

Paper Review: Drone Relays for Battery-Free-Networks

Luca De Mori
Sorbonne University
75005, 4 Place Jussieu
Paris, France
luca.de_mori@etu.upmc.fr

Andrea Ferlini
Sorbonne University
75005, 4 Place Jussieu
Paris, France
andrea.ferlini@etu.upmc.fr

ABSTRACT

Battery-free sensors widespread usage as identifiers of clothes, manufacturing parts, etc. rises several challenges during the inventory process. These are mainly due to their short range reliability.

Yunfei Ma et al. addressed the aforementioned issue using a drone which acts as a relay. This work aims to review their proposal of enhancement for battery-free sensors range.

Keywords

Battery-Free Sensors, Mobile Networks, Sensor Networks, Drones

1. SUMMARY

At *SIGCOMM17*, Yunfei Ma et al. presented "Drone Relays for Battery-Free-Networks" [1].

In their paper, Yunfei Ma et al. introduce RFly, a full-duplex relay for battery-free networks which leverages on drones. RFly preserves phase and timing of the forwarded packets, allowing the Radio Frequency Localisation (RF-Localisation).

1.1 Context

Nowadays Radio Frequency Identification (RFID) widely adopted to identify an tracks objects both in factories, warehouses and supply chains. Furthermore, the RFID market is currently the fastest growing market of network devices, accounting more than 5 billion units in 2016. Since RIFD are battery free devices that can not be powered from long distances, they have a low distance range reliability (less than 5m) [2, 3, 4], and that has strong impacts on the way inventory are performed. In fact, the employee has to walk around the warehouses with the reader, to scan the entire content of the warehouse, wasting an enormous amount of time.

Past literature presents a variety of approaches on relay designs, long-range backscatter communication and localisation. However, they require expensive battery supplied tags and none of them is applied to RFID commercial deployments.

Recently, several startups have started investigating the problem. Their proposals leverage on drones for

the inventory control as well [5, 6]. Despite RFly, all of them mount either a camera or a barcode reader on a drone, being only able to catalog the objects in line-of-sight. Another startup [7] and other research bodies [8, 9] have tried to place the RFID reader directly on the drone. Although it may seem to be the easiest approach, readers are heavy and bulky and it must adopt more powerful drones (e.g. delivery drones) to carry such a payload. The need of bigger drones limits, for safety reasons, the candidate applications to the only outdoors ones. For that reason, Yunfei Ma et al. has prototyped RFly, which is lighter and smaller, and can be carried by small drones.

1.2 Contributions

RFly is an RFID relay system that leverages on the agility of drones to extend the range of operation of a RFID Reader. According to their design, the drones act as a "full duplex repeater" between the readers and the tag. The Reader becomes then capable to sense and localise items in non line-of-sight setting over a wider area. In particular, the relay carried by the drone receive the queries transmitted by the readers (downlink), it filters, amplifies and then forwards them again to reach the RFID. The same process is done in the opposite direction (uplink) sending back to the reader the RFID's backscattered reply. One main advantage of using a drone is that is able to fly over the whole warehouse, with no blind spots. In order to behave as described by the authors, RFly must have the three following key features:

- Maintain the natural bidirectional full-duplex communications, to behave as a transparent relay.
- Phase and time characteristics preserving, to permit the RF localisation.
- A compact design, to cope with the aerodynamic constraints and the limited payload that can be carried by a drone.

The aforementioned characteristics are achieved by:

- Frequency detachment between Reader-Relay and Relay-RFID Tag "half-channels" to avoid relay self-interference 1.2 resulting in an unstable system.
- The self-interference cancellation is entirely done in the analog domain, thus preserving the time characteristics.
- Since the link separation involves a carrier frequency shift, it introduces a phase offset. Thus the system is designed in a symmetric way, so using the same oscillator for the down-link and the up-link and then cancel the phase offset ?? 1

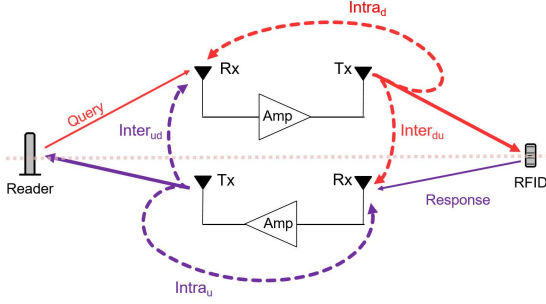


Figure 1: Sources of self-interference *Intra-link*: the forwarded signal feeds back to the receive antenna. *Inter-link*: signal from uplink leak into the downlink or vice-versa due to poor filtering.

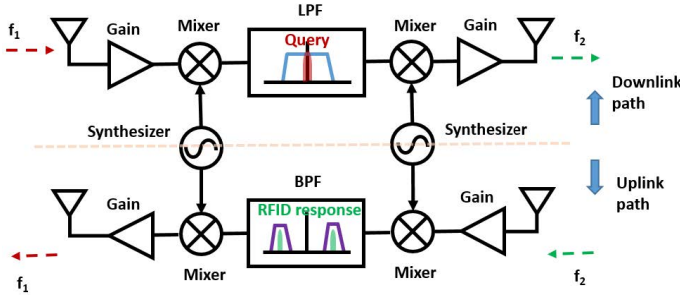


Figure 2: Relay block schema. Demodulation and demodulation are required to separate the two halves of the Reader-tag links. Symmetry is required to enable RF localization. Filtering is necessary to avoid *Inter-link* interference.

Using a drone as carrier of the relay, allows to exploit the relay motion. This way is possible the implementation of a localisation method inspired to Synthetic Aperture Radar (SAR) [10, 11, 12]. Capturing the RFID responses from different points along the trajectory of the drone, the SAR equation can be applied to locate the RFID tag with respect to the drone position. The reader itself processes the localisation. It collects the RFID tag responses and reconstructs the distances with respect to the drone path.

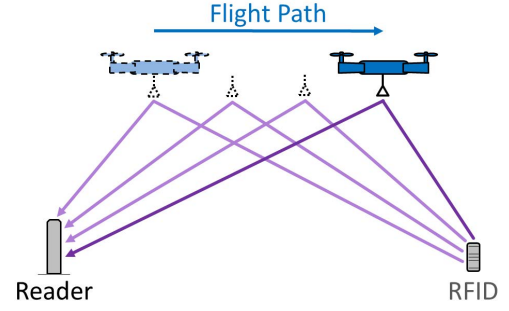


Figure 3: Relay motion effect. Contribution of the two half-links to the phase of the signal received by the reader.

Since the relay is moving as well, the recovered distances have an additional components due to the drone path (Fig. 1.2). Meaning that the SAR equation can not be directly applied. To remove this interfering term from the final equation, the authors include an RFID tag in the drone to recognise its spurious contribution. To successfully implement their localisation technique, the authors also address the multipath interference. The way they do it is simple but smart: they get rid of the "ghost" location produced by the environment reflections.

Yunfei Ma et al. actually built the prototype, showing the following:

- The range over which the reader can communicate is extended from less than 10m to above 50m.
- The localisation accuracy is quite high. Although it decreases with the distance, remains below one meter of median error, even if the distance is more than 50 meters between the RFID tag and the reader.
- Thanks to a custom PCB board the the final size of the relay is 10cm x 7.5cm. The total weight is 35g significantly below the payload limits of a indoor drones (about 200g)

Furthermore, the authors proved that RFly is transparent to the RFID protocol. Thus meaning it can be deployed over the existing infrastructure and that it's possible to leverage past work to cope with multiple tag or multiple readers interferences.

Yunfei Ma et al.'s proposal is not a complete solution and it has some limitations:

- The authors relied on an external vision-based navigation system (OptiTrack [15]) to provide navigation, obstacle avoidance and stabilisation to the drone.
- The operation range of the prototype they developed is still bounded to 55 meters, which is not enough to cover large warehouses areas.

However, the authors proposed some reasonable direction that can be followed in future works to solve the current limitations.

Summing up, RFly provide a big step forward in long-range communication and localisation in battery-free networks. It also opens new research opportunity to combine drone agility with RF sensing techniques.

2. CRITICAL ANALYSIS

2.1 Strengths

The paper submitted by Yunfei Ma et al. is extremely well structured. It has several inner references to subsections, equations, figures, etc. which make it enjoyable and easy to read. In fact, the ease which this paper can be studied with, is surely due to the easiness of the navigation through it. We can state that the clarity of the overall work permits to easily follow all the steps, even the non trivial ones. Moreover, when needed, Yunfei Ma et al. cite other works, allowing the reader to find further useful clarifications. That helps to better understand the majority of the claims and steps described in the paper.

Delineating the problem, the authors clearly state its importance and highlight its topicality. Indeed, it is not confidential that both Amazon, Walmart and other big companies, as properly cited by Yunfei Ma et al. [13, 14], are trying to automate their processes as well. In a society more and more technology oriented and robot-driven, the automatisation, with its consequent speeding up, of the inventory process is clearly an hot and open research question.

The authors describe the proposed solution in an extremely clear way, without being wordy and repetitive. At first glance, RFly seems to be extremely easy. However, deepening in it, it comes out how smart it is. As properly described in the paper, there are some non trivial challenges that have to be faced. Yunfei Ma et al. accounts and smartly solve all of them. Furthermore, they list and resolve all the related issues that may come up, together with a proper explanation.

One of the strongest point of this work is that the team build a prototype to test their solution in practice. Yunfei Ma et al. developed the relay circuit on a custom PCB board and they mounted it on a Parrot Bebop. The real implementation of the solution gives an edge to this work because to prove that it is not only a theoretical concept, but that it actually works. Then, they run different experiments in a testbed environment to prove the accuracy of the system:

- *Inter* and *Intra* link isolation measurement (the higher the Isolation, the higher is the achievable range extension)
- Phase preservation through the relay process (re-

quired to perform RF localization)

- Range evaluation by assessing the reading rate of the tag with respect to its distance from the reader. (Relay-RFID tag kept restricted to 3-5m)
- Localization accuracy with respect to the tag-reader distance.
- SAR aperture influence on the localization accuracy. (useful to tune the localization algorithm)

The authors presented the result with clear and meaningful graphs, together with detailed descriptions that point out the relevant insights.

2.2 Weaknesses

Although the paper is complete and well structured, in our opinion, Yunfei Ma et al. didn't provide meaningful insights on the implementability of their solution in a real case scenario rather than a minimal testbed environment as described in the evaluation section of the paper. In particular, the authors didn't give an evaluation of the performance against:

- the number of tags in the range of the relay, which is likely to be quite high in a real warehouse.
- the complexity of the environment layout which affect the magnitude of the multipath propagation.

Plus, they claim that since the relay is transparent to the RFID protocol, RFly can come with multiple readers interference, leveraging on previous work. However, they don't properly cite any paper on the topic neither prove that the frequency shift technique that they use in the *intra-link* isolation doesn't affect the existent interference avoidance algorithms.

Talking about the localization method, there are no information about the complexity of the algorithm that they implemented which, in our opinion could be interesting to evaluate the scalability of the algorithm with respect to the number of tags that has to be localized.

Moreover, Yunfei Ma et al. state that is possible to extend the same localization algorithm to a 3D case (tags displaced at different heights) if the drone describes 2D trajectories. However, no further proof is given, neither any brief theoretical description of the approach that should be taken to construct a system that gathers enough data to implement a 3D SAR based localization algorithm.

- Not clear how they will address the information processing once gathered by the reader in an existing deployed RFID structure. How they interface with commercial readers and which kind of system will implement the SAR-like localisation algorithm (they used a USRP radio -> custom, to be able to recover the timing and phases to reconstruct the path)

- No information on the complexity of the algorithm and the time required to compute the estimated location of the tag (+ RESOLUTION)

- no mention to autonomy of the drone. who decides the path, who keeps the trace of the drone position to retrieve the absolute position of the tags in the area (not only w.r.t. the drone). Battery duration and recharging?

3. CONCLUSION

SUMMARY OF BEST STRENGTHS COMPARED WITH WEAKNESSES

4. REFERENCES

- [1] Y. Ma, N. Selby, F. Adib, "Drone Relays for Battery-Free-Networks", ACM SIGCOMM, Los Angeles, 2017.
- [2] L. Ukkonen, L. Sydänheimo, and M. Kivikoski. "Read Range Performance Comparison of Compact Reader Antennas for a Handheld UHF RFID Reader", IEEE International Conference on RFID, 2007.
- [3] J. wook Lee, H. Kwon, and B. Lee "Design Consideration of UHF RFID Tag for Increased Reading Range", IEEE MTT-S International Microwave Symposium Digest, 2006.
- [4] H. Yojima, Y. Tanaka, and Y. Umeda "Analysis of read range for UHF passive RFID tags in close proximity with dynamic impedance measurement of tag ICs", IEEE Radio and Wireless Symposium (RWS), 2011.
- [5] CNN. Are flying robots the perfect co-workers. <http://www.cnn.com/2016/05/12/africa/drone-scan-inventory-technology-south-africa/>.
- [6] Hardis-Group. Eyesee: the drone allowing to automate inventory in warehouses. <http://www.hardis-group.com/en/our-activities/re-ex-supply-chain-solutions/eyesee-drone-allowing-automate-inventory-warehouses>.
- [7] Yard Management. <http://www.pinc.com/>. PINC Inc.
- [8] M. Longhi, G. Casati, D. Latini, F. Carbone, F. Del Frate, and G. Marrocco "R drone: Preliminary experiments and electromagnetic models", IEEE EMTS, 2016.
- [9] C. Swedberg, "RFID-reading drone tracks structural steel products in storage yard", RFID Journal, 2014.
- [10] J. C. Curlander and R. N. McDonough. "Synthetic aperture radar." John Wiley & Sons New York, NY, USA, 1991.
- [11] S. Kumar, S. Gil, D. Katabi, and D. Rus., "Accurate indoor localization with zero start-up cost", In ACM MobiCom, 2014.
- [12] J. Wang and D. Katabi., "Dude, where's my card? RFID positioning that works with multipath and non-line of sight", In ACM SIGCOMM, 2013.
- [13] New York Times. Walmart looks to drones to speed distribution. <https://www.nytimes.com/2016/06/03/business/walmart-looks-to-drones-to-speed-distribution.html>.
- [14] USA Today. Amazon just opened a grocery store without a check-out line. <http://www.usatoday.com/story/tech/news/2016/12/05/am-go-supermarket-no-checkout-no-cashiers-artificial-intelligence-sensors/94991612/>.
- [15] Optitrack. <http://www.optitrack.com>.