CALCULATION AND SIMULATION OF ELECTROMAGNETIC WAVE PROPAGATION PATH LOSS BASED ON MATLAB

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Abstract- In order to reliable data transmission of wireless sensor network (WSN) in indoor environment, the indoor field intensity distribution and transmission characteristics of electromagnetic wave were researched. First of all, the 3D model in specific indoor environment was built by the finite difference time domain method (FDTD). Then, layout of room, different furniture, position of field source and field source frequency had an influence on indoor field intensity distribution that were studied, and the field intensity distribution was simulated by MATLAB. According to simulation of three dimensional field intensity distribution, and it had directly shown that various factors had an influence on the indoor field intensity distribution, thus indoor wireless sensor network nodes can be reasonable deployed by it, the packet loss rate of WSN transmission was reduced from information source, and it provided theoretical basis for further improving WSN information transmission reliability.

Index terms: FDTD, Electromagnetic wave, Field intensity distribution, Reliability, WSN.
I. INTRODUCTION

Wireless sensor network (WSN) is composed of a large number of wireless sensor nodes that interact with each other in the sensing area [1] [12], the node deployment is the first step for sensor network, and it is directly related to accuracy, completeness and timeliness of network monitoring information. Reasonable node deployment not only can improve work efficiency and optimize network resources, but also can change the number of active node according to variation of application requirements, so as to dynamically adjust node density of network. Wireless sensor network has the characteristics of smaller transmission power, closer covered distance and larger environment change. For different buildings, the change of factors such as indoor layout, material structure, building scale and application type are very larger, the propagation environment is not the same so far as to different locations in the same building, and the difference is very bigger [4][13][14]. Installation location and type of antenna have a strong effect on wireless communication. Due to the effect of shielding and absorption of buildings themselves, the transmission loss of electromagnetic wave is very larger, and the field strength will be weakened, even blind area can be caused. Scholars at home and abroad have been studied wireless sensor network node deployment in indoor environment and improved reliability of communication [2] [3][15], most researchers mainly have been studied from the aspects of transmission path, communication algorithm and hardware structure, the studies in the aspects of field intensity distribution of nodes are few now. In order to improve the unreasonable distribution when sensor nodes are random deployed, improve effect of network coverage, and reduce the packet loss rate of WSN transmission from information source, this paper studied field intensity distribution and transmission characteristics of electromagnetic wave for wireless sensor network nodes under indoor environment, according to field intensity distribution, wireless sensor network node can be reasonable deployed, and provided theoretical basis for further improving WSN information transmission reliability.

II. ELECTROMAGNETIC WAVE TRANSMISSION CHARACTERISTICS AND MODEL

Electromagnetic wave propagation in indoor environment is affected by many factors, compared with outdoor environment, it is more complex. Signals at the receiving end are made up of
incoming signal by the means of multiple paths. In addition to possible direct signals, these incoming signals have different intensity, phase, and time delay through emission, transmission, diffraction and scattering at the receiving end, the attenuation and phase changing signals were formed after superposition. At present, in the aspects of indoor electromagnetic wave propagation research, two kinds of modeling methods are widely adopted, and they are ray tracing method and finite difference time domain method (FDTD) respectively [5]. Ray tracing method usually is used to simulate the characteristics of main building, but building’s interior decoration, furniture and so on are not considered, and the more items are simulated, the more trace rays are required, so it is difficult to accurately model for the environment, thus the accuracy and application range of this method are affected. But, for FDTD method, as long as the calculation area does not be changed, even if items are added, the memory requirements will not be increased, and which can be accurately modeled on the environment. And the field intensity distribution around the wireless sensor network node is regional, and ray tracing method can only get the point-to-point field strength prediction, therefore, the analysis of electromagnetic wave transmission characteristics were implemented by FDTD.

a. Theory analysis of Finite Difference Time Domain

Finite difference time domain method is a kind of main time domain electromagnetic field calculation method, and it has been widely applied to analysis of electromagnetic problems. Its main idea is that field variables are discrete in three-dimensional space and time axis, and replace partial differential difference with central difference, the max-well equations can be converted to difference equation, so the space field solution was calculated in certain of boundary and initial conditions. Maxwell curl equation in free space was given by [6] [7][11]

\[
\nabla \times H = \frac{\partial D}{\partial t} + J \\
\n\nabla \times E = -\frac{\partial B}{\partial t} - J_M
\]

(1)

The certain weight of H or E in \(xyz\) coordinate system was expressed with \(f(x,y,z,t)\). Where \(x,y,z\) and \(t\) composed of four dimensional space, and it was discrete in the four dimensional space, was given by
\[ f(x, y, z, t) = f(i\Delta x, j\Delta y, k\Delta z, n\Delta t) = f^n(i, j, k) \] (2)

The first order partial derivatives and central difference approximate of \(xyz\) space and \(t\) were realized by \(f(x, y, z, t)\), was given by:

\[
\begin{align*}
\frac{\partial f(x, y, z, t)}{\partial x} \bigg|_{x-i\Delta x} & \approx \frac{f^n(i+1/2, j, k) - f^n(i-1/2, j, k)}{\Delta x} \\
\frac{\partial f(x, y, z, t)}{\partial y} \bigg|_{y-j\Delta y} & \approx \frac{f^n(i, j+1/2, k) - f^n(i, j-1/2, k)}{\Delta y} \\
\frac{\partial f(x, y, z, t)}{\partial z} \bigg|_{z-k\Delta z} & \approx \frac{f^n(i, j, k+1/2) - f^n(i, j, k-1/2)}{\Delta z} \\
\frac{\partial f(x, y, z, t)}{\partial t} \bigg|_{t-n\Delta t} & \approx \frac{f^{n+1/2}(i, j, k) - f^{n-1/2}(i, j, k)}{\Delta t}
\end{align*}
\] (3)

In the process of \(FDTD\) discrete, the spatial distribution of E and H node was shown in Figure.1, namely, Yee cellular automata.

For \(FDTD\), once initial values of electromagnetic problems were determined, and the space distribution of electromagnetic field in each time point can be obtained through initial values. The average approximation value of \((i + 1/2, j, k)\) node in \(E_x\) was given by:

\[ E^{n+1/2}(i + 1/2, j, k) = \frac{E^{n+1}(i+1/2, j, k) + E^n(i+1/2, j, k)}{2} \] (4)
On the basis of it, FDTD difference equation of $(i + 1/2, j, k)$ node in $E_x$ can be obtained under the three dimensional $xyz$ system, was given by

$$E_x^{n+1}(i + 1/2, j, k) = CA(m)E_x^n(i + 1/2, j, k) + CB(m) \left[ \frac{H_z^{n+1/2}(i + 1/2, j + 1/2, k) - H_z^{n+1/2}(i + 1/2, j - 1/2, k)}{\Delta y} \right] + \frac{\Delta y}{\Delta y} \left[ \frac{H_z^{n+1/2}(i + 1/2, jk + 1/2, k) - H_z^{n+1/2}(i + 1/2, j, k - 1/2)}{\Delta y} \right]$$

(5)

Where, $CA(m) = \frac{1 - \sigma(m)\Delta t/2c(m)}{1 + \sigma(m)\Delta t/2c(m)}$ and $CB(m) = \frac{\Delta t/c(m)}{1 + \sigma(m)\Delta t/2c(m)}$.

b. Numerical stability conditions

In order to reduce numerical dispersion, when space grid size was selected, $\lambda_{\text{min}} \geq 10\hat{\lambda}$ should be guaranteed, $\hat{\lambda} = \min(\Delta x, \Delta y, \Delta z)$ was minimum wavelength value of media space that was studied. So it can be seen that the numerical dispersion could be reduced when the size of the grid was decreased, but it would cause the increase of storage, so it need to be comprehensively considered and processed. In order to make the numerical stability, according to the Cournam stability conditions, the choice of time step was as followed [6] [8] [9].

$$c\Delta t \leq \frac{1}{\sqrt{1/(\Delta x)^2 + (1/\Delta y)^2 + (1/\Delta z)^2}}$$

(6)

Where $c = \sqrt{\mu/\epsilon}$ is the speed of light in vacuum, generally, $\Delta t = \Delta x/2c^2$ and the stability of the algorithm can be ensured when it was run by means of longer time step.

c. PML boundary conditions

In order to simulate infinite space inside limited space, the absorbing boundary conditions must be considered in calculating. The perfectly matched layer (PML) absorbing boundary condition is commonly used in absorbing boundary conditions. Perfectly Matched Layer is a special dielectric Layer which is set up by FDTD area truncation boundaries, the wave impedance of medium Layer and that of adjacent medium are matched exactly, and incident wave has no reflection when it is into the PML Layer through interface. And because the PML layer is loss medium, the transmission wave in PML layer will decay quickly, even if the thickness of PML is limited, it
still has good absorption effect on incident wave. For FDTD formula of boundary conditions have shown in references [5] [6] [10].

d. Indoor FDTD model

![Indoor environment plan and sources](image)

Figure.2 Indoor environment plan and sources

The office that has a metal cabinet and four wooden tables was modeled, and it is 6m long, 3.6m wide and 3m high. To metal cabinet, it is 1.5m long, 0.9m wide and 1.8m high. Four wooden tables are the same, they are 1.2m long, 0.6m wide and 0.6m high, all furniture are the solid cube, and materials are evenly distributed. Waves are harmonic source whose frequencies are 0.6 GHZ and 1.2 GHZ in simulation calculation. For FDTD, it requires numerical stability, numerical dispersion and determine grids, in this paper, grid lengths are \( d_x = 3\text{mm} \), \( d_y = 3\text{mm} \), \( d_z = 3\text{mm} \). Indoor environment plan and field source have shown in Figure.2.

In this paper, source location has four points, namely, P1, P2, P3 and P4. P1 point was located at the central of room ceiling, P2 point was located at right front of room ceiling, P3 point was located at left behind of room ceiling, P4 point was directly located at beneath of P1 and its height was 1.5 m, P1 and P4 were overlap in the floor plan. Spatial distribution of sources have shown in Fig.3. According to symmetry, indoor electromagnetic wave propagation path loss can be mastered.
Indoor environment simulation related parameters were dielectric coefficient $\varepsilon$, electrical conductivity $\mu$ and magnetic permeability $\sigma_m$. According to the simulation environment, Relative permeability $\mu_r = 1$, Magnetic permeability $\sigma_m$ was 0, Space electric conductivity $\sigma$ was 0, File cabinet electrical conductivity $\sigma = 1 \times 10^7$, Conductivity $\sigma$ of desk was 0, Space relatively dielectric coefficient $\varepsilon_r$ was 1, File cabinets relative dielectric coefficient $\varepsilon_r$ was 1, desk relative dielectric coefficient $\varepsilon_r$ was 2.8.

III. SIMULATION ANALYSIS

In this paper, the finite difference time domain method was adopted, the electromagnetic wave propagation in indoor environment was simulated with Matlab. According to the previous analysis, due to FDTD numerical stability must be considered, so $\Delta \delta$ is very small, it is a few millimeters in general. If the 6m building was walked, computer memory that required was very larger. House, metal cabinet and wooden tables were reduced 20 times in the aspects of size when model was built, their frequencies were 0.6 GHZ and 1.2 GHZ, $\Delta \delta = 3mm$, the thickness of PML was $8 \Delta \delta$, namely, $8 \Delta \delta = 24mm$. Due to $\Delta \delta = 3mm$, and the size of grid was changed from $2000 \times 1200 \times 1000$ to $100 \times 60 \times 50$. According different height $z$ and different frequency $f$ of four sources, indoor electromagnetic waves propagation loss were analyzed, source heights were taken as $z = 0.58$ m, $z = 0.7$ m, $z = 1.78$ and $z = 1.9$ m, respectively, and its frequencies $f$ were taken as $f = 0.6$ GHZ and 1.2 GHZ.
a. Indoor without furniture
Source was located at P1, its heights were 0.58m, 0.7m, 1.78m and 1.9m, respectively, the field intensity distribution under the condition of different frequencies have shown in Figure.4 and Figure.5.

Figure.4  \( z = 0.58m \)  \( f = 0.6\text{GHz} \)

Figure.5  \( z = 0.58m \)  \( f = 1.2\text{GHz} \)

Figure.4 had shown that the effect of absorbing boundary method PML was very good, and the naked eye was invisible to the boundary surface reflection. In the same plane generally, the closer that source was, and the stronger that the field was. According to Figure.5, it can be seen that field strength changed according to the cosine function because of field source was harmonic source, it can be seen in Figure.4 that source intensity was in the positive half shaft, and it was in the negative half shaft in Figure.5. Figure.4 and Figure.5 had shown that the same source, under the condition of the same height, the larger that frequency was, and the greater that the field was.
Figure 6 had shown that the same frequency, under the condition of different height, the closer that source was, and the larger that field strength was, the farther that source was, the weaker that
field strength was. Among them, Figure.6(a), Figure.6(b) and Figure.6(c) had shown that electromagnetic wave reached x axis, but did not reach y axis, in this case, not only the length of the electromagnetic wave on the x axis can be studied, but also the field intensity can be observed, and this conclusion had universality.

Figure.7  $z = 1.78m$  $f=0.6$GHZ

Figure.8  $z = 1.78m$  $f=1.2$GHZ

Figure.7 and Figure.8 had shown plane transient chart when frequency was 0.6 GHZ and 1.2 GHZ respectively, height $z = 1.78m$ and t = 300.
Figure 9  $z = 1.9m \ f = 0.6 \text{GHz}$

Figure 10  $z = 1.9m \ f = 1.2 \text{GHz}$

Figure 9 and Figure 10 had shown plane transient chart when frequency was 0.6 GHz and 1.2 GHz respectively, height $z = 1.9m$ and $t = 300$. As you can be seen, $z = 1.78m$ and $z = 1.9m$ was similar with $z = 0.58m$ and $z = 0.7m$. The purpose of this setting was to study that the surface and inside of obstacles had influence on field strength.

According to Figure 9 and Figure 7, you can seen that yellow ring color in Figure 9 should be deep, and shown that under the condition of the same frequency and different height, the closer that the source was, the greater the field strength was.

All in all, PML method can perfect absorb boundary, the feasibility of PML method was verified under the conditions of same height, different frequency and absence of furniture interference, the larger that source frequency was, the greater that field strength was. Overall, the closer that the
source was, the greater that field strength was. When frequency was same, height was difference, the closer that the source was, the greater that field strength was, the farther that source was, and the smaller that field strength was.

b. Indoor with furniture

The distributions of field strength in different frequency were as follows when the sources were located at P1 and P4.

P1 and P4 were difference in the height of source, the others were the same. P1 was located at the middle of the ceiling, and P4 was located at the center of the whole room.

![Figure 1](image1.png)

(a) P4 point

![Figure 2](image2.png)

(b) P1 point

Figure 11  $z = 0.58m, f = 0.6 \text{GHZ}$

Figure 11 had shown that different material obstacles had difference influence on electromagnetic waves, due to height of measurement was lower than that of wooden tables and metal cabinet, the
field intensity was weaker inside wooden table, the field strength was almost zero inside metal cabinet. When the time was same, height was same and the frequency was same, the closer that source was, and the greater that field strength was. Because of P4 point was closer away from $z = 0.58$ plane, it can be seen that field strength of Figure.11 (a) was higher than that of Figure.11 (b).

Figure.12 $z = 0.58m \, f=1.2\,\text{GHZ}$

(a) P4 point

(b) P1 point
According to Figure.12 and Figure.13, it can be seen that the same source and the same height, the higher that frequency of source was, the greater that the field was. As was shown in Figure.11 (a), the color in four corners was light blue, and the corresponding value was 0.05. As was shown in Figure.12 (a), the color in four corners was yellow, and the corresponding value was from 0.1 to 0.2. Under the same condition, compared with 0.6 GHZ, the field intensity inside wooden table was weaker, and metal cabinet interior field strength was almost zero.

Due to observation point height was above the table, and was below metal cabinet, Figure.13 had shown that field strength on the wooden table surface had been enhanced, and the metal cabinet interior field strength was almost zero.
Figure 14: $z = 0.7m, f=1.2\text{GHz}$

Figure 15: $z = 1.78m, f=0.6\text{GHz}$

Figure 14 had shown that field strength on wooden table surface was stronger than that of its surrounding. Because of observation point height was slightly lower than metal cabinet, Figure 15 had shown that metal cabinet interior field strength was almost zero, and field intensity around metal cabinet had been enhanced. Due to height of P4 was 1.5m, and height of P1 was 3m,
$z = 1.78m$ plane was near the P4 field source, it can be seen from colors, Figure.15 (a) was half shaft of sine harmonic field, Figure.15 (b) was negative half shaft, so only compared field from the depth of the color. Figure.15 (a) was deep yellow, and Figure.15 (b) was light blue, it was obvious that field strength in Figure.15 (a) was larger than Figure.15 (b).

Figure.16 $z = 1.78m = 1.2$GHz

Figure.16 had shown that the metal tank internal field intensity was zero, the field strength inside obstacles was weakened, but, compared with wood material internal, metal materials internal was worse, the surface field strength around the metal tank was stronger.
Because of $z = 1.9m$ plane was less than 2.25m, so it was closer away from P4. Figure.17 (a) was sine half shaft harmonic field, Figure.17 (b) was negative half shaft, according to the color shades, and the field can be judged. Figure.17 (a) was deep yellow, Figure.17 (b) was light blue, and it was obvious that field strength in Figure.17 was greater than that of Figure.17 (b). According to
Figure 17, it can be seen that the metal tank surface field strength was stronger. Because the observation point height was above the metal cabinet, according to Figure 18, the metal cabinet surface field strength was strong, and it was consistent with the conclusion of Figure 17.

According to the above analysis, it can be obtained that different materials obstacles had different effects on field intensity, and obstacles internal can weaken field intensity, obstacles surface can increase field strength. Whether it was weaken or strengthen, compared with woodiness material, metal material has obvious effect on field strength.

The distributions of field strength in different frequency were as follows when the source was located at P2.

![Figure 19](image1960.png)  
**Figure 19**  \(z = 0.58m \ f=0.6\text{GHz} \)

![Figure 20](image1960.png)  
**Figure 20**  \(z = 0.58m \ f=1.2\text{GHz} \)

According to Figure 19, field intensity range was from 0 to \(5 \times 10^{-3}\). If it was more, sample effect was not obvious, and it was light blue and light yellow. Observation point height was lower than
that of wooden table, and source was near wooden table, compared with field strength around the metal tank, field strength around wooden table was better.

Figure.19 and Figure.20 had shown that, the same source and the same height, the greater that the frequency was, and the greater that field strength was. Wooden table was closer away from source, and the metal cabinet was father away from source field intensity around the table was greater than field strength around the metal tank. In Fig.20, field strength in left area was weak, wireless sensor network nodes should be specific deployment in the left area, in order to enhance indoor field intensity, reduce packet loss rate, ensure reliable data transmission.

Figure.21  $z = 0.7m$  $f=0.6GHZ$

![Figure.21](image)

Figure.22  $z = 0.7m$  $f=1.2GHZ$

According to Figure.21, it can be seen that the observation point height was above the table, and was below metal cabinet. wooden table was closer away from source, wooden table surface field strength was stronger, metal cabinet was far away from the source, metal cabinet interior field strength was almost zero, field intensity around the metal tank was weaker. Figure.22 and Figure.21 had shown that, the same source and the same height, the greater that frequency was,
and the greater that field strength was. Wooden table surface field strength was stronger, and field intensity in left area was weaker in Figure.22.

Figure.23  \[ z = 1.78m \quad f=0.6\text{GHz} \]

Figure.24  \[ z = 1.78m \quad f=1.2\text{GHz} \]

Figure.23 had shown that metal cabinet interior field intensity was zero, field intensity all round it was increased, due to it was far away source, enhancement effect was not very clear. Figure.23 and Figure.24 had shown that, the same source and the same height, the greater that frequency was, and the stronger that field strength was. Field intensity all round it was increased, due to it was far away source, enhancement effect was not very clear.
According to Figure.25 and Figure.26, it can be seen that because of observation point height was above the metal cabinets, field strength on the metal surface was increased, but it is not obvious. All in all, the location of the source varied from center to near the corner of the table, namely, P2. The closer that it was away from source, the stronger that field intensity was, the farther that it was away from source, the weaker that field strength was. Because of P2 was near the table, so when P2 was taken as field source, field strength in P3 was very weaker. The distributions of field strength in different frequency were as follows when source was located at P3.
Figure.27  \( z = 0.58m \)  \( f=0.6\text{GHz} \)

Figure.28  \( z = 0.58m \)  \( f=1.2\text{GHz} \)

Figure.27 and Figure.28 had shown that metal cabinet was closer away from source, but its internal field intensity was zero, and enhanced field effect was obvious round it. Table that was the furthest away from source, field strength was very weak. Field intensity of 1.2 GHz source frequency was generally stronger than that of 0.6 GHz, the range of field intensity was from 0 to \( 5 \times 10^{-3} \) in Figure.27, and the range of field intensity in Figure.28 was from 0 to 0.016.
Figure.29  \( z = 0.7m \  f=0.6GHZ \)

Figure.30  \( z = 0.7m \  f=1.2GHZ \)

Figure.29 had shown that observation point height was above the table, and was below metal cabinet. Wooden table was far away from source, and wooden table surface field strength enhancement effect was not obvious. Metal cabinets were closer away from source, metal cabinet interior field strength was almost zero, and field intensity around metal cabinet was more obvious. According to Figure.29 and Figure.30, it can be seen that the same source, the same height and the frequency, the greater that field intensity was, and the weaker that right area field was.
According to Figure.31 and Figure.32, it can be seen that observation point height was slightly lower than that of metal cabinet, metal cabinet interior field intensity was zero, but field intensity all round it was significantly enhanced, and field intensity in the bottom right area was weak. So when source was the same, height was the same and frequency was the same, the greater that field intensity was, and the weaker that field strength in the lower right area was.
As was shown in Figure.33 and Figure.34, when measurement point was higher than metal cabinet, field strength on the metal surface was significantly enhanced. Compared with Figure.25 and Figure.26, metal cabinet was closer away from source, field strength on the metal surface was more obvious, and field intensity in the lower right area was weaker.

All in all, according to the previous analysis, the correct analysis of indoor field intensity distribution can provide the basis for reasonable deployment of wireless sensor network nodes. In order to ensure that the electromagnetic wave signals can better receive in indoors, and field strength weak place was reasonable deployed wireless sensor network nodes, so as to ensure that
wireless sensor network data transmission in indoor environment was reliable, and reduce data packet loss.

IV. CONCLUSIONS

Based on the electromagnetic propagation theory, in this paper, three-dimensional FDTD method was introduced into indoor environment communication research, and distributions of indoor field strength were analyzed under the condition of different field source frequencies, different field source locations, presence of obstacles and distribution of different obstacles. So it can provide the basis for reasonable deployment of wireless sensor network nodes, reduce the packet loss rate of WSN information transmission, and provide theoretical basis for further improving WSN information transmission reliability.

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