Radio Frequency Identification (RFID): Evaluation of the Technology supporting the Development of Program Latihan Khidmat Negara (PLKN) Participants Tracking Application

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Abstract—Radio Frequency Identification technology has been adopted into goods tracking, human tracking and identification of valuable items to fulfill the needs of identification. Reliable RFID communication requires good communication protocols as well as decision support protocols. The purpose of this paper is to review the current RFID technology and to explain the anti-collision protocol which is the communication protocol that eliminates the collisions between reader and tag as it will prevent reader from obtaining data from tags. Besides, this paper will also introduce the positioning protocol as a part of decision support protocol which is used to help the system to determine the location of required tag. These protocols are the random back-off anti-collision protocol which uses counter to generate random duration for next transmission to avoid tags from transmitting at the same time, simple positioning protocol and receiving power based triangulation method using Heron's formula for positioning protocol use the concept multi readers to formulate the location of tag. Simulations have been done to illustrate how the protocols work. These protocols may be used in certain low end systems which cater fewer functions and limited number of mobility tags. As a conclusion, these protocols are able to be implemented into National Service participants tracking application to fulfill the requirements of tracking moving objects.

1. INTRODUCTION

Radio Frequency Identification has been in use for some time with the RADAR being one of its early ancestors when it was introduced during World War 2. This concept allowed pilots to identify an incoming airplane as friend or foe. RFID technology as such has a history back to the late 60's and early adopters were identification of live stock and tracking of rail cars in the USA. By emitting radio frequency energy, the RFID reader interrogates its surroundings for the presence of a RFID tag marking an object of interest. When exposed to the radiated power, the tag responds by transmitting information back to the reader using the received energy as its source of power. In its simplest form the tag returns a pre programmed serial number or even a single bit in contrast to more sophisticated cases adding capabilities of on-board memory and sensors as well as data processing capabilities by integrated microprocessors. This is the result of intensive research within the field of VLSI production techniques and low power circuits making the production of miniature RFID tags with high efficiency with on board batteries possible. Finally there is a rapid increase in available on board processing capacity leading the way to a brand new range of promising applications to be produced.

2. RFID COLISSION AND INTERFERENCE PROBLEMS

Simultaneous transmissions in RFID systems lead to collisions as the readers and tags typically operate on the same channel. To understand this, the concepts of *interrogation region* and *interference region* of RFID readers must be understood [7]. The interrogation region is the region around a reader where a single tag can be successfully read in the absence of any interference from another tag or reader. The interference region is a similar region where the signal from the reader reaches with sufficient intensity so that it interferes with a tag response. There is no known relationship between the interrogation and interference regions. For the research work carried out, it was assumed that these regions can take any arbitrary shape. During communication between readers and tags, three types of collisions are possible.

- Tag-tag collisions
- Reader-tag collisions
- Reader-reader collisions

A. Tag-tag collisions

This occurs when multiple tags are present in the interrogation region of a reader and transmit IDs at the same time. See Figure 6. An appropriate linklayer protocol is needed to schedule the tag responses in a collision-free manner. Two broad categories of such tag anti-collision protocols exist in literature: one based on framed Aloha and the other based on tree-splitting. Framed-Aloha based protocols attempt to reduce collisions by transmitting in randomly chosen slots. The protocols based on tree splitting take a

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different approach. They split the set of tags into two subsets and attempt to recognize each subset in a recursive fashion, process of recursion happens until the set has only one tag.

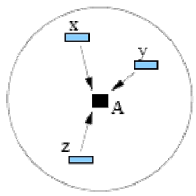

Figure 6: Tag-Tag Collision: Tags x, y, and z respond to reader A simultaneously, causing collision at A. [7]

B. Reader-tag collisions

In order to explain this type of collision, two readers; reader A and reader B will be used in the example below. When reader B is within the interference region of reader A, which can be seen in Figure 7, interference from A will "drown" the backscattered signal from a tag targeted for B. Reader-tag collision can be avoided by

- Assigning different frequency channels to near-by readers, or by
- Scheduling the near-by readers to be active at different time slots

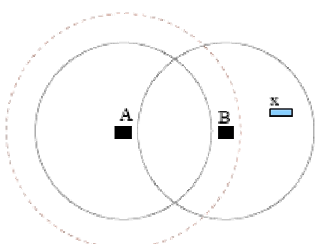

Figure 7: Reader-Tag Collision: Reader B lies within the interference region of reader A. The response from tag x to reader B is "drowned" by the interference from reader A causing a collision. [7]

C. Reader-reader collisions

This happens when the interrogation regions of multiple readers overlap causing their signals to interfere at one or more tags. When two such readers with overlapping interrogation regions are active at the same time, the tags in the overlapped region cannot differentiate between the two signals. This collision cannot be avoided by operating these two readers in two different frequency channels. The only way the collision can be avoided is by ensuring that the interfering readers are active at different points in time. Reader-reader collision is illustrated in Figure 8.

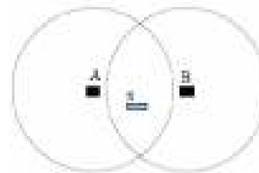

Figure 8: Reader-Reader Collision: Reader A and reader B are active at the same time, their queries colliding at tag x. [7]

D. Tree based protocols

The tree based tag anti-collision protocols such as the binary tree protocol and the query tree protocol are able to eliminate collision effectively but they will cause long delay as they split the collided tag into subsets until they transmit data successfully [4].

Tree based tag anti-collision protocols implement the tag identification process repeatedly by using reading cycle system. In a reading cycle, reader will sent a query signal to all the tags in order to request ID from them. Since passive tags are not able to determine whether collisions happen or not, therefore the reader will detect the occurrence of collisions and determine the next cycle according to the result. Upon receiving a query from the reader, the tag decides whether to transmit or not. Only if a single tag transmits in a reading cycle, can the reader recognize it successfully. The reader recognizes all the tags within its reading range in a process, which consists of several reading cycles. The reader attempts to recognize a set of tags in a reading cycle. A set includes tags, which transmit at the same reading cycle. If a set has more than one tag, tag transmissions lead to collision. When tag collision occurs, the mechanisms split the set into two subsets by tag IDs or random numbers. After that, the reader tries to recognize two subsets one by one in the same process. By continuing the splitting procedure until each set has only one tag. Tree based protocols are capable of recognizing all tags in the reader's range. The performance of tag identification is influenced significantly by how efficiently it splits the tag set.

The binary tree protocol (BT) uses random binary numbers generated by colliding tags for the splitting procedure. The tag has a counter initialized to 0 at the beginning of the process. The tag transmits ID when the counter value is 0. Therefore, all the tags within the reader's reading range, at the start of the process, form one set and transmit concurrently. The reader transmits a feedback to inform tags of the occurrence of tag collision. According to the reader's feedback, all the tags change its counter. The tag randomly selects a binary number when its transmission causes collision (i.e., the counter value is 0). By adding the selected binary number to the counter, a set is split into two subsets as shown in Figure 9. When tag collisions occur, the tag which is not involved in collision (i.e., the counter value is not 0) increases its counter by 1. When the reader's feedback indicates no collision, all tags decrease their counter by 1. The tag infers the successful transmission from the following feedback indicating no collision. The tag recognized by a reader does not transmit any signal until the ongoing process is terminated. In BT, the reader also has a counter in order to terminate a process. It initializes the counter with 0 in every process. The counter value of the reader indicates the number of tag sets which are not recognized. If tag collision occurs, the reader adds 1 to the counter since the number of tag sets, which the reader should recognize, increases. Otherwise, it decreases the counter by 1. When the counter is less than 0, the reader terminates the process.

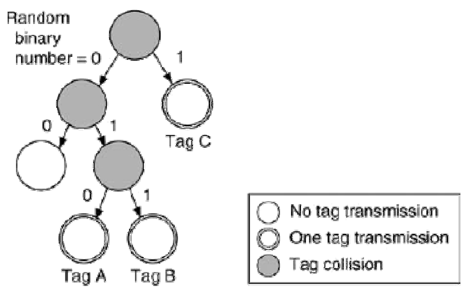

Figure 9: Tag identification at the binary tree protocol [4]

The query tree protocol (QT) uses tag IDs to split a tag set. The reader transmits a query including a bit string. The tag whose first bits of ID equal the bit string of the query responds by transmitting ID. If tag responses of

query $q_1q_2...q_x$ $(q_i \in \{0,1\}, 1 \leq x \leq b$

and b is the number of bits in the tag ID) collide, the reader uses two one-bit longer queries, q1q2...qx0 and q1q2...qx1 in next reading cycles. The set of tags which match q1q2...qx is split into two subsets; one is a set of tags which match q1q2...qx0 and the other is a set of tags which match q1q2...qx1 as shown in Fig. 10. The reader has queue Q for bit strings of queries. At the beginning of the process, Q is initialized with two one-bit strings, 0 and 1. The reader pops a bit string from Q and transmits a query at a time. If tag responses collide, the reader pushes two one-bit longer bit strings into Q. By expanding the query until either a response or no response follows, all the tags are recognized. Contrary to BT, QT imposes simple functions on tags. QT is also called a memory less protocol because tags need not have additional memory except ID for identification. However, the identification delay is affected by the distribution of tag IDs. As tags have much similar IDs, delay is increased.

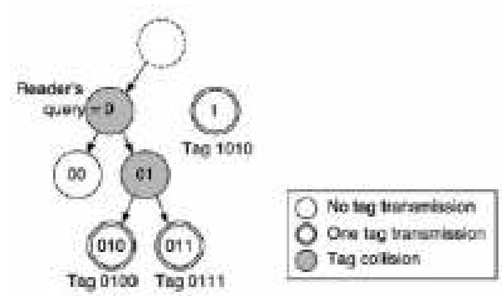

Figure 10: Tag identification at the query tree protocol [4]

3. RANDOM BACK-OFF FOR ANTI COLLISION PROTOCOL

When two or more tags are sending signal simultaneously to a reader from the same distance, all the signals that arrive at the reader will most probably suffer from collision. This collision will somehow alter the information of our signal. In order to avoid this, this paper will recommend the random back off duration to overcome this collision.

Each tag will have an internal counter, and the function of this counter is to generate a random numbers when it receives acknowledgement from reader regarding collision. And this random number will then be used for countdown purpose. Whenever the tag receives signal or power, this counter will generate a random number which may be vary for other tags. Based on this number, the counter will count from the number until zero. It will then transmit back signal with all the information it carries when the counter reaches zero. This can be illustrated in Figure 11. However, this counter must produce huge range of random numbers in order to avoid two or more tags having the same number. Due to this, one of the major problem is the randomness of the generation of these random values. Especially when it comes to the consideration whether the tag will have sufficient energy to do the counting and retransmit signal back to reader. This issue is very crucial as passive tags do not have power supply and the received energy is very limited.

However, this type of protocol can be used effectively when there are not many tags to detect, and therefore the occurrence of collision may be reduced. Thus, the random generator can be designed such that the range of random numbers could be smaller, and smaller variance. This will highly reduce the power consumption of system for additional calculation. It applies very well in a low cost system which will be managing thirty or forty tags rather than hundreds of tags.

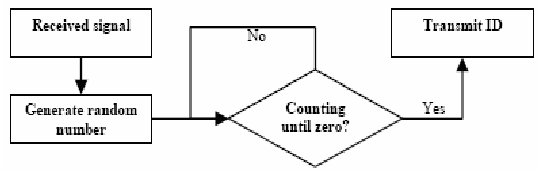

Figure 11: General overview of Random Back-off protocol

A. Random Back-off protocol simulation

Simulations were carried out to see how this protocol would perform .For RFID system which is used for moving objects tracking purposes, the reader of base station should always be static and in this case, having omni directional antenna to cover a flat area. The radius of this area largely depends on the ability of antenna and it has a constant value in each direction. A set of tags are put into simulation with the condition that all the tags are moving from time to time. This will create a situation where objects are moving all the time. Thus, some tags will move inside the range that can be read by reader while others would have gone out of range. And only those tags that are in range will be able to respond to reader, and those out of range will be considered lost.

When more than one tag is trying to communicate with reader simultaneously, collision will happen; therefore reader will send an acknowledgement to tags for next wave of signal. Tags that collide will generate a random number and the processor will do the counting. After the random time, the affected tag will respond to reader by sending signal. This process is repeated until no collision is found. Meanwhile, the distance between reader and tag will be given by symbol, r_x, where x is the specific number of tag. Example, distance between reader than tag no.1 will be r1. Reader will not communicate all the time, it only scan the area periodically. Tags are moving in and out randomly every period.

The simulation observed the percentage of tags appearing in the readable range. This observation was used to help the collection of system info and analysis of system's efficiency. It was then possible to ascertain:

- How many times the tags suffer from collisions
- How many tags suffer from collision at one time
- How long it takes for the whole process to repeat transmission
- The randomness of the back-off ability

This simulation was done using 5 tags and there were 8 periods of observation. Some graphical results are shown below:

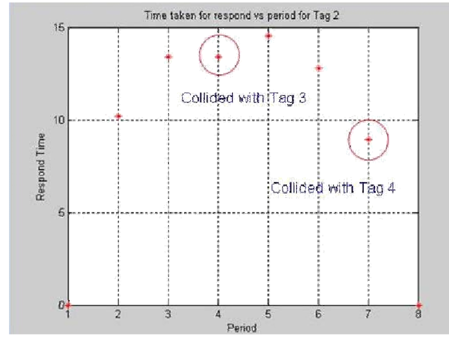

Figure 12: Tag 2 collided with tag 3 during 4th period while collided with tag 4 during 7th period

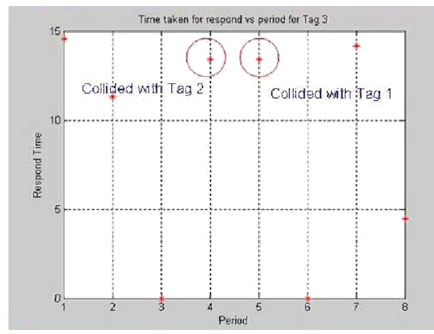

Figure 13: Tag 3 collided with tag 2 during 4th period while collided with tag 1 during 5th period

As an example , it was possible to see that tag 2 was having collision with tag 3 during the 4th period while it also collided with tag 4 during the 7th period (Figure 12). After applying the back-off ability (Figure 14) tag 2 had retransmitted signal during the 4th and 7th period.

Meanwhile, from the observation, the tags will be out of readable range for 2 periods. During 8 periods, there were only 3 collisions happening , where at most one collision happening in one period involving a maximum of two tags. The collided tags took twice the original duration to send signal because the random number is too small and can be considered negligible. Lastly, the randomness of the back-off ability is effective because no overlapping and occurrence of second collision after first collision. This means that the random number generated were always different.

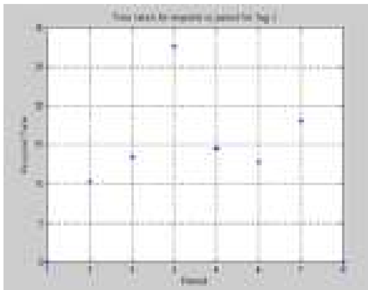

Figure 14: New respond time for tag 2

4. SIMPLE POSITIONING PROTOCOL

Positioning capability can be obtained when there are more than one reader operational such that their interrogation regions overlap. By using this technique it is able to perform simple positioning decision and this can be applied even to other wireless devices which require certain degree of positioning ability. The general idea of this protocol can be illustrated by taking an example where there are two readers. When a tag could be detected by both readers, it can be said that the rough location of the tag would be the place where both reader's interrogation region overlap.

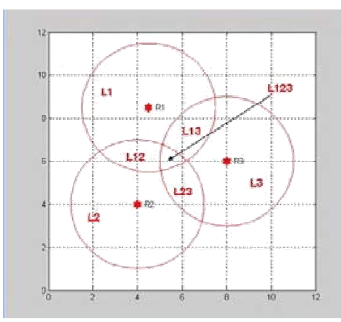

Figure 15: Overlapping of 3 reader's interrogation region to form simple position technique

In this case, there will be 7 specific regions for recognizing a tag position. For example, if a tag can be detected by reader R1 and R3, thus the tag must be in region L13. Likewise, if the tag can be detected by all 3 readers R1, R2, and R3, the exact location of the tag must be in L123.

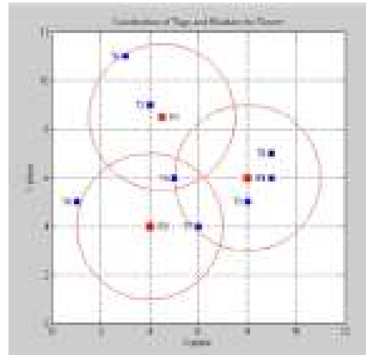

Figure 16: Graphical result from simulation of simple positioning protocol for the 10th period

However, when this method is implemented, the communication protocol and decision support protocol must be such that effective communication can be maintained. The main concern here would be the decision support protocol at which all the reader must report to a specific manager in order to make decision. This is where the data goes to Edgeware and related data will go to Middleware to be processed. From the simulation, R1 will acknowledge Edgeware when it detects a tag in its region while others will also perform the same action if they are able to detect the tag. So Middleware will perform the decision making from the data it receives and to acknowledge user with the result they require. Therefore, some of the simulations result can be seen Figures 16 and 17.

```
Time =

    10

Tag1 is inside L3 area
Tag2 is inside L1 area
Tag3 is inside L3 area
Tag4 is out of coverage area
Tag5 is inside L123 area
Tag6 is inside L1 area
Tag7 is inside L23 area
Tag8 is inside L3 area
```

Figure 17: Data shown for the location of tag according to region for the 10th period

This system can be improved by placing more antennas; by doing so more accurate position may be obtained. For example, region such as L1, L2 and L3 may not be well defined, because even the far end corner of region L1 will still be called L1 and the center of L1 region where the reader R1 is located is also called L1. Therefore, more antennas will reduce the margin of getting undefined region. Besides, the purpose of using more antennas can replace the use of high power single antenna which may not be efficient. Secondly, the coordination of tag will be more detailed compared to single reader. When there are many readers, the services provided by reader towards tags will be better, because one reader will service lesser number of tags and it will cover smaller area. Thus, when the number of tags gets small, the probability of getting collision will be reduced.

5. RECEIVING POWER BASED TRIANGULATION METHOD USING HERON'S FORMULA FOR POSITIONING PROTOCOL

Microwave transmission tends to be attenuated when traveling in free space and this leads to power reduction of transmitted signal. This type of loss is called free-space loss [9]. When transmitter sends out microwave signal, this signal will have a certain level of output power, which is the transmitted power, $P_{T.}$ This signal will go through amplification before it is sent out through antenna, which is called transmitter antenna gain, G_T. It loses some power when traveling to the receiver, which is free space loss, FSL and many other losses such as misalignment loss, refraction and reflection loss and others. In this case, this paper will only consider the free space loss. At the receiver, signal will be amplified with a gain of G_R to boost the signal power level and then being transferred to the reader for signal processing.

Therefore, the received power, P_R can be calculated from the equation below :-

PR = PT + GT + GR – FSL(in dB or dBm) (1)

Therefore, free space loss, FSL can be calculated as follows:

FSL = 32.5 + 20log (d) + 20log (f) (in dB or dBm) (2)

Where d is the distance between receiver and transmitter in km while f is the frequency used in MHz.

Eqns. (1) and (2) will enable RFID System to use the measured received signal power to calculate the distance between reader and tag.

From Figure 18, when received power detected by reader R_1 is big , the power circle formed will be bigger while reader R_3 which detected lesser received power will have such smaller power circle. This circle actually means the distance of tag towards reader but it does not know the exact location on the circle. Therefore, when two readers, R1 and R3 are able to detect a tag, intersection will occur between the two circles and that becomes the possible locations of the tag. However, this is still not sufficient to decide which point is the most exact location. Due to this, this method will require at least 3 readers to determine the exact location of a tag and to perform triangulation as well.

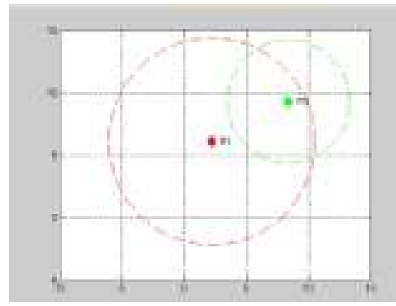

Figure 18: Intersection between two power circles

In the example of Figure 19 below, it can be observed that different level of power will be received by each of the three readers resulting in 3 different power circles of various radii. Intersections happen and coincidently there will be a point where all 3 power circles intersect. This is indicated by a small black circle in Figure 19. It would be possible to make a decision on the position, based on the intersections observed.

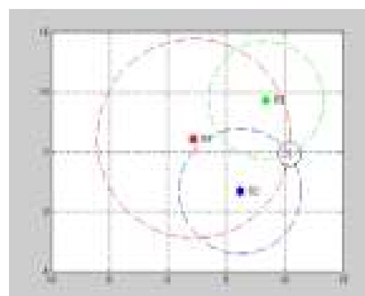

Figure 19: Intersections indicates the existence of tags and as a positioning method

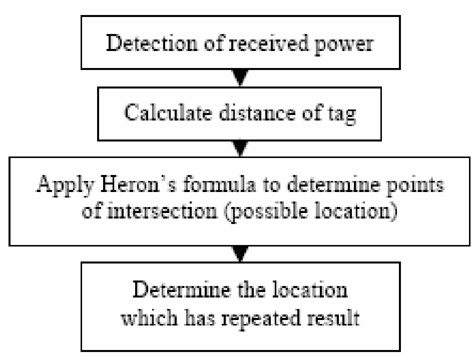

Figure 20: Flow of performing positioning

Heron's formula uses triangulation calculation to determine position with the help of processing steps shown in Fig.20.

It is assumed that RFID reader will be able to read the power level of received signal. It will then send this information to another system to do further calculation. By using free space loss calculation, the system will be able to determine the distance of tag and meanwhile applying the Heron's formula to perform triangulation method. However, this method will result for several possible locations for every reader. From example, 3 readers will produce 12 possible locations where each reader will produce 4. One of the four possible locations is real location, and therefore 3 readers will produce same result. Therefore, by using a decision support system, whenever this location appears in all 3 readers' possible result, the system will decide that the location is the real location.

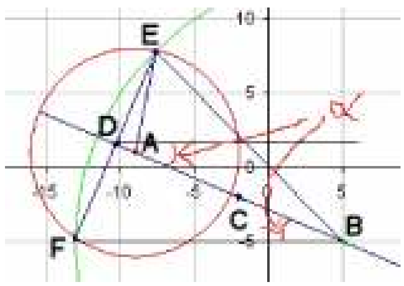

Figure 21: Intersection between circle A & B to produce point E & F [8]

From the Figure 21 above, C is the mid point between A & B while D is the mid point of two points of intersection which are E & F in this case. AB is the distance between A & B while CD is the distance between C & D. Meanwhile X_A means the coordinate of point A on X-axis while Y_A mean the coordinate of point A on Y-axis. It also applies to other points B, C, D, E and F. From Heron's formula (4), k equals to the area of triangle ABE [8], where

$$k = (1/2) \times AB \times DE \quad (3)$$

$$k = (1/4) \times v\,([(r_A + r_B)^2 - d^2] \times [d^2 - (r_A - r_B)^2]) \quad (4)$$

$$C = [(XA + XB)/2, (YA + YB)/2] \quad (5)$$

$$d = AB = v\,[(X_B - X_A)^2 + (Y_B - Y_A)^2] \quad (6)$$

$$CD = (1/2) \times (r_A^2 - r_B^2)/d \quad (7)$$

$$\cos a = (XB - XA)/d \quad (8)$$

$$\sin a = (YB - YA)/d \quad (9)$$

After having all the necessary equations, point D can be calculated with the help of equation 10 & 11:

$$XD = XC + CD (\cos a)$$
$$= X_C + (1/2) \times (X_B - X_A) \times (r_A^2 - r_B^2)/d^2 \quad (10)$$

$$YD = YC + CD (\sin a)$$
$$= Y_C + (1/2) \times (Y_B - Y_A) \times (r_A^2 - r_B^2)/d^2 \quad (11)$$

Therefore, the coordinate of point D is able to be determined. After that, either find point E or point F can be calculated by referring to point D and by using the equation below:

$$\text{Since } k = (1/2) \times AB \times DE$$
$$DE = 2k/AB = 2k/d \quad (12)$$

$$XE = XD + DE (\sin a)$$
$$= X_D + 2k \times (Y_B - Y_A)/ d^2 \quad (13)$$

$$YE = YD + DE (\cos a)$$
$$= Y_D + 2k \times (X_B - X_A)/ d^2 \quad (14)$$

Therefore, point E (X_E, Y_E) is obtained as one of the intersected point. Further calculation is then performed using the equation for point F but with some variation on the equation. The general equation can be seen as below:

$$X = X_C + (1/2) \times (X_B - X_A) \times (r_{A2} - r_{B2})/d^2 \pm 2k \times (Y_B - Y_A)/ d^2 \quad (15)$$

$$Y = Y_C + (1/2) \times (Y_B - Y_A) \times (r_{A2} - r_{B2})/d^2 \pm (-2k) \times (X_B - X_A)/ d^2 \quad (16)$$

After finding all the possible points of intersection, the next step is to perform decision making program to choose the locations which produces the same result for 3 times. Figure 22 shows the example of simulation using received power from tag and then by using Heron's formula to obtain all the possible points.

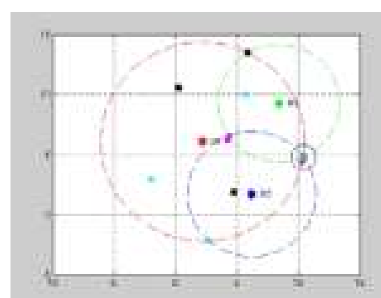

Figure 22: Simulation result that shows all possible points to determine the exact location

This technique requires at least 3 readers and all the readers must be far apart and even the reader itself should be inside the interrogation area of other readers. There are some drawbacks too, where this will cause collisions between readers, but it can be eliminated by assigning different operating frequencies and time slots to each reader.

6. CONCLUSION

RFID has great potential to substitute the tracking capability of other tracking technologies. Mainly due to its characteristics which bring many advantages such as contact-less, does not require line of sight, tiny, light, fast response and able to keep more information. For moving object tracking purposes, the system is required to be able to eliminate collisions, whereby the random back-off capability to avoid collisions is effective enough for small amount of tags. It can also be improved if more complicated random generator can be used which will produce true randomness. Meanwhile, positioning protocol is very important as it provides information about the location of tags. In this case, two positioning protocols have been suggested and both of them have advantages and disadvantages. Simple positioning protocol is very economical and less complicated, but it provides insufficient information about the exact location. On the other hand , received power based triangulation method using Heron's formula for position estimation can perform accurate location identification . However, this method may not be economically wise. As the technologies develop , price of devices gets cheaper . Hence, this system can be low cost and very versatile. It can be seen that the combination of anti-collision protocol and positioning protocol are able to perform effective tracking ability for RFID system together with its unique feature to identify every single tag.

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