BACP+: A More Efficient Beacon Analysis-Based Collision Prevention Protocol

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Abstract. As in traditional wireless networks and Wireless Sensor Networks (WSN), Medium Access Control (MAC) in RFID (Radio Frequency IDentification) networks is a real challenge. RFIDs are increasingly being used for a variety of applications in several fields such as agriculture, industry, commerce, monitoring. Thus, providing MAC solution while preserving the resources (bandwidth, energy, storage, computing and transmission capacities) and ensuring scalability is very challenge. To avoid collisions that may occur between readers, anti-collision protocols use two approaches. The centralized approach based on Time Divisible Multiple Access (TDMA). The decentralized approach is based on the Carrier Sense multiple Access (CSMA) and uses notifications. That's why we offer Called Beacon Analysis-based Collision Prevention more (BACP+) to provide better performance for Called Beacon Analysis-based Collision Prevention (BACP) which uses the centralized approach by optimizing resources, and promoting the greatest number of reading with less interference. BACP+ makes full use of available resources, and frequency channels to ensure proper collision management and coverage time.

Keywords: Radio Frequency IDentification · Anti-colision protocol · Reader-tag

1 Introduction

RFIDs networks are increasingly used in several fields. The development and exponential growth of new information and communication technologies makes it possible to consider many applications distributed in space and a clear evolution towards the Internet of Things (IoT). However, because of the inherent characteristics of RFID readers and tags (energy, computing, storage and transmission capacities are limited), RFID networks do not adapt to the MAC communication protocols (MAC layer and network) proposed for wireless networks (mobile, ad-hoc, sensor) because of the significant costs generated and the variety of types of communication. Thus, for RFID specific approaches have been developed in recent years to resolve collisions, especially those between readers. In this way

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that CSMA-based decentralized protocols use a multichannel approach [2,4,8–12,16–18] to resolve reader-tag and reader-reader collusion. Those based on the TDMA [3–7,14,15] use a single-channel approach to adjust only reader-reader collusion. Their main disadvantage is the low reading rate and the relatively high energy consumption. Most protocols based on the centralized approach are derived from [14,15]. BACP is proposed to be a protocol that solves problems in GDRA [16] and DRCA [17], allocates resources to readers in order to ensure a maximum use of available resources while activating the largest number of readers in a round so that they can read the tags with minimal interference. However, BACP has a default on the random choice of time intervals and the activation of the maximum of reader. That's why we offer Called Beacon Analysis-based Collision Prevention more (BACP+) to provide better performance for BACP by optimizing resources, and promoting the greatest number of readings while minimizing interference. BACP+ makes full use of available resources, frequency channels to ensure good collision management and coverage time. The rest of the paper is as follows. Section 2 presents the state of the art on reader anti-collision protocols, including centralized protocols. A description of BACP [18] and its limitations are provided in Sect. 3. BACP+ solution is presented in Sect. 4. We make performance analysis and evaluation in Sect. 5. Finally, we conclude the paper and identify research perspectives in the section.

2 State of Art

Collisions degrade the performance of RFID systems. Thus, to ensure the necessary coordination between readers and avoid collisions, a Medium Access Control (MAC) must be established between readers and/or tags. For this, we distinguish two existing approaches [1]. The decentralized approach in which available system resources such as frequencies and time are distributed among the readers to prevent them from collisions [2–12]. This approach can effectively reduce the risk of readers collisions. However, its protocols are based on TDMA [3–7] or CSMA mechanisms [2,8–12]. In RFID, most distributed protocols based on TDMA approaches are derived from an earlier algorithm called Distributed Color Selection. They use a dedicated communication channel between readers to organize their activity [2]. They solve effectively the problem of reader collisions. However, the actual communication takes place between the reader and tag. This type of protocol does not take into account the problems of collision between reader and tag, which reduces RFID performance. As a result, with decentralized protocols, reader collisions persist, throughput and computation are generally very low, but mobility and equity are taken into account. In centralized approach where protocols are usually based on the TDMA, readers require a coordinator (a Central Server) for the RFID network, which manages and allocates resources to readers [14–18]. Readers can communicate by wired or wireless to the server. In the case of wireless, frequency between the readers and the central server is different from the frequency that readers use to communicate with the tags [13]. These protocols are less responsive to reader mobility, but they come over the problem of throughput, equity and sometimes reader-tag collision for which decentralized protocols suffer from. The single-channel approach was first developed to allow readers to discuss the medium with less interference [14,15]. So, in dense deployments where multiple readers are nearby and lead to increasing collisions, multichannel solutions are implemented [16,20]. It provides readers with four different channels to query tags, making tag readings less competitive and less prone to collisions. However Geometric Distribution Reader Anti-collision solution (GDRA) [16] has the disadvantage of poor resource management. To reduce collisions and promote maximum reading notion of changing channel is introduced by the Distance Based RFID Reader Collision Avoidance (DRCA) protocol [17]. But, channel abandonment still persists and prevent channel loss by introducing read priority to separate conflict in a channel. Nevertheless, BACP has shortcomings related to time slots lost at the beginning of the execution of the protocol, consistent collisions in high time slots and quite a lot of inactivated drives in a cycle. Thus, we propose BACP+ to overcome these problems.

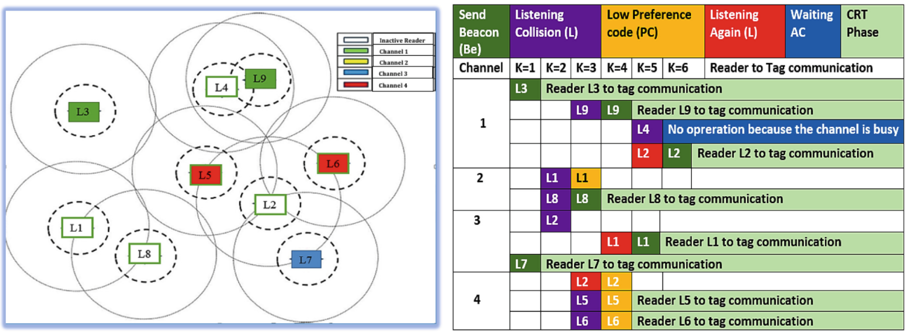
3 Review of BACP Protocol

3.1 Problem in GDRA and DRCA

In GDRA, when collision happen between two readers, they leave the channel and select another random channel and wait for the next round. As a result, the abandoned channel is unused and resources are wasted. Although GDRA is a multichannel protocol, it does not use this function correctly, because it is possible for a reader to read the tags with another reader in the channel without any interference. However, this question is not taken into account in this protocol and readers leave the channel as soon as it is busy. The DRCA protocol makes improvements to the problem of abandoning the channel and waiting for the next round. Thus, when the readers detect that the channel is busy, if they are not around the active reader, then they increment their time interval to one and choose another channel. Indeed, they can try to participate again in the current round. On the other hand, the problem with the DRCA is that readers which have the ability to access the channel again are allowed to randomly select one of the four existing channels. Therefore, with a probability of 25%, a reader chooses his previous channel. However, it wastes energy because it caused the reader to unsuccessfully attempt to access the channel [18]. Thus, the problem of GDRA is not solved in some cases. It is in this sense that the BACP was introduced to correct this weakness.

3.2 Description of BACP

BACP aims to resolve weakness in GDRA and DRCA by allocating resources to readers in ways that ensure maximum use. It also tries to activate more readers in round so that they can read the tags with minimal interference. In BACP, readers communicate with a central server. The server announces the start of each round by sending an AC (Arrangement Command) message to the readers. The duration of each AC is considered to be 2.83 ms and each round is divided into two phases. The contention phase, during which readers are in contention to access the channel by sending a tag message. The contention phase is divided into K slots, the duration of each time interval is Tslot = 5 ms. The readers are equipped with a bistatic antenna and can therefore send a beacon message in each time interval. In addition to listening to the channel. The duration of sending a tag message is TBeacon = 0.3 ms. In the BACP protocol, each time slot is divided into 16 sub-slots, and each reader selects in its time interval to send a tag message randomly. The duration of each time interval is the time it takes to send a beacon message. Each reader sends a beacon message during the selected sub-slots from its time slot and listens for the channels to receive beacon messages from the neighboring readers. In the same time interval if a large number of neighboring readers are there, then a collision occurs between the tag messages sent in the sub-slots, but with a very low probability. In the BACP protocol, each reader sends a tag called Preference_Code (PC). Each Preference_Code contains Reader_ID and a bit called Prev_state. Each network drive to a specific unit called Reader_ID. Prev_state is a bit (the last bit from the left) that refers to the readers state in the previous turn If the reader was able to read the tags of the previous round, then the value of Prev_state is zero (0); otherwise, it's one (1). To better illustrate BACP, we consider the scenario of Fig. 1-(a) and Fig. 1-(b) which show respectively the deployment topology of readers and their behavior during a round. The readers randomly select time slots and frequency channels after the central server sends the AC message. After selection, the readers are divided into the following four categories: channel 1={L3, L9, L4}, channel 2 ={L1, L8}, Channel 3={L2, L7} and Channel 4={L5, L6}.



(a) (b)

Fig. 1. Example: scenario for BACP

At the beginning of the first interval, k = 1, readers L3 and L7 send respectively their Preference_Code (PC) to the channels 1 and 3. Then they listen to the channel until the end of the first time slot, since they do not receive any PC from the neighboring readers, so they use the channel and start reading the tags.

- When the second time interval (TI) begins, the readers L1, L8 and L2 listen to the channel. Since the reader L7 reads the tags, reader L2 understands that the channel is busy and therefore calculates its distance to the reader L7. Since the reader L2 is in the interference range of the reader L7 and moreover the distance between the two readers is greater than 2 * drt (distance reader-tag) then L2 increases his TI by one unit and selects randomly another channel (channel 4, k = 4).
- After the end of the second TI, k = 2, the readers L1 and L8 compare the PCs received from each other. Since the L8 reader's PC is bigger, it occupies the channel (it is assumed that Prev_state of all drives is zero in this round) and L2 will change channels. He randomly chooses channel 3 and increments his TI to k = 5.
- At the beginning of the fourth TI, then in the third TI the readers L2, L5 and L6 have identified that the channel is free. They start sending their PC to the selected sub-slots. At the end of the fourth time slot, L2 compares the codes received from L5 and L6 with his PC, as his PC is smaller, he changes channels. The reader L5 also compares his PC with the received codes. Since L5 has only received the L2 PC and its PC is larger than L2, it can access the channel. The same goes for the L6 reader. The BACP protocol enables more readers in one round. In the BACP protocol, no reader needs to continually listen to the channel. If the reader has selected the time interval k, it only listens to the channel during the time interval (k−1), this reduces the power consumption. The evaluation of BACP with other protocols indicates that it has a good throughput.

3.3 Limits of BACP

The random selection of time intervals is a real problem in BACP. When readers have the opportunity to have a new channel, this means that the probability of interference in the highest TI, increases and possibly more drives are inactive. This is due to the use of the sift function [19] defined by probability formula: $pk = \delta * \frac{1}{\alpha^k}$ by this protocol. This function makes it possible to select with a high probability intervals: $\delta = \frac{(1-\alpha)+\alpha^k}{1-\alpha^k}$, where α is a constant between 0 and 1 and δ is a computable constant and K is the number of TI and k is a values between 1 and K. However, BACP presents some weakness that we will try to correct later:

- if the reading area of two readers is in interference, then they will have to wait for the next AC if they have chosen the same slot.
- if the coverage area of two readers overlaps, then the reader with hight priority will keep the channel and the other will change channels in the next time slot. On the other hand, if the collision occurs in the hight time intervals, then readers may wait for the next round. Applying equity for readers that are in the same channel and time-slot can reduce the chance of reading multiple

readers in this time-slot. For example, if L2 was more important than L5 and L6 then they would have to leave the channel. In this case we lose two readings for a single reading as shown in Fig. 2.

The delay is long because the readers did not start their interrogations very early.

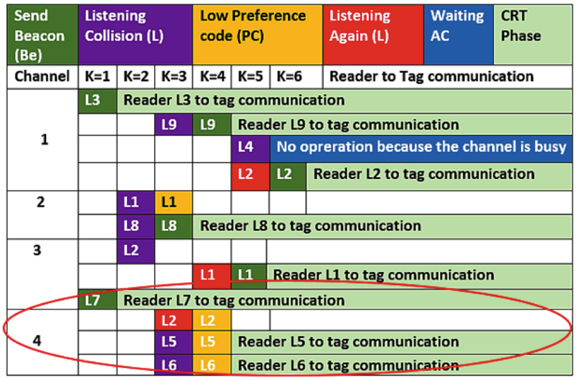


Fig. 2. Collisions in BACP

4 BACP+

4.1 Solve the Problem of Lost Time Slots

In BACP all readers randomly choose a time-slot, if there are readers that interfere, then they will randomly choose sub-slots from the 16 available in the same slot. Then they will compare their PC. The reader which has the largest PC will keep the channel and the others will change channel and the TI will be incremented by one. We can note that this can lead to empty TI at the beginning of the round and others overloaded because it is possible that no reader chooses the beginning slots due to the randomness of the choice. To bring a solution for this, we propose in BACP+ to solve collisions of readers very early. In this case all readers must start sending their tags to $k = 1$ in order to scan the network. If collision is detected between readers then they compare their PC and the one with the biggest will read the tags and the others will increment their time-slot by 1. So all the TI will be busy. Figure 3 shows the slots time lost in BACP.

However in BACP+, since all the readers will try to communicate at the time interval $k = 1$ to avoid losing TI, this can lead to collisions (at the beginning of the TI) that we will try to solve in Sect. 5.2.

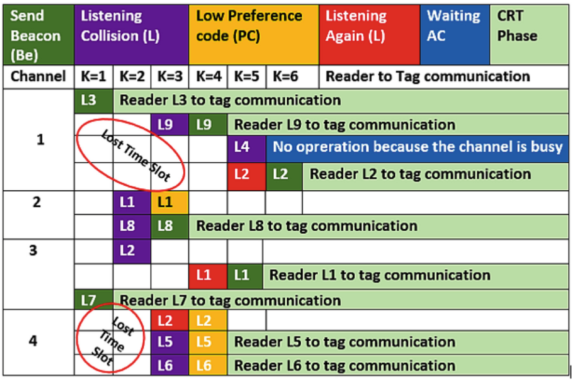


Fig. 3. Lost slots time in BACP

4.2 Deal with the Loss of the Channel Due to the Same Slot

In BACP if several readers have chosen the channel and the same time-slot as the distance between the readers is less than 2 times drt as it is the case between L4 and L9 (see Fig. 1-(a)), they wait for the next round and the channel is lost because their communications may collide with the response of a tag. In order to keep the channel, BACP+ compares the PC of the two readers, and reader with biggest priority will keep the channel and the other one expects the next AC.

4.3 Make Compromise Between the Density of Readers and the Number of Time Slots

If the density of the readers is very high then we will have a lot of collision in the TI. Thus, we can provide a solution that will make a compromise between the time slots and the number of readers. This will reduce collisions in time intervals.

5 Analysis and Evaluation

In this section we make evaluation and analysis of BACP+ and BACP to determine and justify its performances. To do this, we use in the first reader reading throughput as a comparison metric.

5.1 Comparison of Reading Throughput

In the scenario of Fig. 4, we can see that BACP+ increases the read throughput compared to BACP. This is generally due to the exploitation of free slots time at the beginning which will allow all readers to compete during the contention phase and avoid the congestion at the end of the round which makes some readers to wait for the next AC if they do not do not win the channel. If we know that the time slot is 5 ms and that the reading period of the readers on the tags is 0.46 s, we can quantify the read throughput d of each solution depending of the read throughput of one reader per ms using the formula below: D= d (T_slot * N_slot + T_com), where D is the read throughput of a reader; d is the quantification throughput of each solution (BACP or BACP+); T_slot is the duration of a time interval, it is equal to 5 ms; N_slot is the number of time slots occupied by the reader in his communication and T_com is the communication time between reader and tags. Thus, we have determined the total reading throughput BACP and BACP+ in Table 1 based on this formula: the reading throughput of reader L5 is $D_5 = \mathrm{d}(t5.10 - 3 * 5 + 0.46) = 0.485\mathrm{d}$ bits/s.

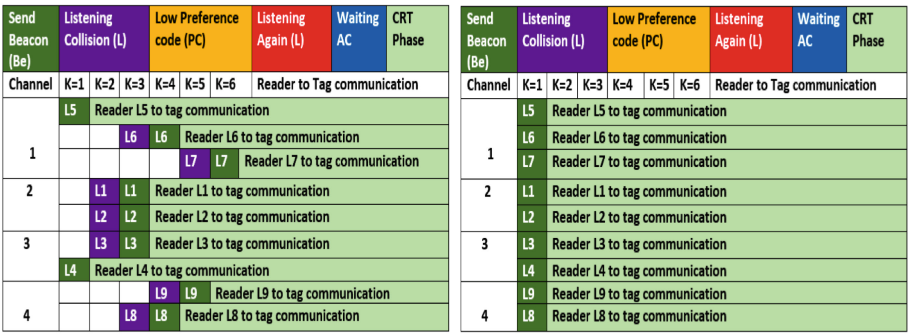
Table 1. Reading throughput in d bits/s

Reader	L1	L2	L3	L4	L5	L6	L7	L8	L9	Total throughput
BACP	0,475	0,475	0,475	0,485	0,485	0,475	0,46	0,4853	0,485	4,266 bits/s
BACP+	0,485	0,485	0,485	0,485	0,485	0,485	0,485	0,485	0,485	4, 365 bits/s

The total read throughput is equal to the sum of the throughputs $\sum_{L=1}^{n} D$ for each reader, is 4,266d bits/s for BACP and 4,365d bits/s for BACP+. This is achieved by this formula $\sum_{L=1}^{n} D_i$ with n the number of readers. From Table 1, throughput of BACP+ is 0.099d bits/s higher than that of BACP. Similarly, it has been found that the BACP+ flow throughput remains higher than that of the BACP in the others Figs. 4, 6 and 8.

5.2 Analysis Based on Channels Without Interference

In this section, we try to implement the deployment effect of non-interference readers through Figs. 4-(a) and Fig. 4-(b) to measure the behavior of both solu-



(a) (b)

Fig. 4. Channels without interference

tions. The readers randomly chose channels as follows: Channel 1 = {L5, L6, L7}, Channel 2 = {L1, L2}, Channel 3 = {L3, L4} and Channel 4 ={L8, L9}.

If the choice of channels is such that there is no interference, then BACP+ is more efficient than BACP because at the beginning of slot all readers have reads without collision. This helps to reduce the cycle time compared to that of the BACP protocol. While we find that there is no collision on either side of the two protocols but in terms of cycle time, we find that BACP+ takes less time than BACP. This is due to the random choice of time intervals in BACP. Thus we have a read throughput of 98.98% in BACP+ and 96.73% in BACP.

5.3 Density-Based on Mobility

Here, we try to implement reader density to justify the solutions' performance. We can see that there is less reading in both solutions because many readers wait for the next AC. However, in high-density where the reading areas of multiple readers overlap, as shown in Figs. 9 and 10, BACP+ has a better read throughput than BACP. In this case, BACP prevents the activation of all these interfering readers while BACP+ chooses one readers which increases the reading throughput. After random channel selection the readers are distributed as follows: Channel 1 = {L6, L7, L8}, Channel 2 = {L1, L2}, Channel 3 = {L3, L4} and Channel 4 = {L5, L9}. Figures 5 and Fig. 6-(a) and Fig. 6-(b) highlight the scenario in Fig. 7. If the system is dense then BACP+ activates more readers than BACP with a time less than that of the BACP. For BACP and BACP+, we determine from Table 2, the total read throughput:

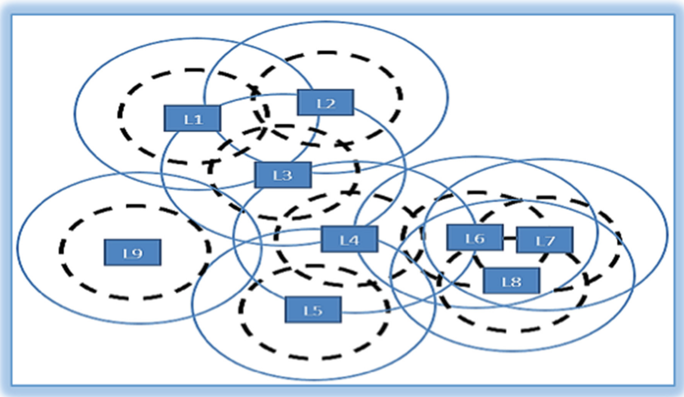
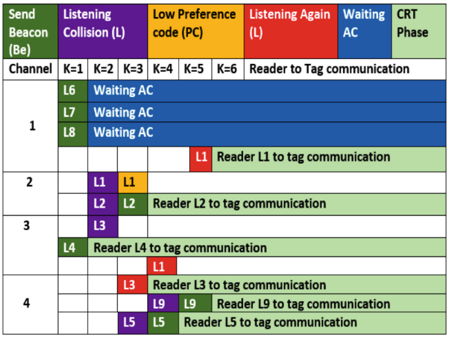
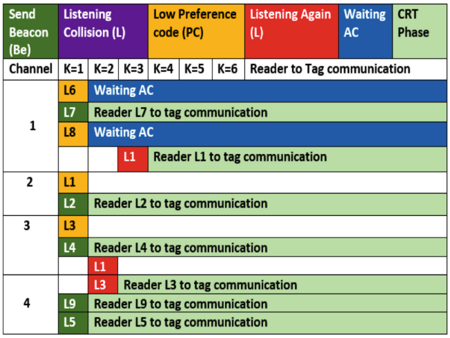


Fig. 5. Hight density of readers

It can be seen that the read throughput in BACP+ (2.9 bit/s) is 0.063d bit/s higher than that of BACP (2.837d bit/s). Thus, we reach a reading throughput of 98.47% in BACP+ against 96.33% in BACP. With mobility, we try to implement reader mobility to justify the performance of solutions. We see that the



(a)



(b)

Fig. 6. Hight density without mobility

Table 2. Reading throughput

Reader	L1	L2	L3	L4	L5	L6	L7	L8	L9	Total throughput
BACP	0,466	0,475	0,475	0,485	0,47	0	0	0	0,466	2,837 bits/s
BACP+	0,475	0,485	0,475	0,485	0,485	0	0,485	0	0,485	2, 9 bits/s

trend is basically the same because there are many readers waiting for the next AC. However, in high mobility situations where the reading areas of multiple readers overlap, as shown in Fig. 7, BACP+ has a better read throughput than BACP. Indeed, in such circumstances, BACP prevents the activation of all these interfering readers, while BACP+ chooses one of these readers.

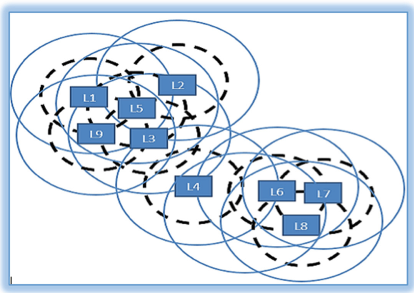


Fig. 7. Hight density deployment of reader

After random channel selection the readers are distributed as follows: Channel 1 = {L9, L5, L1, L2}, Channel 2 = {L3, L4}, Channel 3 = {L6, L7} and Channel 4 = {L8}. For a high density of mobile readers, we find that the BACP+ protocol activates more readers than the BACP protocol in a round. For example in BACP the reader L4 is at the end of the cycle he can not because he is in the last time slot. While in BACP+ this problem does not happen because L4 participated very early in the cycle so he will have time to change channel and be active. In addition, the TI is more shorter in BACP+ than in BACP (Fig. 8).

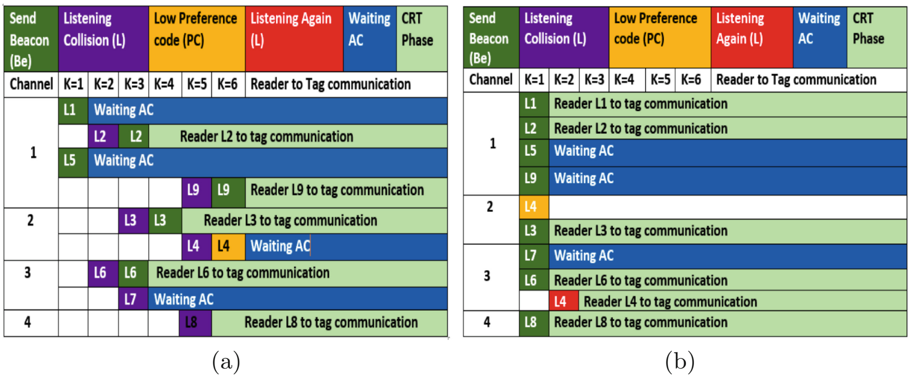


Fig. 8. Hight density with mobility

6 Conclusion

In this paper, after having developed a state of the art in which the distributed and centralized reader anti-collision protocols are presented, we have turned to multichannel protocols that offer a higher reading throughput via simultaneous readings. But they nevertheless exhibit more interference than single-channel protocols. Even if GDRA, DRCA can manage these interferences, BACP, a last proposed solutions, is more efficient. We have proposed BACP+, a BACP enhancement that tries to keep all its benefits while increasing its reading speed. Manual simulation scenarios based on concrete and precise examples allowed us to detect some trend criteria related to interference, density and mobility. We have been able to determine that if neighboring readers choose different channels so that they do not interfere, then even if the number of reads is the same for BACP as for BACP+, the reading time is shorter in BACP+ than in BACP. In this way, we have to find a channel selection or allocation algorithm in order to prevent interference between neighbors. We have also shown that the higher the density of the readers, the lower the read throughput in both protocols. However, the bit throughput will be lower in BACP+. We have seen that mobility favors reader-tag collisions. Therefore, a wait for the next AC by readers is common in these cases. In addition, the degree of activity is higher in BACP+ than in BACP at the beginning of the contention period, which may impact energy consumption. It will then be a question of making the compromise between flow of reading and preservation of the energy. We also want to lead in BACP+ a reuse policy of the released channel before the end of the round. We continue to work on the theoretical analysis to better justify the performance of our BACP+ contribution compared to the BACP. We also plan to do simulation taking into account other parameters such as energy consumption to better justify the performance of each solution.

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