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# Multichannel Reader Collision Avoidance Mechanism in RFID-Sensor Integrated Networks

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Abstract. Radio frequency identification (RFID) is a promising technology for ubiquitous computing. To improve its function and capability, it is necessary to integrate RFID with Wireless Sensor Networks (WSNs). Although organized well, the reader collision problem is still one of the critical problems in these networks. In this letter, we propose a Multichannel Reader Collision Avoidance (MRCA) mechanism for the cluster constructed RFID-Sensor integrated networks. In this mechanism, cluster headers collect channel information of nodes and arrange nodes' reading time and transmission energy, while gateway schedules clusters' reading sequence in the same way. By using this mechanism, the system throughput and efficiency can be highly increased according to the simulation.

Keywords: energy efficient, multichannel, reader collision, RFID, wireless sensor networks

## 1 Introduction

It is widely believed that the next revolution in computing technology will be that the widespread small wireless computing and communication devices will integrate seamlessly into daily life. Among technologies, RFID (Radio Frequency Identification) and WSN (Wireless Sensor Network) are two important components of this pervasive computing since both as technology can be used for coupling the physical and the virtual world in pervasive computing environments. RFID system which allows contactless identification of objects using radio frequency, is gaining popularity nowadays. RFID systems have been applied in a number of applications, such as asset tracking, telemetry-based remote monitoring, and real time supply chain management [1].

However, in some applications, tags are embedded into environment sensitive object. It is necessary to integrate RFID system with WSNs. In this case, the environment and location information can be learned through sensor. Capacities of WSNs are also very powerful as a network, which support not only data collection but also routing, localization, aggregation and analysis of information, considering RFID as a specific kind of sensor. A mix of tags and sensor nodes can be deployed in detected area. Smart stations gather information from tags and sensor nodes then transmit it to local host Personal Computer (PC) or remote Local Area Network (LAN). Here RFID and WSN information can be integrated in the base station, which will be more intelligent [2]. The RFID-Sensor integrated networks still need to solve several problems. One of them is the reader collision problem. It occurs when two readers with overlapping interrogation zones communicate using the same frequency at the same time. In order to eliminate or reduce reader collision, various schemes and elaborate algorithms have been proposed. However, these algorithms are not designed for RFID-Sensor integrated networks.

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In this paper, we introduce a clustered system architecture of RFID-Sensor integrated networks that enable applications with rich functions to be designed flexibly. Both environment and location information can be provided. Then we propose a hierarchical reader anti-collision mechanism. In this mechanism, the gateway allocates Cluster Headers (CHs) reading sequence while the latter arrange nodes' reading time and transmission power. It enables several readers simultaneously read tags without collision and guarantees a stable channel access time. Besides, by using power control, it reduces not only the collision but also the energy consumption. The lifetime of the system can be prolonged. According to the result of simulation, the energy efficiency, system efficiency, and throughput can be considerably increased. The remainder of this paper is organized as follows. In section 2 we briefly discuss the reader collision problem in multichannel RFID-Sensor integrated networks. Section 3 presents the existing mechanisms to solve the reader collision problem. In section 4, we introduce our proposed mechanism. Section 5 is the performance evaluation. Conclusion is drawn in section 6.

## 2 Reader Collision Problem in Multichannel RFID-Sensor Integrated Networks

In this section, we briefly introduce the architecture of the location-aware RFID-Sensor integrated networks and the RFID reader collision problems of single channel. Then the reader collision problem in the multichannel systems is analyzed.

### 2.1 Architecture of RFID-Sensor Integrated Networks

The integration of the technologies of RFID and WSNs will maximize their effectiveness, give new perspectives to a broad range of useful applications, and bridge the gap between the real and the academic world. This is because the resulting integrated technology will have extended capabilities, scalability, and portability as well as reduced unnecessary costs. The main purpose of RFID is to support object tracking and management, such as inventory management, access control, supply chain management, and telemedicine. RFID networks have limits when they are used in environment-sensitive objects (e.g., food, flowers, and medicines), which are very sensitive to the environment conditions, such as temperature and humidity. On the other hand, WSNs are sophisticated of environment condition sensing and communication.

Location is another vital information for object tracking. Many applications need to know the physical location of objects. Although there are many positioning protocol for RFID, the localization of WSNs is more convenient. Moreover, Capacities of WSNs are very powerful as a network, since it is not only to support data collection but also routing, aggregation and analysis of information. There are abundance protocols for routing, data aggregation and localization for WSNs. Besides, the communication frequency of RFID and WSNs are on the different wave bands. RFID standards suggest the use of a frequency between 860 MHz and 960 MHz [3], while usually the sensor nodes use 2.4 GHz to communicate. The RFID-Sensor integrated nodes may take advantage of this benefit to communicate simultaneously without interference.

Based on the above reasons, the RFID-Sensor integrated networks are necessary for effectiveness and efficiency. There are three types of architectures of integrated RFID and WSNs: integrated sensors with tags, readers, and mix architecture. We use the second type, which is integrating RFID readers with sensor node. Technological convergence is one of hot issues due to the limitation of technologies, functions and markets. Although RFID technologies have considerable advantages, some major hurdles still exist. There are some works about how to integrate RFID and sensor networks which collect environment and location information [4]. SARIF [5] is a sensor and RFID integration networks for environment-sensitive object tracking and management.

Although technologies related RFID have advanced considerably in recent years, some major hurdles still exist in RFID networks. Some problems such as data management, transformation and aggregation are mentioned. It is also pointed out that RFID networks have limits when they are used in environment-sensitive objects which are sensitive to the environment conditions such as temperature and humidity. In an emergency situation such as an earthquake, the demand for emergency products such as pharmaceutical products and blood pouches can greatly increase, and the loss of emergency products caused by environment changes is a critical problem. Hence, if the environmental conditions in the storage of emergency products go outside of the acceptable range, the emergency control center must receive notification as soon as possible.

Our work is based on RFID-Sensor integrated network. In this network, the module node is constituted by three parts which are RFID reader (908.5 MHz to 914 MHz), micro-controller, sensor (temperature, humidity, check) and RF transceiver (2.4GHz). The reader works on a multichannel mode. Fig. 1 shows the system architecture of the RFID-Sensor integrated networks [6]. This integrated RFID-Sensor integrated node also can be called node for simple. The RFID reader is able to communicate with tags within their respective interrogation zone which attached on the objects storing the information of them. The sensor can gather the environment information such as temperature, humidity and its location information. Integrated nodes can be fixed or moving depending on the application requirement. By using this node, system can provide both remote monitoring and location tracking services such as finding the inventory and checking the temperature of the storehouse and location of the products.

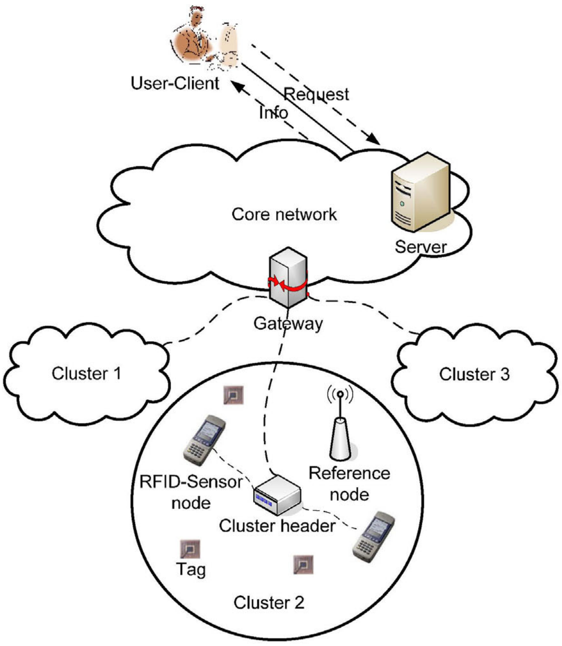



**Fig. 1.** System Architecture of RFID-Sensor Integrated Networks

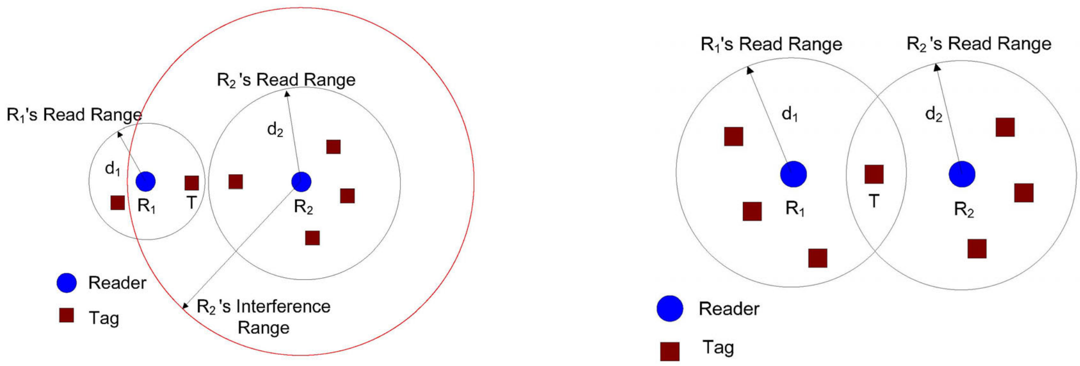
In RFID-Sensor integrated networks, service provider publishes services through integrated server. User client sends their application request to the server. Gateway is the connection between core network (Internet) and RFID-Sensor integrated networks. It organizes the nodes hierarchically. Nodes are divided into clusters. Each cluster has a cluster header (CH), which has more energy and computing capability. Nodes send information to CHs. CHs transmits information to gateway. Then gateway forwards it to the server. At last, the server delivers the results to the user client. In this system, passive tags are used because of the low cost. Reference nodes equipped by Global Position System (GPS) devices are used for localization. There are four layers in the network: gateway, CHs, RFID-Sensor integrated nodes and tags. RFID reader communicates with the tags using an allocated frequency between 908.5 MHz and 914 MHz while nodes communicate to CH and each other using 2.4GHz frequency. This cluster architecture facilitates the distribution of control over the network and achieves spatial reuse of network resources.

In the communication tree of the system, there are four layers: gateway, CHs, RFID-Sensor integrated nodes and tags. RFID readers communicate with the tags using multiple channels between 9908.5 MHz and 914 MHz frequency. RFID-Sensor integrated nodes communicate to CHs using 2.4GHz frequency. In this system, location information is essential. There are some reference nodes around which are used for localization. The coordinators can get their own locations from the signal of reference nodes and the localization algorithm. We assume that there is localization protocol in this system and the node can get their location information. In certain application systems, there are fixed reference nodes which are GPS receiver equipped or pre-programming nodes with their locations. CHs get their own locations by using the localization scheme. For RFID communications, international standards suggested the use of a frequency between 860 MHz and 960 MHz.

### 2.2 Reader Collision Problem in Single Channel Systems

In RFID-Sensor integrated networks, each reader has a fixed limited interrogation zone. Only within this range can the tag be recognized. When multi-readers are deployed in a limited area, two or more readers' interrogation zone can be overlapped. If these readers read in the same time, collision may occur. It's called reader collision problem [7].

The reader collision can be divided into two categories. One is reader-to-reader interference. It occurs when a reader transmits a signal that interferes with the operation of another reader, thus preventing the second reader from communicating with tags in its interrogation zone. Fig. 2(a) shows the reader-to-reader interference. In Fig. 2(a), if R1 and R2 communicate with tags at the same time using the same frequency, the collision will occur. The second type of reader collision, called reader-to-tag collision, may occur when a tag is in the interrogation zone of multiple readers and more than one reader simultaneously. Fig. 2(b) indicates the reader-to-tag interference. Tag T is in the interrogation zones of both R1 and R2. If R1 and R2 send read-tag command at the same time, their signals will collide with each other at T.




(a) Reader-to-reader interference (b) Reader-to-tag interference

**Fig. 2.** Reader collision problem

### 2.3 Reader Collision Problem in Multichannel Systems

For RFID communications, international standards suggested the use of a frequency between 860 MHz and 960 MHz [8]. A frequency ranging from 908.5 MHz to 914 MHz with 25 channels of 200 Hz bandwidth each was standardized for mobile RFID networks, as shown in Table 1 [9]. To minimize adjacent channel interference, the spectral mask of a channel transmission should follow the values shown in Fig. 3 [10].

**Table 1.** Channel numbers and bandwidths for mobile RFID

| Channel No. | Channel frequency | Channel No. | Channel frequency |
|---|---|---|---|
| Protection | 908.50MHz~908.75MHz | 14 | 911.35MHz~911.55MHz |
| 1 | 908.75MHz~908.95MHz | 15 | 911.55MHz~911.75MHz |
| 2 | 908.95MHz~909.15MHz | 16 | 911.75MHz~911.95MHz |
| 3 | 909.15MHz~909.35MHz | 17 | 911.95MHz~912.15MHz |
| 4 | 909.35MHz~909.55MHz | 18 | 912.15MHz~912.35MHz |
| 5 | 909.55MHz~909.75MHz | 19 | 912.35MHz~912.55MHz |
| 6 | 909.75MHz~909.95MHz | 20 | 912.55MHz~912.75MHz |
| 7 | 909.95MHz~910.15MHz | 21 | 912.75MHz~912.95MHz |
| 8 | 910.15MHz~910.35MHz | 22 | 912.95MHz~913.15MHz |
| 9 | 910.35MHz~910.55MHz | 23 | 913.15MHz~913.35MHz |
| 10 | 910.55MHz~910.75MHz | 24 | 913.35MHz~913.55MHz |
| 11 | 910.75MHz~910.95MHz | 25 | 913.55MHz~913.75MHz |
| 12 | 910.95MHz~911.15MHz | Protection | 913.75MHz~914.00MHz |
| 13 | 911.15MHz~911.35MHz | | |

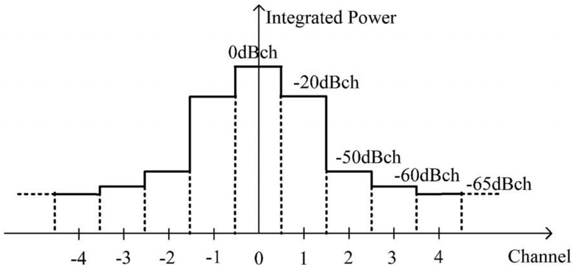



**Fig. 3.** Spectral mask of a channel transmission

The distance of two readers in reader-to-reader interference is larger than reader-to-tag interference. Therefore, if we can avoid the former one, the latter one can be also prevented. We just consider the reader-to-reader problem.

To understand some properties of the reader collision problem, a simple situation can be considered. Given two readers *i* and *j,* the distance between them is $d_{ij}$. Tag *t* locates in the read range of reader *i*, which has a distance $d_{it}$ from reader *i*. It is shown in Fig. 4. Reader *i* uses channel *i*. Reader *j* uses channel *j*. The spectral mask of channel *i* and channel *j* is $SM_{ij}$.

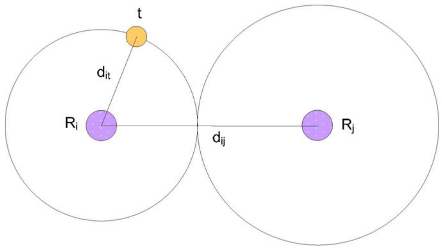



**Fig. 4.** Interference caused by Reader j

In a backscatter communication system, SNR based on power must meet a required threshold $R_{required}$, which is decided by the tag encoding method and Bit Error Rate (BER) desired. For reader *i*, the following must hold for successful tag detection if we ignore the thermal noise.

$$\frac{P_{ri}}{I_{ji}} \geq R_{required} , \quad \textbf{(1)}$$

where $P_{ri}$ is the backscatter power from tag *t*, $I_{ji}$ is the interference caused by reader *j* at reader *i*. $P_{ri}$ can be calculated in terms of the reader transmission power $P_{ti}$, the path loss from reader to tag and back $PL_{iti}$, and the power ratio $R_{act}$ to activate the tag.

$$P_{ri} = P_{ti} \times PL_{iti} \times R_{act} . \quad \textbf{(2)}$$

The path loss $PL_{iti}$ can be evaluate by

$$PL_{iti} = K_1 / d_{it}^{4q} , \quad \textbf{(3)}$$

where $K_1$ simplified presents the reader and tag antenna gains, modulation indexing and wavelength. *q* is the path loss exponent. Interference caused by reader *j* at reader *i* is given as

$$I_{ji} = P_{tj} \times PL_{ji} \times SM_{ij} , \quad \textbf{(4)}$$

where $P_{tj}$ is the transmission power of reader *j*, $PL_{ji}$ is the path loss from reader *j* to reader *i*. The $PL_{ji}$ can be calculated by

$$PL_{ji} = K_2 / d_{ij}^{2q} , \quad \textbf{(5)}$$

where $K_2$ presents the constant properties such as antenna gains of two readers, and wavelength. From the above formulae, given the transmission power and the distance from reader *i* to tag *t*, we can get the minimum distance ($d_{ij\text{-}min}$) between reader *i* and reader *j* to avoid the reader collision.

$$d_{ij\text{ - }min} = \left( \frac{K_2 \times P_{tj} \times R_{required} \times SM_{ij}}{P_{ti} \times PL_{iti} \times R_{act}} \right)^{1/2q} . \quad \textbf{(6)}$$

Based on the calculation, we can calculate the distance between two readers to avoid reader-to-reader interference. Table 2 shows the distances according to channel differences.

**Table 2.** Distances according to channel differences

| Distance of tag (m) | Total loss | Interference distance | |
|---|---|---|---|
| | | Same channel | Adjacent channel |
| 1 | 74.0 | 28.7 | 7.7 |
| 2 | 89.1 | 77.1 | 20.7 |
| 3 | 97.9 | 137.6 | 36.9 |

In summary, the interference distance is much shorter when the spectral mask between two readers is smaller, which means the distance between two channels is larger.

## 3 Related Work

In this section, we discuss briefly about the existing reader anti-collision protocols in RFID system. These protocols can be categorized as Time Division Multiple Access (TDMA) based, Frequency Division Multiple Access (FDMA) based, Carrier Sense Multiple Access (CSMA) based, power control, and resource allocation. In TDMA based anti-collision mechanisms, transmission time is divided into frames with several fixed-length time slots. To avoid simultaneous transmission search reader is required to operate at a different time slot in a frame.

The Colorwave [11] reader anti-collision algorithm is a well-known TDMA based approach. In this algorithm, each slot is allocated with a different color. Each color ranges from [0, Maxcolors] and the readers in the network randomly choose a color from [0, Maxcolors]. A reader with a queued request for transmission can transmit data in its color timeslot. If the transmission collides with that of another reader, the transmission request is discarded and the reader randomly choosed a new color and reserves it. If the neighbor has the same color, it chooses a new color and transmits a control packet (called a kick packet). Each reader synchronizes with the other readers by continuously tracking the current time slot. The value of colors varies according to the network situation. Colorwave is a simple, very flexible and distributed protocol. However, there is no tag side consideration in Colorwave. A reader cannot detect collision s in the network without being aware of the tag. Further, in mobile RFID systems, overhead due to time-slot reselection increases continuously and significantly, because Colorwave needs the tight time synchronization among the readers.

The HiQ [12] is a hierarchical, online learning algorithm that finds dynamic solutions to the reader collision problem in RFID system by learning the collision patterns of the readers and by effectively assigning frequencies over time to the readers. However, it may take long time to learn the collision pattern if the network size is large. In addition, HiQ assumes collision detection for readers which are not in sensing range of each other. Actually not all collision might be detected leading to incorrect operation of the protocol.

The Pulse [13] divides the channel to the control channel and data communicating channel. Control channel is used to communicate between readers to negotiate reading sequence. The data communication channel is used for reading tags. It works by Listen Before Talk (LBT) scheme. Before reading tags, a reader transfers a beacon message to its neighbors through the control channel. Even it can solve the hidden terminal problem, it may cause unfairness problem. Furthermore, in a dense mobile environment, readers sending a "pulse" might end up disabling a lot of their neighbors highly impacting the throughput and efficiency of the system.

OSL [14] is fed with information about the load (number of competing tags per reader) to properly compute throughput, which is expressed as a closed-form formula. At the beginning of each scheduling period our scheduler decides the channel and slots to be assigned to each reader by maximizing (with respect to these variables) the expected throughput using a simulated annealing solver. However, OSL lacks of support of fairness and priority.

The Distributed Multi-Channel Collision Avoidance (DiMCA) [15] protocol is proposed for readers to exchange messages on two different control channels operating at different ranges. The first one covering the reading range of the reader where messages containing the ID of the reader are sent and the second channel covers the interference range where messages containing both the reader's ID and its chosen channel are sent. While this solution improves both the throughput and efficiency of the RFID system, it relies on an overhead created by the exchanged messages which can impact the delay.

Fair Reader Collision Avoidance (FRCA) [16] has two versions. They both make observations regarding the lacuna in both NFRA and GDRA and address them. In FRCA1, readers follow the same scheme as in NFRA with a central server sending commands and readers randomly selecting slots and sending beacons. However, in case of a beacon collisions when two readers chose the same timeslot, instead of both getting disabled as in NFRA, they compare their number of successes. The reader with the lowest success rate gets access to the medium and the other one waits for the next round. This allows the protocol to be fairer regarding the shared medium access. In addition to the success rate match, readers also compute the distance between them based on the received signal strength of the exchanged beacons. Based on the distance between them, the failing reader with the higher success rate, can compete on the next timeslot but on a different channel. Indeed, if the distance is greater than twice that of the reading range, the reader may interrogate tags next to its neighbor on a different channel. Authors also propose the use of Sift distribution in order to decrease the number of contending readers on lower timeslots.

Distributed Efficient & Fair Anti-collision for RFID (DEFAR) [17] is a scheme to retrieve at least one of the contending readers in case of a collision. This improvement is made using beacon exchange between neighboring readers. Based on reader IDs and priority levels, a reader is chosen. The priority levels are set depending on the success of readers during previous contentions. Another version of this algorithm was proposed in [18] to address mobile deployments. While these solutions improve the fair access to shared medium among readers, they rely on a precedent beacon exchange which is itself subject to collisions.

Enhanced Distributed Multi-Channel (EDMC) [19] is an improved version of DiMCA by having readers check if they have received other messages from neighbors after they chose their channel and before sending their own message. This decreases the chance for message collisions or misheard messages from neighbors right before tag interrogation. Authors claim to slightly improve the delay as well as reduce the collisions using this technique compared to DiMCA.

Efficient Multichannel Reader Collision Avoidance (EMRCA) [20] is an improvement of Pulse, to take into account multichannel aspect introduced by the standard. Authors identify two types of collisions based on the interrogation and interference range of readers. Readers start by sensing the common control channel used by all nodes to communicate. If no activity is detected during a given period, reader begins contending phase. Otherwise, depending on the source of activity, either starts a new listening session at the end of the current activity or, pursues the timer before contending. During contention, readers wait for a randomly drawn backoff. If a reader receives a beacon during backoff, it goes back to sensing the control channel, otherwise if the backoff runs out without any reception of beacon, the reader moves on to tag interrogation. It then occupies the chosen interrogation channel and periodically sends out a beacon to advertise on the common control channel. This protocol improves the overall fairness and efficiency of Pulse but still suffers from mobility and high density of reader deployment.

## 4 The Proposed Reader Anti-Collision Mechanism

Based on the RFID-Sensor integrated system, we propose a Multichannel Reader Collision Avoidance (MRCA) mechanism for the cluster constructed RFID-Sensor integrated networks. In this mechanism, gateway arranges clusters' reading sequence based on their location and radius. CHs assign the nodes' transmission power i.e. read range to minimize the overlapping area. Then CHs allocate nodes' reading sequence in the same way.

Fig. 5 indicates the flow chart in CH. Before communicating with the tags, the RFID-Sensor integrated node has to complete association procedure to construct the hierarchical system. Next CH polls nodes to get their location information. So each CH has the global view of its cluster. After that, CH reports its cluster's location and radius to gateway. Gateway receives it and allocates reading sequence of each cluster. If two clusters have range overlapping, they will be allocated in difference reading sequences.

After allocation, gateway sends the allocation message to each CH. The allocation message indicates in which time the nodes in its cluster can read the tags. Then CH allocates the transmission power and reading sequence to nodes in its cluster. By using power control, the lifetime of network can be prolonged. CH sends the allocation to the nodes. Nodes will read in the allocated time using determined power.

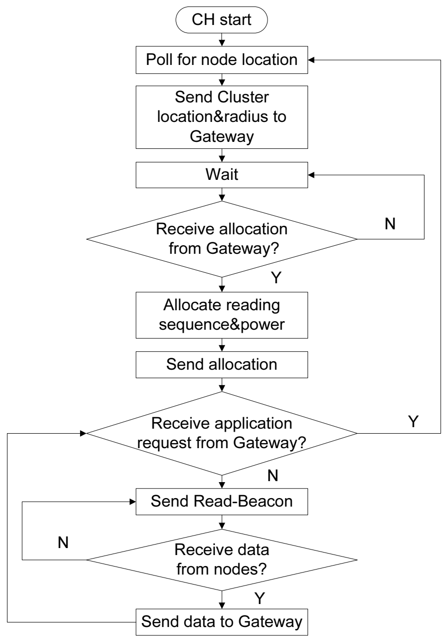



**Fig. 5.** Flow chart for reader collision avoidance in CH

To adjust the transmission power of reader of node based on the location, firstly, we use Delaunay triangulation [21] to find the 'Point for Interrogation Range Decision (PIRD)' which minimizes the overlapping areas. Then it uses the PIRD as a pivot to balance energy consumption among readers by following objective function as follows:

$$minimize: f = \frac{1}{2}\sum_{k=0}^{2} r_k^{\,2} q_k - S_{triangle}, \tag{7}$$

$$s.t.\ r_k^{\,2} = (x_{P_{IRD}} - x_k)^2 + (y_{P_{IRD}} - y_k)^2. \tag{8}$$

After getting the optimal read ranges, it uses the Friis free-space formulation to get the optimal transmission power of each reader. Finally, the read range and transmission power are

$$r_k = \frac{l}{2p}\sqrt{\frac{P_t(k)G_tG_r}{P_{th}} \times \frac{R_cR_a}{\left|Z_c + Z_a\right|^2}}, \tag{9}$$

$$P_t(k) = \frac{4\pi^2}{\lambda^2} \times \frac{P_{th} \times \left|Z_c + Z_a\right|^2}{G_tG_rR_cR_a} \times r_k^{\,2}, \tag{10}$$

where $\lambda$ and $P_{th}$ denote wavelength and minimum threshold power, respectively. $Z_c$ and $Z_\alpha$ are chip and antenna impedances. $R_c$ and $R_\alpha$ are chip and antenna resistance. $G_t$ and $G_r$ mean the gain of transmitting and receiving antennas, respectively. These parameters are reported to CH when the node executes association procedure.

After determining the transmission power and read range of each node in its cluster, CH allocates reading sequence to them using the same allocation method as gateway. When the location of node $i$ is ($x_i$, $y_i$), its read range is $r_i$ and its interference range is $i_i$. Using this algorithm, nodes which can collide if read at same time will be allocated to the different reading sequence. There is an example of allocating the reading sequence. In this example, after receiving location information, CH allocates node 1 in the first reading sequence. For node 2 and node 3, since they have read range overlapping with node 1, they are allocated to the different sequences, separately. For node 4, its distance to node 1 is long enough for simultaneous reading, so it is allocated to the first sequence.

Then CH broadcasts Reading Sequence Allocation (RSA) message to each node in its cluster to announce the allocation. After receiving RSA, node sends back acknowledgement and stores its reading sequence. When there is an application request which arrives in gateway, gateway sends messages to CHs. CHs send out beacon message to announce every node the start of reading. There is a margin time between two reading time. The length of reading time and margin time depends on the different design of the readers. Readers read the tags ID and other information then send to the CH. Environment information such as temperature and humidity is also sent if necessary. CHs transfer them to gateway after data integration.

## 5 Performance Evaluation

We conducted the simulation of the RFID-Sensor integrated networks by using Matlab to evaluate the performance of proposed mechanism. The simulation model has the following assumptions: no interchannel interference between the 2.4GHz and 960MHz channels; free space propagation path loss; no fading; Signal to Noise Ratio (SNR) based reception; omni-directional antennas; negligible data processing and channel switching delay; packet collision is the only cause of packet loss. Table 3 shows the characteristics of the simulation model. We used a field of 10×10 m area. The network data rate is 2Mbps. Nodes are randomly uniform-distributed. Node's initial read range; interference range and sensor communication range are set to 1.62m, 7.1m and 15m respectively. There are 400 tags place throughout the simulation field with 0.5m interval, forming a grid of 20×20m. We assume all the nodes in simulation are same. The number of readers is 3, 8, 18, 23, 35, 50 and 66 respectively. The application packet arrives with exponential inter-arrival time of average 500μsec throughout the experiment time of 60s.

**Table 3.** Simulation parameter

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| Scale | 100 $m^2$ | Sensor communication range | 15 m (initial) |
| Frequency | 2.4 GHz (for WSN)<br>960 MHz (for tags) | Beacon interval | 5000 μs |
| Data rate | 2 Mbps | Reading time | 156 μs |
| Read range | 1.62 m (initial) | Control packet size | 5 byte |
| Interference range | 7.1 m (initial) | Data packet size | 40 byte |

We compared MRCA with three other RFID reader collision avoidance mechanisms: Colorwave, HiQ, Pulse, and OSL in three metrics: the energy efficiency, system efficiency, and throughput. The energy efficiency ($E_e$) is defined as:

$$E_e = \frac{\sum_{i=1}^{n} E_s(i)}{E_t} \times 100\%, \quad \textbf{(11)}$$

where $E_t$ is the total energy consumption, including successful query and collisions. $E_s(i)$ is the $i$th successful query. The system efficiency ($E_s$) is defined as:

$$E_s = \frac{N_s}{N_t} \times 100\%, \quad \textbf{(12)}$$

where $N_t$ is the total number of query, including successful query and collisions. $N_s$ is the number of successful query. The throughput ($Thp$) is defined as the number of successfully sent queries per second as follows.

$$Thp = \frac{\sum_{i=1}^{n} Q_s(i)}{T}, \quad (13)$$

where $T$ is the total time. In most systems, readers identify the tags by query-response protocol. The more successful queries, the higher throughput and number of tags identified. High efficiency indicates low rate of collision. So we can use both throughput and efficiency to evaluate the effectiveness of a protocol.

From Fig. 6, we can know that the energy efficiency of MRCA is higher than the others. Using Colorwave, when there are 49 readers, energy efficiency decreases to 93.2%. HiQ provides higher energy efficiency than Colorwave. By using Pulse, the energy system efficiency is 99% when there are 4 readers. However, it decreases faster and it fails to give better system efficiency than MRCA. The main reason of energy waste in the communication procedure is retransmission after collision. The MRCA reduce the reader collision. Hence, the energy efficiency can be increased.

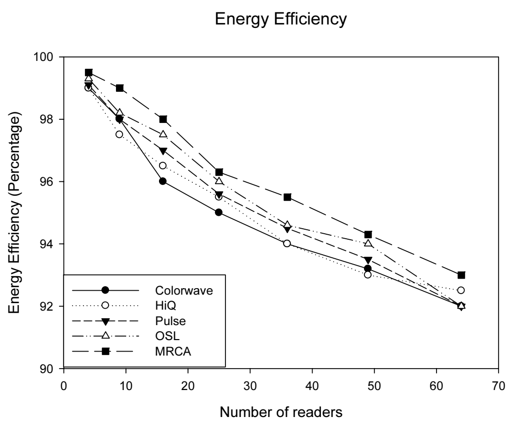



**Fig. 6.** Energy efficiency with varying number of readers

Fig. 7 illustrates that the system efficiency of the proposed MRCA mechanism is higher than the others. Using Colorwave. OSL provides higher efficiency than Colorwave. The system efficiency is above 92% which shows collisions between readers are reduced greatly. The proposed mechanism uses multi-channel. Therefore, the successful reading per second can be increased.

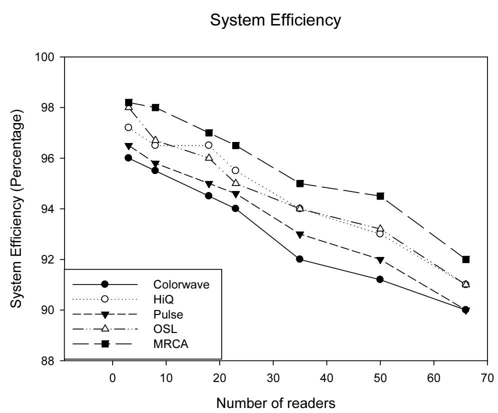



**Fig. 7.** System efficiency with varying number of readers

Fig. 8 shows that the throughput of Colorwave is worst. HiQ has higher throughput compared with Colorwave. However, with the increase of the number of readers, its system throughput decreases sometimes. In Pulse algorithm system, throughput keeps increasing with the increase of the number of readers. Since the proposed MRCA mechanism mitigates the reader collision, the number of retransmission can be reduced. Thus the throughput is higher.

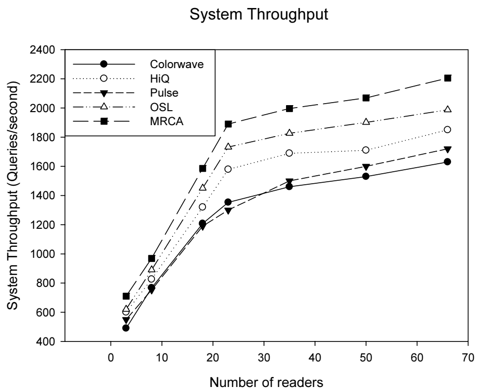



**Fig. 8.** Throughput comparison with different number of readers

## 6 Conclusion

In this paper, we introduced a structure of RFID-Sensor integrated networks. This network increases both the capability and functions of RFID systems, which can provide environment and location information. Based on this system, we have proposed a mechanism to address the reader collision problem in RFID-Sensor integrated networks. In this mechanism, CH determines the transmission power and reading sequence of readers in its cluster while gateway schedules CHs in the same way. From the results of simulation, the system throughput and efficiency are increased considerably. The proposed system and mechanism can be used in supply chain management, asset tracking, transportation, etc. The mechanism we proposed can be used in the RFID-Sensor integrated networks to avoid reader collision and improve the network performance. The limitation of proposed mechanism is the lower performance in the high speed moving scenario. We plan to apply the cognitive radio technology on the RFID-Sensor integrated networks in the future work. The network performance can be improved further more.

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## References

[1] S. Kim, R. Vyas, J.K. Finkenzeller, RFID Handbook: Fundamentals and Applications in Contactless Smart Cards and Identification, John Wiley & Sons, New York, 2003 (Chapter 3).

[2] H. Khojasteh, J. Misic, V. Misic, A two-tier integrated RFID/sensor network with a WiFi WLAN, in: Proc. the International Wireless Communications & Mobile Computing Conference, 2012.

[3] GS1 EPCglobal Inc., Radio-frequency identity protocols class-1 generation-2 UHF RFID protocol for communications at 860 MHz-960 MHz. <https://www.gs1.org/sites/default/files/docs/epc/ Gen2_Protocol_Standard.pdf>, 2013 (accessed 18.09.01).

[4] N. Pan, Integration of RFID and industrial WSNs to create a smart industrial environment, [dissertation] Ontario, Canada: University of Western Ontario, 2018.

[5] J. Cho, Y. Shim, T. Kwon, Y. Choi, SARIF: a novel framework for integrating wireless sensor and RFID networks, Wireless Communications 14(6)(2007) 50-56.

[6] S. Haoru, D. Ko, S. An, Power-aware location-based anti-collision protocol for RFID-sensor networks, in: Proc.the First

International Conference on Ubiquitous and Future Networks, 2009.

[7] A.A. Mbacke, N. Mitton, H. Rivano, A survey of RFID readers anticollision protocols, IEEE Journal of Radio Frequency Identification 2(1)(2018) 1-11.

[8] M.O. Balitanas, T. Kim, Anti-collision protocol for RFID-sensor network and the security threats, in: Proc. the 12th WSEAS International Conference on Automatic Control, Modeling & Simulation, 2010.

[9] K. Shin, W. Song, Rac-multi: reader anti-collision algorithm for multichannel mobile RFID networks, Sensors 10(1)(2009) 84-96.

[10] Y. Zhao, W. Hong, S. Cheung, S. Li., The impact of reader to tag collision on RFID tag identification, in: G. Pandurangan et al. (Eds.), Wireless Algorithms, Systems, and Applications, Springer-Verlag, Berlin, 2010, pp. 115-119.

[11] J. Waldrop, D.W. Engels, S.E. Sanna, Colorwave: a MAC for RFID reader networks, in: Proc. IEEE Wireless Communications and Networking Conference (WCNC), 2003.

[12] S.S.J. Ho, D.W. Engels, HiQ: a hierarchical q-learning algorithm to solve the reader collision problem, in: Proc. International Symposium on Applications and the Internet Workshops, 2006.

[13] S. Birari, S. Iyer, Pulse: a mac protocol for RFID networks, in: Proc. International workshop on RFID and Ubiquitous Sensor Networks (USN), 2005.

[14] J. Vales-Alonso, F.J. Parrado-Garcia, J.J. Alcaraz, OSL: an optimization-based scheduler for RFID dense-reader environments, Ad Hoc Networks 37(2)(2016) 512-525.

[15] H. Safa, W. El-Hajj, C. Meguerditchian, A distributed multichannel reader anticollision algorithm for RFID environments, Journal of Computer Communications 64(1)(2015) 44-56.

[16] H. Rezaie, M. Golsorkhtabaramiri, A fair reader collision avoidance protocol for RFID dense reader environments, Wireless Networks 24(2)(2017) 1-12.

[17] A.A. Mbacke, N. Mitton, H. Rivano, Distributed efficient & fair anticollision for RFID protocol, in: Proc. WiMob, 2016.

[18] A.A. Mbacke, N. Mitton, H. Rivano, RFID anticollision in dense mobile environments, in: Proc. IEEE WCNC, 2017.

[19] Z. YuJing, C. Yinghua, Edmc: an enhanced distributed multichannel anti-collision algorithm for RFID reader system, in: Proc. American Institute of Physics Conference, 2017.

[20] Y. Jiang, R. Zhang, W. Cheng, W. Sun, An efficient multi-channel reader collision avoidance protocol in RFID systems, in: Proc. IEEE Wireless Communications and Networking Conference, 2016.

[21] C. Ok, C.H. Quan, H.S. Mo, K.Y. Choi, C. Lee, Adaptive channel hopping algorithm for reader anti-collision in RFID systems, in: Proc. 10th International Conference on Advanced Communication Technology, 2008.