically varying populations or applications where goods are moving through the reader beam at unexpected times, e.g. airport baggage on a conveyer belt, the third option is virtually the only solution, i.e. the reader has to continuously wake up newcomers. This will lead to very high levels of interference and will effectively jam tags for a very wide area around the reader. (See also comments on bandwidth below).

A side effect of having to poll for tags is that the rate of polling determines the timing resolution with which tags can be detected, and it determines the speed at which tags can be allowed to move, independently of the speed of the anti-collision algorithm. Polling will also result in reading the same tags repeatedly, affecting the protocol performance.

5.7 Conclusions

Sufficient grounds exist for the re-opening of the TTF vs. RTF debate. TTF tags are less complex, require smaller silicon die and can be much cheaper. They also require much lower bandwidths. Multiple TTF read-only readers can be operated in close proximity, while RTF readers will probably interfere with each other.

It would be easier to achieve co-existence with TTF tags than with RTF tags. Compatible high performance read-only and read/write TTF protocols exist that would satisfy the requirements of supply chain management today and in the future.

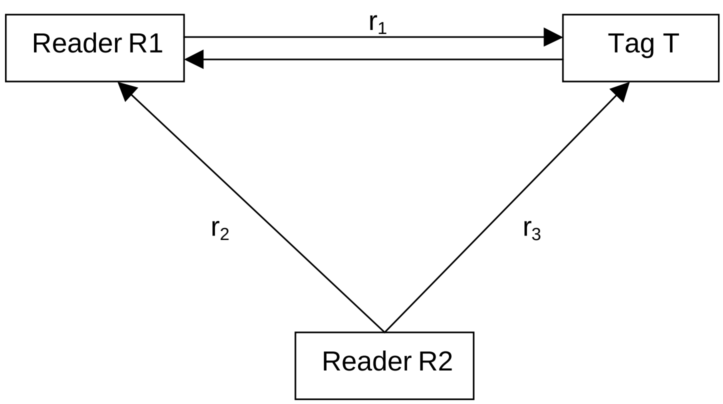
Through the implementation of a standard, coupled with judicious spatial, frequency and time separation, tag and reader proliferation can be managed successfully.

There is a huge market for very low cost read-only anti-collision tags (the lowest possible cost). These low cost tags will be the in majority and will be present even when other tags with more features (like R/W devices and ISO 18000-6) are also present. The presence of large numbers of these low cost tags might enforce a de facto standard. It would be better to take cognisance of this fact in an ISO standard.

Appendix A

Analysis of minimum separation distances for RTF systems

Consider the scenario depicted below:



Reader R1 attempts to communicate with Tag T. Reader R2 is polling for tags or communicating with tags in its own vicinity.

For R2 not to interfere with the communication from R1 to T, its signal must be smaller than R1's at T. Depending on Tag T's threshold settings the voltage as a result of R2 (V_{R2}) should at the very least be less than half the voltage as a result of R1 (V_{R1}).

For the purpose of the following calculations we will assume omni-directional antennas on both tag and readers. Directional antennas can make matters better, depending on the actual system layout and the level of reflections off nearby objects. We will also assume that both readers transmit at the same power level and modulation index.

In the analysis below, the following naming conventions are used:

V_{R1}, P_{R1}	is the signal voltage and power at T as a result of transmissions by R1
V_{R2}, P_{R2}	is the signal voltage and power at T as a result of transmissions by R2

At Tag T:

$$V_{R1} > 2V_{R2} \qquad (1)$$

$$P_{R1} \propto \frac{1}{r_1^{\,2}} \;\Rightarrow\; V_{R1} \propto \frac{1}{r_1}$$

Similarly:

$$V_{R2} \propto \frac{1}{r_3}$$

From (1):

$$r_3 > 2r_1$$

Power varies as the inverse square of the distance, but voltage varies just proportional to the inverse of the distance. r_3/r_1 will always have to be more than the ratio of signal strengths that the tag can reliably discern.

However, the more serious interference occurs at Reader R1, where the signal from R2 interferes with the backscatter from Tag T. The backscatter signal power obeys the Radar law and varies proportional to the inverse fourth power of the distance, while the interfering signal power from R2 only varies as the inverse square of the distance. In addition, the strength of the backscatter signal is affected by the RCS (Radar Cross Section) of the tag. The tag is not a perfect reflector and only a portion of the incident radiation is reflected.

In the analysis below, the following naming conventions are used:

- V_T is the signal voltage at R1 as a result of the backscatter from T
- V_{R2} is the signal voltage at R1 as a result of transmissions by R2
- P_T is the signal power at R1 as a result of the backscatter from T
- P_{R2} is the signal power at R1 as a result of transmissions by R2
- P_2 is the signal power transmitted by R2
- G_1 is the gain of R1
- G_2 is the gain of R2

We now we have at R1:

$$V_T > 2V_{R2}$$

$$\Rightarrow \quad P_T > 4P_{R2} \qquad (1)$$

$$P_{R2} = \frac{P_2 G_2 A_{e1}}{4pr_2^2}$$

$$A_{e1} = \frac{l^2}{4p} G_1$$

$$\Rightarrow \quad P_{R2} = \frac{P_2 G_2 G_1 l^2}{(4pr_2)^2} \qquad (2)$$

From the radar equation:

$$P_T = \frac{P_1 G_1^2 l^2 s}{(4p)^3 r_1^4} \qquad (3)$$

where σ = RCS (radar cross section)

Combining (1), (2) and (3) gives:

$$\frac{P_1 G_1^2 l^2 s}{(4p)^3 r_1^4} > 4 \frac{P_2 G_2 G_1 l^2}{(4pr_2)^2}$$

With $G_1 = G_2$, $P_1 = P_2$ and simplifying:

$$\frac{s}{4pr_1^4} > \frac{4}{r_2^2}$$

$$r_2 > 4 \cdot \sqrt{\frac{p}{s}} \cdot r_1^2 \qquad (4)$$

With $\sigma \approx 10\ \mathrm{cm}^2$ for a typical tag (Matrics)

$$\Rightarrow \qquad r_2 > 71 r_1^2$$

This implies that RTF readers with reading ranges in excess of 10 m will have to be spaced by at least 7.1 km (worst case).

As said before, directional reader antennas can make matters better, depending on the actual system layout and the level of reflections off nearby objects. The above analysis assumed that R2 was directed towards R1. In addition, low modulation indexes might also improve matters. A 10% modulation index will effectively mean that the energy in the modulation is 100 times lower, which reduces the required separation by a factor 10 (710 m instead of 7.1 km).