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Performance Comparison of Blind Anti-collision for RFID Systems

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Abstract

With advancements in Internet of Things (IoT) technology, Radio Frequency Identification (RFID), has been widely applied in every corner of our life and attracting more and more researchers' attention. RFID belongs to the sensing layer of the IoT, and the development of RFID will promote the development of the IoT. However, as the tags always communicate in the same wireless channel, it will result in the reader receiving the mixed signals. This phenomenon is often called a collision. It is the main problem hindering the development of RFID systems. So far, there are many anti-collision algorithms that have been proposed, like ALOHA-based anti-collision algorithms and binary search-based anti-collision algorithms, both are avoiding the collision by reducing the number of labels identified at the same time, then allows only one label to be identified at one time. The algorithms mentioned before both not only need a lot of time to identify the labels, but also a low success rate. To solve this problem, researchers proposed to separate the mixed label signals by FastICA algorithm which is one of the blind source separation (BSS) methods, and received a better performance than the traditional algorithms. Separation mechanism-based BSS application for anti-collision has become increasingly significant in RFID. This paper aims to compare the performance of BSS algorithms like PowerICA, ICA_p, SNR-Max when used to the RFID system. Simulation results and analysis demonstrated that, the ICA_p algorithm has the best performance among the mentioned algorithms, and the FastICA algorithm is very unstable, and with a lower separation success rate, the SNR-MAX has the worst separation performance compared with other algorithms application in the RFID system.

Keywords

RFID; BSS; FastICA; PowerICA; ICA_P; SNR-Max.

1. INTRODUCTION

With a promising automatic identification functionality, RFID plays an increasingly important role in IoT applications. It consists of three parts, the computer, the reader and the tags [1,2]. All of the tags communicate with the reader through the same wireless channel [3], if there are more than one tags in the scope of a reader, the signals backscattering by the tags will be mixed and the reader cannot get the correct signals that the tags send. To solve this problem, the reader must use specific methods to avoid the collision, i.e., anti-collision algorithm [4,5,6].

RFID is an essential part of the IoT sensor network, and it provides a wireless connection for various sensors connect to the IoT [7,8]. As IoT plays a more and more import role in the

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future world, there are enormous challenges for an RFID system, and it needed to be faster and with low latency [9-12]. It is crucial to search for fast and stable RFID anti-collision algorithms. Through robust algorithms, the RFID system will perform better and match the IoT better.

The most commonly used anti-collision algorithms are ALOHA-based anti-collision algorithms and binary search-based anti-collision algorithms. Both are based on TDMA and easy to build, but these algorithms may need an amount of time and have the possibility of missing tags [13-15]. The main idea of the TDMA anti-collision methods is narrowing the tag's response to one at one time, and these methods need to query the tags several times and may kill the tags when the channel's situation is bad [16]. The maximum throughput of the reader using the dynamic frame slotted Aloha anti-collision is only 42.6%, and the maximum throughput of the reader using the binary-tree searching of regressive index anti-collision algorithm binary is lower than 50% [17,18]. After that, some researchers propose the anti-collision algorithm based on the FastICA algorithm [19,20]. These algorithms received a better result, the algorithm's throughput rate is to 69% of the highest [21-26], but there are still some problems exist, for example, the FastICA algorithm has a low success rate in low SNR, and it is not stable, even in high SNR channel. The missing tags still exist [27].

The contribution work of this paper is aiming to find the fast and stable blind algorithms through the simulation of the other advanced blind source separation methods like PowerICA, ICA_p, SNR-max. The level of similarity between the source signal and the separate signal can represent the performance of the algorithm. The scientific name is the correlation index, which is in the range of zeros to one. When the correlation index is bigger than 0.92, we believe that the separation is a success. The rate of success can be another index to express the performance of the algorithms. We compare the two indexes in different SNR channels, then we change the length of the labels and do the same comparison.

The rest of the paper is structured as follows. In section 2, we construct the model of the RFID system and the model of a collision, and put up the problem which we need to solve. In section 3, the basic principles of FastICA, PowerICA, ICA-p algorithms and SNR-Max are introduced. In section 4, the computer simulations of these mentioned algorithms are implemented. In section 5, the conclusions are drawn, and some advice about the next work for RFID anti-collision is suggested.

2. SYSTEM MODEL AND PROBLEM FORMULATION

Generally, the RFID systems have no more than 8 antennas in one reader, and with hundreds or thousands of tags [4]. The reader is expected to identify hundreds of tags one time in real life, and this made the model becoming an undetermined model. However, the algorithms we used are both determined or overdetermined, so we need to divide the tags into several groups then separate the groups one by one.

Assume that there are m reader antennas, the received signals are $\mathbf{R}=[\mathbf{r}_1,\mathbf{r}_2,\ldots,\mathbf{r}_m]'$, the symbol " ' " represent the transformation of the matrix. $\mathbf{r}_1,\mathbf{r}_2,\ldots,\mathbf{r}_m$ is the received signals of each reader antenna. Suppose that each group has n tags, the unknown signals of the n tags are $\mathbf{S}=[\mathbf{s}_1,\mathbf{s}_2,\ldots,\mathbf{s}_n]'$, where $\mathbf{s}_1,\mathbf{s}_2,\ldots,\mathbf{s}_n$ is the source signal of each tag. After the S transmits through the wireless channel, the signals may randomly be mixed, and the received signals R are far different from S, we presume the mixing matrix is $\mathbf{A}^{m\times n}$. Then the relation between R and S is:

$$\mathbf{R}=\mathbf{A}\bullet\mathbf{S}+\mathbf{n} \tag{1}$$

The received signals R cannot be processed by the traditional reader, in other words, the collision has happened. The n is the noise matrix, it is white Gaussian noise normally. The

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symbol"•" represent the matrix multiplication. We can see the model of RFID and collision from figure1 and figure 2.

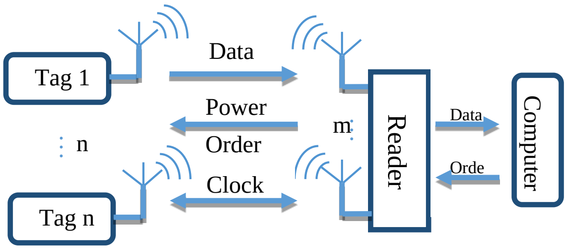

Figure 1. RFID model

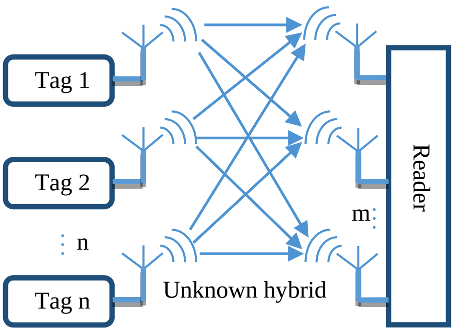

Figure 2. Collision model

We can see from figure 2, each tag's signal can be received by all the reader's antenna, due to the uncertainty of the wireless channel we cannot know how the signals are mixed so that we cannot separate the signals. The traditional way to solve this problem is to avoid this mixing by letting the tags communicate one by one. It will increase recognition time and reduce the efficiency of the RFID system. We can see the process in figure 3.

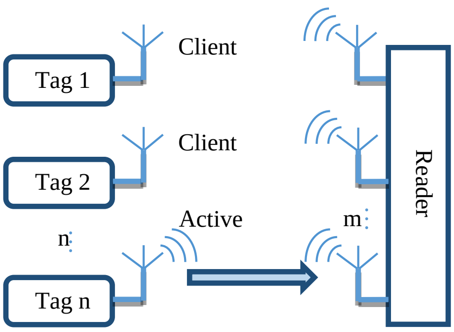

Figure 3. Traditional anti-collision method

BSS is a signal processing method that posed in the 1980s [28,29]. It involves extracting and recovering the underlying source signals from multivariable statistical data. The source signal is unknown and either the character of the hybrid system is not known in advance or there is only a small amount of prior knowledge such as non-Gaussian, cycle-stability, and statistical independence.

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The tags signal is the signal we want to get and we don't know before, and the mixed process in the wireless channel is unknown too. The priori knowledge we know is the tags generate the signals independent and the signals the make is uncorrelated. The distribute of the source signal is non-Gaussian distribute. So, the RFID collision can use the BSS method to dispose of. The BSS algorithms can calculate a de-mixing matrix W by the received signal R, which can make the equation:

$$\mathbf{W} \bullet \mathbf{A} = \mathbf{I} \tag{2}$$

I in equation (2) is an identity matrix. It is equal to the equation:

$$\mathbf{W} = \mathbf{A}^{-1} \tag{3}$$

When we multiply the W to the R, we can get the source signal, as:

$$\mathbf{Y} = \mathbf{W} \bullet \mathbf{R} = \mathbf{W} \bullet \mathbf{A} \bullet \mathbf{S} = \mathbf{I} \bullet \mathbf{S} \tag{4}$$

Use the BSS method to separate the mixed signals. We can identify several tags in one time, from serial to parallel, it can save a lot of time cost and improve the efficiency of the RFID system significantly. We can see the new anti-collision method in figure 4.

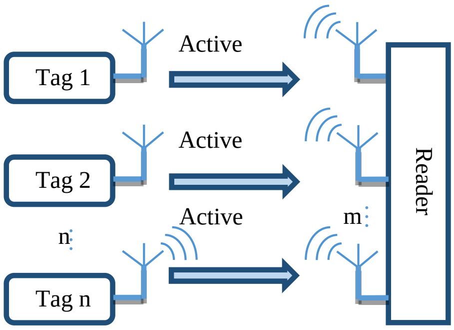

Figure 4. BSS anti-collision method

3. BSS ALGORITHMS

BSS algorithms include several algorithms like Independent Component Analysis (ICA), Principle Component Analysis (PCA), Non-negative Matrix Factorization (NMF), Sparse Component Analysis (SCA) and so on. The ICA is a powerful tool for signal processing, in the next work, we will introduce the traditional FastICA algorithm and the improved PowerICA and ICA_p algorithm. To make a comparation, the SNR-MAX algorithm is also included for its simplification.

3.1. ICA method

ICA is mainly used to solve the problem of BSS [29]. In cases where the source signal and mixing matrix are unknown, merely assuming that the source signals are statistically independent ensures that ICA can separate the source signals from the mixed signals well [27]. The ICA algorithm assumption that: (1) source signals are real random variables with zero mean and are statistically independent of each other, (2) the number of source signals n should be less than or equal to the number of observed signals m $(n \leq m)$. The mixing matrix A is an $m \times n$ unknown matrix with full rank. (3) Only one source signal is allowed to satisfy the Gaussian distribution. The schematic block diagram of the ICA is depicted in figure 5.

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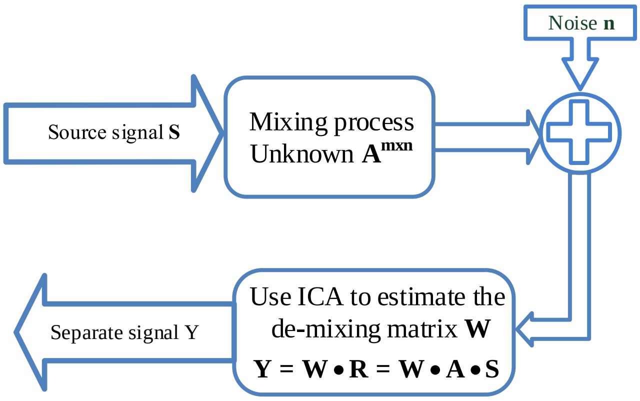

Figure 5. Block diagram of ICA

The ICA method minimizes the statistical dependence between each component of the signal, highlight the essential structure of the source signal. One of the most popular ICA algorithms is the FastICA fixed-point algorithm, and the data use FastICA to separate must be centered and pre-whitened. We can subtract the mean of the received signal to center the data.

$$\mathbf{R} = \mathbf{R} - \mathrm{E}(\mathbf{R}) \tag{5}$$

E(.) is the operator to get the expectation. The whitening process can be finished by the following steps: First, we calculate the eigenvalues: $\mathbf{E}=(e_1,e_2,\ldots,e_m)$ and eigenvectors $\mathbf{D}=(d_1,d_2,\ldots,d_m)$ of the received data, Then the whitening matrix can be calculated by:

$$\mathbf{T} = \mathbf{D}^{-1/2}\mathbf{E}^{\mathrm{T}} \tag{6}$$

Then the whiten data:

$$\mathbf{Y}_1 = \mathbf{T} \bullet \mathbf{R} \tag{7}$$

Then the data can be separated successfully by the FastICA algorithm. The FastICA algorithm finds the de-mixing matrix W by iteration objective function:

$$J(\mathbf{y}) \approx \sum_{i=1}^{p} k_i \left\{\mathrm{E}\left[G_i(\mathbf{y})\right] - \mathrm{E}\left[G_i(\mathbf{v})\right]\right\}^2 \tag{8}$$

Where k_i is a positive constant and v is a random variable of the Gaussian with zero mean and unit variance. $G_i(\bullet)$ is a non-quadratic function, the select of G is different from the Gaussian character. As the RFID signals are sub-Gaussian so the G can be chosen as follows,

$$\begin{gathered} G(\mathbf{u}) = \frac{1}{a_1}\log\cosh(a_1\mathbf{u}), G'(\mathbf{u}) = \tanh(a_1\mathbf{u}) \\ 1 \le a_1 \le 2 \end{gathered} \tag{9}$$

Then maximizes the Lagrangian:

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$$L(\mathbf{w},\lambda)=\left|\mathrm{E}\left[G\left(\mathbf{w}^{\mathrm{T}}R\right)\right]\right|-\frac{\lambda}{2}\left(\mathbf{w}^{\mathrm{T}}\mathbf{w}-1\right) \tag{10}$$

3.2. PowerICA method

The ICA algorithm has some drawbacks like: The traditional fixed-point ICA algorithm cannot run on a parallel, and there are some unnecessary assumptions in the iteration. The classical derivation of the FastICA algorithm has difficult in separating large sets of real data quickly and accurately. To solve the problems mentioned before, the PowerICA and the ICA_p algorithm have been proposed respectively.

Shahab Basiri [27] provided a novel power iteration algorithm for FastICA which is remarkably more stable than the fixed-point algorithm, when the sample size is not orders of magnitudes larger than the dimension, and the PowerICA algorithm can be run on parallel computing nodes. Basiri cut the oversimplified assumptions of the Lagrangian and the Jacobian matrix in the FastICA algorithm, and put up with a new power iteration method for FastICA. The new PowerICA algorithm can converge in the case of the $n=m$, and drastically reduce the computational time by a run on parallel computing nodes. They change the Lagrangian to:

$$\mathrm{L}(\mathbf{w},\lambda)=\left|\mathrm{E}\left[G\left(\mathbf{w}^{\mathrm{T}}\mathrm{R}\right)\right]\right|-\frac{\lambda(\mathbf{w})}{2}\left(\mathbf{w}^{\mathrm{T}}\mathbf{w}-1\right) \tag{11}$$

Thus, the algorithm solving:

$$\mathrm{F}(\mathbf{w})=m(\mathbf{w})-\lambda(\mathbf{w})\mathbf{w}=0 \tag{12}$$

Iterates:

$$\mathbf{w}\leftarrow\frac{m(\mathbf{w})-\beta(\mathbf{w})\mathbf{w}}{\left\|m(\mathbf{w})-\beta(\mathbf{w})\mathbf{w}\right\|} \tag{13}$$

Until convergence. The $\beta(\mathbf{w})$ in (13) is a scalar multiplier defined as $\beta(\mathbf{w})=\mathrm{E}\left[g'\left(\mathbf{w}^{\mathrm{T}}\mathbf{x}\right)\right]\in\mathrm{R}$.

3.3. ICA_p method

Pierre Ablin [30] introduced a Preconditioned ICA for the Real Data algorithm, which is a relative L-BFGS algorithm preconditioned with sparse Hessian approximations. They found that the Hessian approximations have a low cost per iteration but not accurate enough on real data. To solve this problem, the use of an optimization algorithm which 'learns' curvature from the past iterations of the solver, and accelerates it by preconditioning with Hessian approximations. They put the Hessian approximations as follow:

$$\begin{cases}\hat{h}_{ijl}=\hat{\mathrm{E}}\left[\varphi_i'(\mathbf{y}_i)\mathbf{y}_j\mathbf{y}_l\right],\mathrm{for}1\le i,j,l\le\mathrm{N}\\ \hat{h}_{ij}=\hat{\mathrm{E}}\left[\varphi_i'(\mathbf{y}_i)\mathbf{y}_j^2\right],\mathrm{for}1\le i,j\le\mathrm{N}\\ \hat{h}_i=\hat{\mathrm{E}}\left[\varphi_i'(\mathbf{y}_i)\right],\mathrm{for}1\le i\le\mathrm{N}\\ \delta_i^2=\hat{\mathrm{E}}\left[\mathbf{y}_i^2\right],\mathrm{for}1\le i\le\mathrm{N}\end{cases} \tag{14}$$

They denote the approximation by $\tilde{H}^2$ in the first step:

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$$\tilde{H}^2_{ijkl} = \delta_{il}\delta_{jk} + \delta_{ik}\delta_{jl}\hat{h}_{ij} \tag{15}$$

Then denoted $\tilde{H}^1$,goes one step further and replaces $\hat{h}_{ij}$ by $\hat{h}_i\hat{\sigma}_j^2$ for $i \neq j$:

$$\begin{cases} \tilde{H}^1_{ijkl} = \delta_{il}\delta_{jk} + \delta_{ik}\delta_{jl}\hat{h}_i\hat{\sigma}_j^2 \\ \tilde{H}^1_{iiii} = 1 + \hat{h}_{ii} \end{cases} \tag{16}$$

They designed an algorithm to precondition the data based on the Hessian approximation mentioned before.

3.4. SNR-Max method

ZHANG Xiao-bing [24] propose a low computational complexity instantaneous liner mixture blind separation algorithm. They take care of the complexity of the traditional algorithms, eye on the character that SNR is maximal when statistically independent source signals are entirely separated. They expressed the source signals and noise to the generalized eigenvalue problem, and get de-mixing matrix without iteration. They use the difference between the source signal and the estimated signal: $\mathbf{e} = \mathbf{s} - \mathbf{y}$ as a noise signal. The get the SNR function:

$$SNR = 10\log\frac{s \bullet s^{\mathrm{T}}}{e \bullet e^{\mathrm{T}}} = 10\log\frac{s \bullet s^{\mathrm{T}}}{(s-y)\bullet(s-y)^{\mathrm{T}}} \tag{17}$$

But the source is unknown, so the use the moving average $\tilde{y}$ of the signal to replace the source signal s ,so the SNR change to:

$$SNR = 10\log\frac{s \bullet s^{\mathrm{T}}}{e \bullet e^{\mathrm{T}}} = 10\log\frac{\tilde{y} \bullet \tilde{y}^{\mathrm{T}}}{(\tilde{y}-y)\bullet(\tilde{y}-y)^{\mathrm{T}}} \tag{18}$$

After some simplification, the final objective function is:

$$F(y) = SNR = 10\log\frac{y \bullet y^{\mathrm{T}}}{(\tilde{y}-y)\bullet(\tilde{y}-y)^{\mathrm{T}}} \tag{19}$$

They use a gradient descent method to find the maximum value of the object function, the get the suitable de-mixing matrix w.

4. SIMULATION ANALYSIS AND DISCUSSION

We use computer software MATLAB to do the simulation. This work set a RFID system with m reader antennas and n tags need to be identified every time. We use k binary random number to replace the source signal (tag's signal), thus the source matrix is a n by k matrix named S. We use a n by n positive definite random matrix which called A to simulate the mixing processing in the channel. Then we multiply the A by S, after this, we get the signal waiting for separate named R, easy to know the $\mathbf{R} = \mathbf{A} \bullet \mathbf{S}$ is a m by k matrix. After that, we use the algorithms mentioned before to separate R, then we get the matrix of separate signal called Y. The block diagram of the simulation process which added the basic communication technology is shown in figure 6.

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This paper compares the result in comparing the correlation between S and Y and the success rate change with the SNR. Secondly, comparing the correlation between the source signal S and the separated signal Y change with the source signal's length.

Aiming to get a better comparison, we set a RFID system with 5 reader antennas and 5 tags need to be separated each time. When compare the correlation and the success rate change with the SNR, we set the length of the tag to 1000, the SNR change from 0 to 30, you can see the simulation from figure 7 and figure 8. When to compare the correlation and the success rate change with the length of the source signal, we set SNR to 25 and not change, the length of each tag change from 500 to 5000 with a step of 500, you can see the result from figure 9 and figure 10.

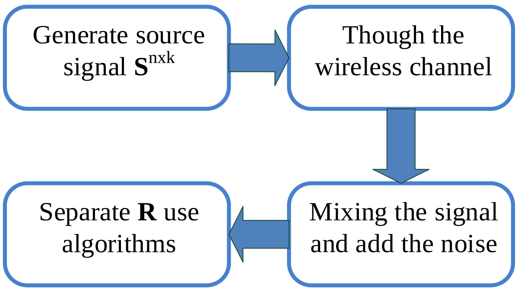

Figure 6. Block diagram of the simulation process

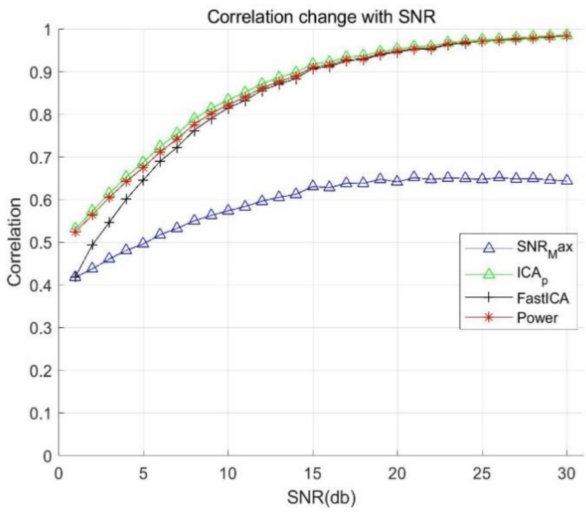

Figure 7. Correlation change with SNR

In figure 7, we can see the algorithms' performance in different SNR channel, as it shows the ICA_p algorithm has the best performance among the four algorithms no matter in low SNR or high SNR channel. The PowerICA algorithm has almost the same performance with the ICA_p algorithm, but not so good as later. The FastICA algorithm has a low correlation, especially in the low SNR channel. Actually, the FastICA algorithm is not stable, the data it separated have many lost, the picture is drawn by the left data. As the low computational complexity of the SNR_MAX algorithm, its performance poor in the RIFD system.

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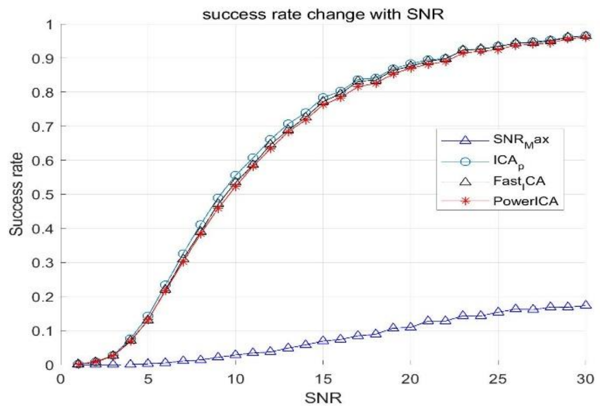

Figure 8. Success rate change with SNR

The paper also compared the success separate rate change with the channel's SNR, shown in figure 8. Usually, if the correlation index big than 0.92, we claim the separate is a success, we note the time the algorithms successes and divided the totally separate time, then we get the success rate. In the curve, we found the FastICA, ICA_p, PowerICA algorithm have the related success rate, but the ICA_p algorithm performance a little better. The SNR_MAX algorithm is hard to satisfy the system.

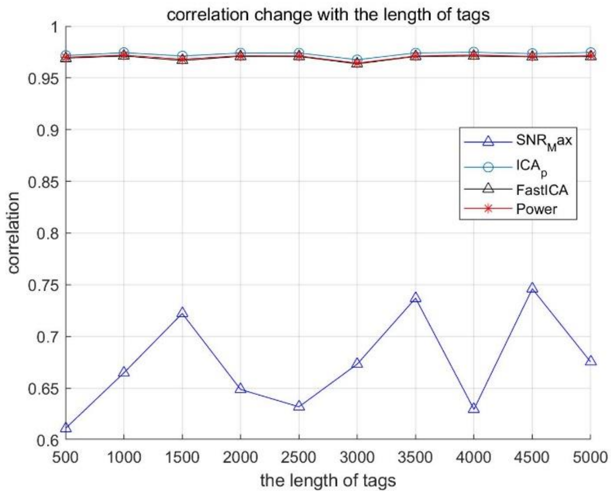

Figure 9. Correlation change with the length of tags

We found that when the channel's SNR up to 25, the curve become smooth which means the algorithms' performance will not increase, so we set the SNR to 25, then compare the algorithms' performance in different length of tags. Figure 9 shows the performance, it tells the trues that all of the algorithms do well when the length of the tags change from 500 to 5000. Because of the relation between the correlation and the success rate, we believe that the success rate has the same trend as the correlation. Figure 10 verify the guess.

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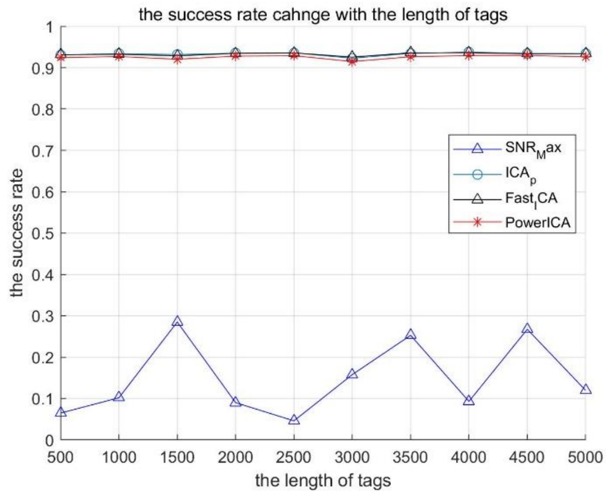

Figure 10. The success rate change with the length of tags

As we said before, the FastICA algorithm is unstable, figure 11 shows the FastICA algorithm separate default time change with the SNR, even when the SNR is 22, the FastICA can still lose the tags, but the PowerICA and the ICA_p will not occur such thing. The reason why this situation arises is that the algorithm oversimplified the Lagrangian and the Jacobian Matrix.

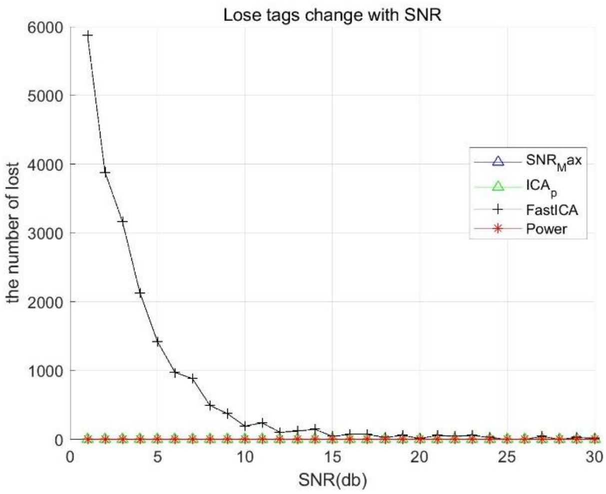

Figure 11. The tag lose change with SNR

We put the source signal, the mixed signal and the algorithm separate signal in there to see the performance intuitively. Considering the convenience of view, we set the number of the tag to 3, then put the signal waveform in figure 12 and figure 13. And put the algorithm separate signal in figure13 to figure 18.

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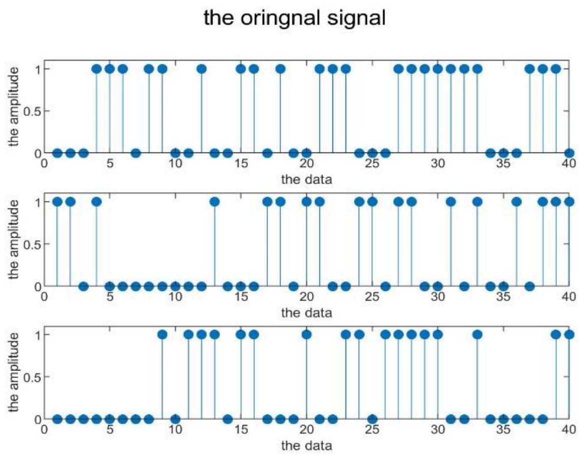

Figure 12. The original signal

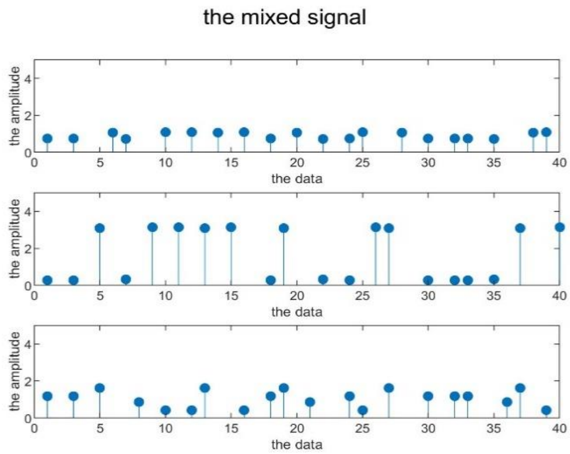

Figure 13. The mixed signal

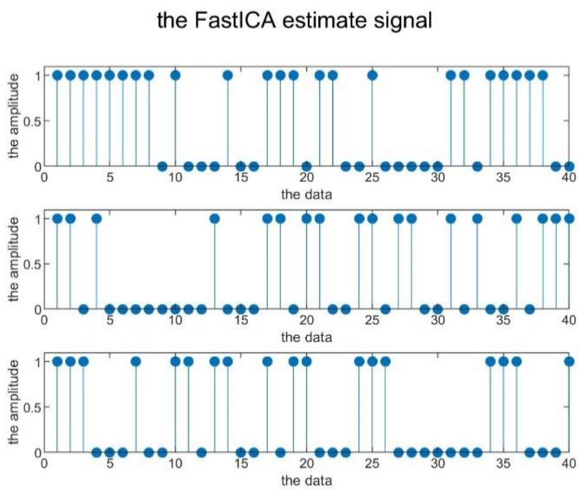

Figure 14. The FastICA separation signal

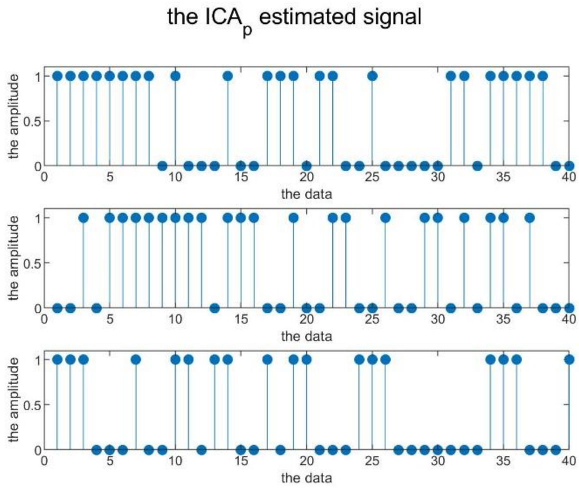

Figure 15. The ICA_p separation signal

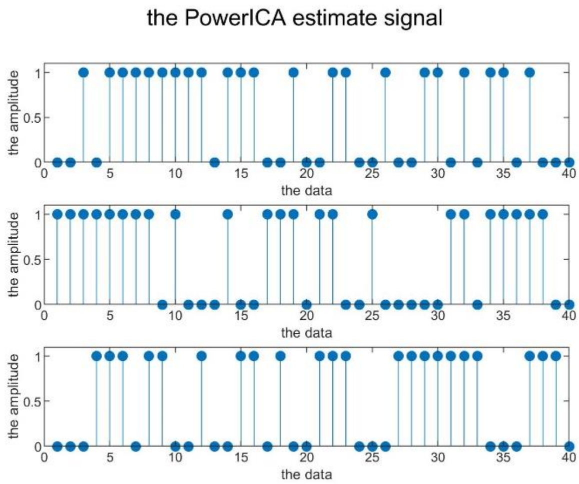

Figure 16. The PowerICA separation signal

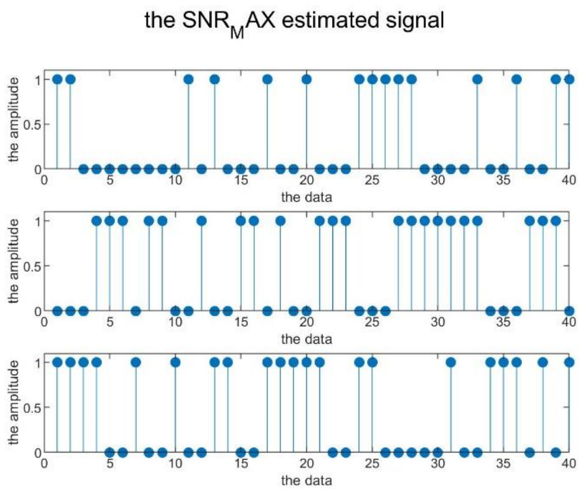

Figure 17. The SNR_MAX separation signal

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We can see from figure 13 to figure 18 that the BSS methods change the order and the polarity of the signal, and most of the signal be separate successfully. The changing doing nothing for us to recognize the information the tags send.

In the end, we compared the time the algorithms need change with the length of the tag, we can see it in figure 14. The SNR_Max uses the least of time, and the Power needs the most of the time, the others between them. But the PowerICA can run in parallel, so it can perform better in parallel systems.

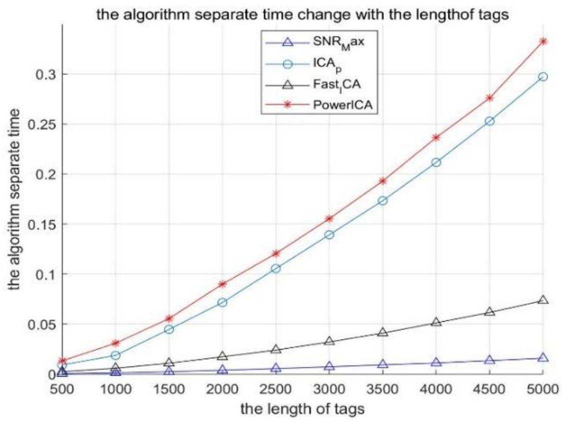

Figure 18. the algorithms separate time change with the length of tags

We make a table to show the performance of the algorithms we used. You can see it in table 1.

Table 1. Algorithms performance

Algorithm	Accuracy	Stability	instantaneity
FastICA	Medium	Low	High
PowerICA	High	High	Medium
ICA_p	High	High	Medium
SNR_MAX	Low	medium	High

There are some useful simulation data to prove our conclusion. The data in table 2 got in the channel which has a 25 SNR and the tags' length is 1000. We do the simulation 1000 times, then get the average data. As we can see the ICA_p algorithm has the highest correlation in this situation. From the low correlation and the mean success rate we can say that the ICA_p and the PowerICA algorithm are stable. From the time for one separate, we know the Fast ICA algorithm is the most real-time and with excellent performance.

Table 2. some useful data

Algorithm	Highest correlation	Low correlation	Mean successes rate	Time for one separate
FastICA	0.9952	0.8222	0.9680	0.0053s
PowerICA	0.9970	0.8662	0.9680	0.0176s
ICA_p	0.9999	0.8439	0.9680	0.0126s
SNR-Max	0.8055	0.5302	0.3440	0.0006s

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5. CONCLUSION

RFID plays an important role in IoT, as IoT develop so fast that RFID technique has to be more effective and real-time in practical applications. Through the simulation, the FastICA algorithm performs well in real-time but has poor stability performance. The PowerICA and the ICA_p algorithm performs well in stability and accuracy, but need a little more time. And the SNR-Max algorithm is not suited for the RFID system. In conclusion, we can design a system which uses ICA_p algorithm or PowerICA algorithm when the channel's SNR is low and use the FastICA algorithm to reduce the time when the channel's SNR is very high. The ICA_p algorithm has the best general performance. In the future work, the underdetermined receiving model will be engaged for anti-collision in RFID application.

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