Mobility Improves Performance of RFID Library Systems

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***Abstract*—This work demonstrates that a RFID Gen2 reader on a moving cart can offer tag reading rates close to 100%, provided that multiplexing (and not splitting) is used at the antennas connected to the reader, by exploiting the changes (due to mobility) of the wireless propagation channel. Library RFID systems could largely benefit of such cost-effective approach, given that only a single reader is employed.**

***Index Terms*—antenna, propagation, measurement.**

I. Introduction

Keeping inventory track of books in a library has been typically addressed with scanning methods at checkout or check in; the latter however do not address misplaced (and thus, missing) items and usually suffer from increased processing delays. Since 1948, when the use of modulated backscatter as a means of communication was proposed by Stockman [1], many interesting applications of backscatter transducers (or RF tags) have emerged including, radio frequency identification (RFID).

However, RFID systems suffer from the idiosyncrasies of the wireless propagation channel and the short tag-to-reader range. Wireless signal propagation suffers due to multipath (i.e. destructive addition at the receiver of multiple useful tag signal reflections), while RFID tag short range is due to the RF energy harvesting requirements of the tag's integrated circuit (IC) and the high data rate used in such systems. Due to these problems, cost-effective and successful deployment of RFID systems is challenging in large indoor areas, such as libraries.

Typical methods to address room-size RFID coverage include multiple antennas connected to multiple readers. Prior art has studied the use of antenna networks with intelligent splitters or antenna selection multiplexers (constructed by commodity hardware) [2], [3] that connect several antennas to a number of immobile readers. Work in [4] exploited the dyadic backscatter channel and demonstrated multiple RF tag antennas, while work in [5] offered transmit diversity by phase conjugating the forward link associated with each reader antenna; both methods improved performance in fading environments of passive RFID systems.

Apart from RFID technology advancements, there has been an increasing interest on relevant accurate coverage estimation. Link budgets of RFID systems have been extensively studied in [6] and [7]. Stochastic analysis of the propagation environment in [8] offered probabilistic evaluation of successful tag identification. A model tailored to wireless propagation for RFIDs was proposed in [9], where various experimental system parameters were taken into account. A stochastic model suitable for multiple reader and tag antennas, was presented in [10], and diversity gains due to multiple tags were investigated. Careful study of the propagation environment, taking into account site-specific information, as well as the stochastic nature of propagation, has revealed computationally-inexpensive ways to estimate coverage and plan reader installation at specific locations [11].

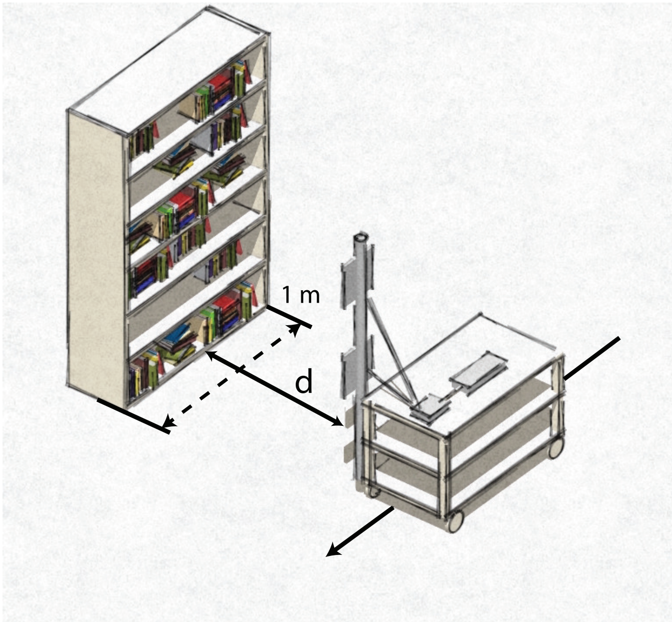

Fig. 1. A commodity Gen2 RFID reader is placed on a (mobile) library cart for the experimental measurement campaign.

In this paper we improve the coverage of RFID systems used in libraries and simultaneously reduce the total system cost by exploiting the changes of the wireless propagation channel, due to mobility of a single reader with multiple antennas on a library cart. We measure the performance of a moving cart with antennas illuminating a 1m-width bookcase vs a static setup; the cart is fixed opposite of the bookcase. Furthermore, we compare a time-scheduling technique for the operation of the multi-antenna system of the cart vs. a simultaneous operation of the same antennas, fed by a splitter and justify the

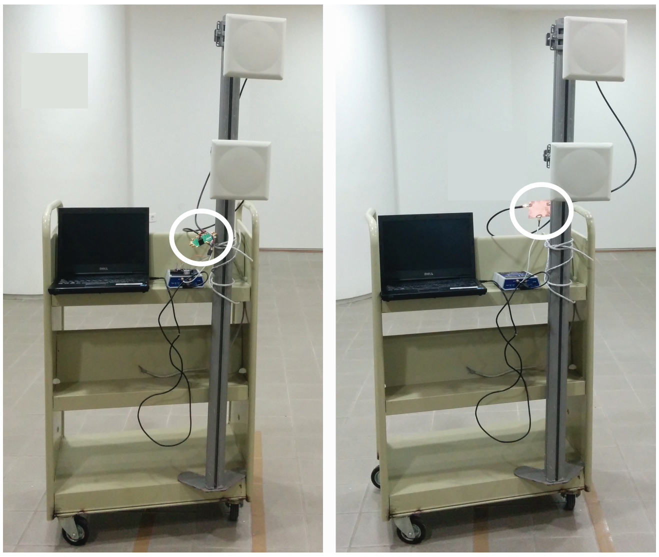

Fig. 2. Left: cart-mobile reader with the programmable multiplexer. Right: cart-mobile reader with the splitter.

superiority of the former theoretically and experimentally. In all cases, it is clearly shown that the reader mobility improves reading rate performance; given that a single reader and commodity hardware are used, such approach could decrease the total RFID system cost.

II. Approach

Coverage of large spaces, as in libraries, with commercial Gen 2 RFID tags typically require multiple readers. Since the RFID readers are static and the antennas illuminate at fixed directions, the propagation environment is static and coverage blind spots will always exist. Typical Gen 2 RFID readers have two to four antenna ports, with full duplex capability through circulator(s). Hence, to further increase the total number of antennas, either splitters or multiplexers must be utilized. The RF splitter divides the power transmitted by the reader to its output ports, resulting to decreased transmit power per antenna, since all antennas transmit simultaneously. On the other hand, the RF multiplexer uses time division between it's output antennas, hence only one antenna is active and transmitting at each time window, at full power (i.e. no power splitting).

Even though the increased number of antennas improves coverage, there will always exist blind coverage spots; the latter occur due to the immobility of the reader antennas and the destructive addition of multiple copies of the tag's signal due to multipath. In order to overcome this problem, instead of multiple static RFID readers, a moving library cart is employed. The cart contains the Gen2 RFID reader, a host computer which controls the reader, an uninterrupted power supply (UPS) and the reader antennas (Fig. 1). The latter are connected to the reader with two different ways, i.e. with a splitter or a multiplexer, as explained below. The mobility of the cart changes the multipath components of the communication tag-to-reader channel and modifies the blind coverage spots, i.e. the spots where multipath signal components add destructively. In that way, as the cart-reader moves, previously blind spots become visible and the reading rates of tagged items are improved. Such performance improvement is cost-effective since a *single* commodity RFID reader is utilized, with small number of antennas.

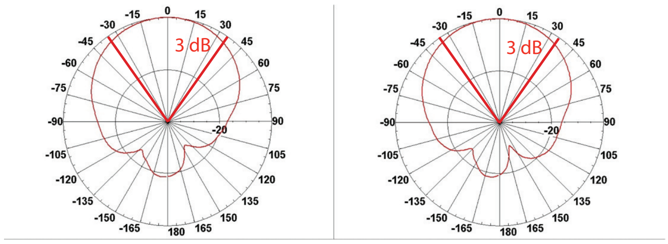

Fig. 3. Reader antenna directivity pattern (Left: azimuth, Right: elevation).

III. Setup Description

The experimental measurement campaign examined performance rates with a static, i.e. immobile Gen2 RFID reader in contrast to the same reader on a moving cart. In order to connect multiple antennas to a reader port, a radio frequency (RF) splitter or a RF multiplexer were utilized. The experiments took place in a lab with a bookcase full of books and one RFID tag attached to each book. At the immobile scenario the antennas and the reader were placed in front of the bookcase, while on the moving case, the cart passed in front of the bookcase with walking speed and followed a straight line track, parallel to the bookcase. In both scenarios, the antennas were $d = 0.5, 1, 2$ meters away from the bookcase (as shown at Fig. 1) and the reading time was the same for each scenario, i.e. the static reader was active the same amount of time as the mobile one. It should be emphasized that the bookcase was only 1m width and the radiation patterns of the static-antennas configuration illuminated well the entire bookcase (3 dB beamwidth equals $69°$ in the horizontal and the vertical plane). The mobile cart was only moved for a few wavelength opposite to the bookcase, as illustrated in Fig. 1. We made sure that the illumination volume in both cases was comparable in order to highlight the performance-benefits due to the misplacement of the propagation "holes" thanks to the proposed technique.

All experiments utilized two antennas at the reader, connected to one reader port, either through a splitter or a multiplexer (Fig. 2). A custom 1×2 Wilkinson splitter was used with 3.41 dB loss at the $865.6 - 867.6$ MHz frequency range (which belongs to the UHF industrial, scientific and medical (ISM) UHF band in Europe). The commercial 1×8 multiplexer had 1 dB insertion loss and 22 dB return loss.[1] Total cable loses (excluding connector losses) were on the order of 2 dB. Signal through the multiplexer incurred an additional 1 dB loss, while signal through the splitter incurred approximately 0.5 dB (apart from the 3 dB division loss).

[1]The multiplexer was used in a 1×2 configuration.

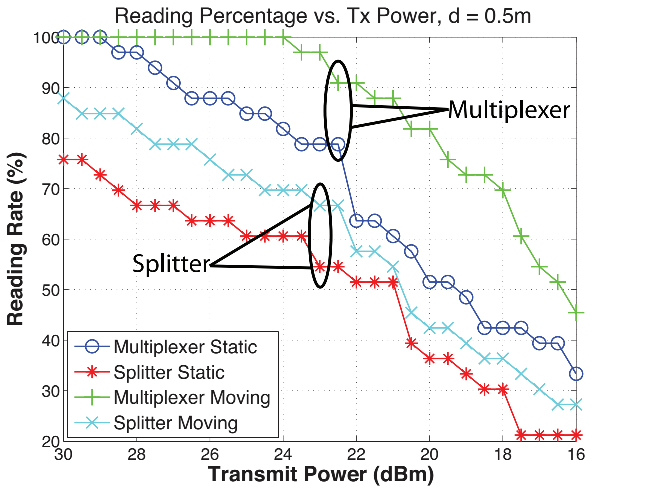

Fig. 4. Reading percentage vs. reader port transmission power (excluding antenna gain and cable/connector/insertion losses) vs. static or mobile reader vs. splitter or multiplexer, $d = 0.5$ meters away from the bookcase.

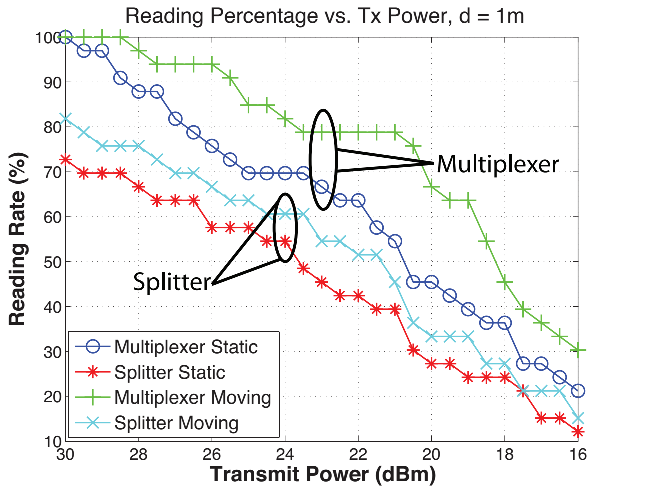

Fig. 5. Reading percentage vs. reader port transmission power (excluding antenna gain and cable/connector/insertion losses) vs. static or mobile reader vs. splitter or multiplexer, $d = 1$ meter away from the bookcase.

The multiplexer (mux) was controlled by an Ethernet-based Arduino board, which could be in turn set up through a web interface. The mux performed time division multiplexing (TDM) between two distant (on the mux printed circuit board) carefully selected output ports, so that mutual electromagnetic coupling among them was minimum.

Two commercial circularly-polarized antennas were utilized, operating at $865 - 904$ MHz, with 7 dBic gain and directivity patterns shown at Fig. 3. Typical RF type-N to SMA cables were used to connect the antennas to the RFID reader, through either the splitter or the multiplexer (Fig. 2). A commercial Gen 2 reader with one input/output port was utilized, operating in the European RFID band $865.6 - 867.6$ MHz.

The total radiated power by the reader antenna in each scenario (using either the multiplexer or the splitter) differs due to the different losses of the two devices. Using the multiplexer, with maximum power 30 dBm transmitted by the reader port, antenna gain 7 dBic (approximately 4 dBi), 4 dB cable and connector losses and 1 dB loss due to multiplexer insertion loss, the total radiated power was at maximum 29 dBm EIRP or 26.85 dBm ERP. Using the splitter with the same configuration and 3.5 dB loss due to power splitting and insertion loss, the total radiated power was at maximum 26.5 dBm EIRP or 24.35 dBm ERP. Both scenarios comply within the European ISM regulation limits at 868 MHz: 27 dBm ERP power limit (no beamwidth constraint), 30 dBm ERP power limit (for antenna beamwidths of less than 180°) or 33 dBm ERP power limit (for antenna beamwidths of less than 90°). Furthermore, the commercial Gen 2 tags were placed on the books with random antenna orientation. The reader was set to communicate with the Gen2 tags at the maximum baud rate of 640 kHz. For the case of multiplexer, antennas were alternatively connected to the reader port every 0.5 sec.

IV. Experimental Results

The percentage of successfully identified tagged books was examined, focusing on four scenarios: immobile or mobile reader with splitter or multiplexer, at $d = 0.5, 1, 2$ meters range from the bookcase and various reader port transmit power (and not *radiated* power, which can be easily calculated considering antenna gain and cable/connector/insertion losses, as described in the previous section).

The immobile scenario emulates a system where multiple readers are installed in a library room at fixed locations. Since the readers are static and the antennas illuminate at fixed directions, blind coverage spots will always exist. On the contrary, the mobile scenario reader on the cart addresses the coverage problem, since mobility introduces changes to the multipath components of the signal, and thus, location alterations of the blind spots. Thus, the moving topology increases the probability of a tagged item to be successfully identified by the reader.

Figs. 4, 5 and 6 offer the experimental percentage rate of identified tags, for $d = 0.5, 1, 2$ meter distance from the library bookshelf, respectively, as a function of reader's port transmit power. As shown, the static scenario (splitter- or multiplexer-based) has considerably smaller reading rates than the mobile scenario, since slow mobility - compared to the tag transmission speed - reduces the coverage blind spots. As expected, the splitter setup is worse than the multiplexer setup due to the following reason: as analyzed in [2], when multiple antennas are fed by a splitter, they must be placed close to each other and should illuminate different angular areas of the propagation environment; the purpose of using multiple antennas (with a splitter) is to increase the "equivalent" radiation pattern of a single antenna. In any other configuration of the multi-antenna system, as in this case, the antennas behave like an array, thus introducing nulls (due to the direct field of each antenna) at several locations, even in

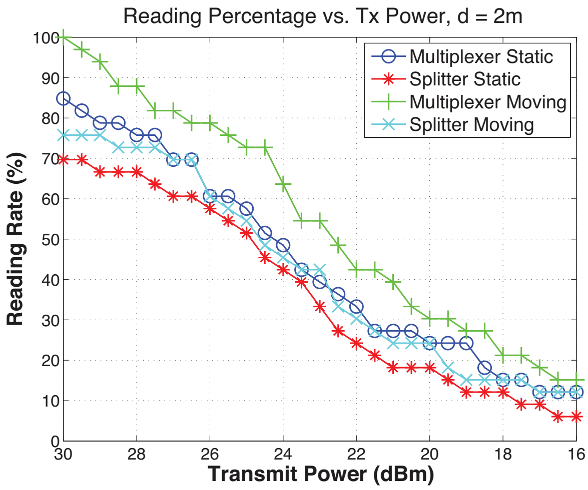

Fig. 6. Reading percentage vs. reader port transmission power (excluding antenna gain and cable/connector/insertion losses) vs. static or mobile reader vs. splitter or multiplexer, $d = 2$ meters away from the bookcase.

the vicinity of the antennas (time-schedulled phase-shifting techniques were proposed in [2] to overcome this problem). Nevertheless, even in this case, improved performance was recorded for the moving cart.

The combination of the moving cart and the multiplexer offers the best reading percentage rates in all tested ranges, reaching 100%. Moreover, mobility can offer 100% reading rates at approximately $2-5$ dB smaller reader transmission power (compared to the static case) for $d \leq 1$m, while for $d = 2$ the combination of mobile reader with multiplexer is the only way to achieve 100% reading percentage rate.

V. Conclusion

This work examined the use of a *single* mobile Gen2 RFID reader connected with multiple antennas for library RFID applications. It was shown that mobility of the reader offered improved tag reading percentage rates, in contrast to the immobile case. In order to connect multiple antennas to the reader, the use of a splitter or a multiplexer was further examined. The combination of a moving cart with a multiplexer for multiple reader antennas offered the best results, achieving 100% reading percentage rates of tagged books at smaller reader transmission power.

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