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Research Article

Degree-Based Spectrum Management Scheme for CR Networks

[1]Liyan Sun and [1, 2]Jian-Zhou
[1]School of Management Science and Engineer, Anhui University of Finance and Economics,
[2]School of Computer and Communication Engineering, University of Science and Technology Beijing, Beijing, R.P. China

Abstract: This study proposes a novel scheme of spectrum management based on node degree. The spectrum resource is divided into multiple levels by the node degree, with which cognitive nodes select the suitable frequency from some spectrum layer. The nodes with greater degree can choose a frequency that closer to the predominant frequency. The supports of additional equipment and protocol redesign are not necessary for the rapid deployed applications by using this proposed scheme. Finally, the efficiency of proposed scheme is testified with experiments.

Keywords: Ad Hoc, cognitive radio, dominance frequency, node degree, spectrum management

INTRODUCTION

With the rapid development of radio communication service, the old way on using spectrum has severely constrained the wireless network technologies; it only allows the authorized users to use the spectrum resource. The way not only wastes spectrum resource, but also limits the flexibility of communication. However, the problem would be alleviate with the emergence of Cognitive Radio (CR) technology (Mitola, 2000; Akyildiza *et al*., 2006) which improves the utilization rate of spectrum resource, at time supports more flexible communication than traditional wireless network in different environments, different topologies and different tasks, those advantages make it a key technology of next generation network (Akyildiza *et al*., 2006). Cognitive users make use of the ability of cognitive engine to manage spectrum resource and enhance the performance of upper-layer protocols (Claudia and Kaushik, 2009). So various link protocols and routing protocols (Zhao *et al*., 2007; Su and Zhang, 2007; Qing and Huaibei, 2008; Chowdhury and Di Felice, 2009) is designed with joining with spectrum management, but those protocols fail in improving the performance of whole network in spectrum management. With the our proposed scheme Ad hoc cognitive radio network (Akyildiz *et al*., 2009) can manage spectrum resource efficiently and be suitable for complex applications flexibly and efficiently without extra equipment and redesigning protocol.

LITERATURE REVIEW

Currently there are three directions on spectrum management according to the emphasis of research, some schemes aim to reduce the interference for primary users, since we does not consider the emergence of primary uses, so the correlative research isn't be discussed; some schemes aim to reduce the interference and improve the utilization rate of spectrum among cognitive users, the literatures (Clancy *et al*., 2007; Tsagkaris *et al*., 2008; Ghasemi, 2008; Zhi-Jin *et al*., 2009) allow that node selects the suitable frequency independently to reduce the interference among cognitive nodes with collecting statistical to predict the state of frequency in the future or make use of artificial intelligence technology to reason the spectrum state; some schemes suggest frequencies are allocated by the support of additional equipment, such as cognitive users acquire the frequencies from GPS or base station, such as literatures (Ileri *et al*., 2005; Cabric *et al*., 2004; Noishiki *et al*., 2008); some schemes in literatures (Panlong and Guihai, 2008; Wang *et al*., 2009) discus cognitive users have ability and cache to compute the complex algorithm and save much data based on coloring graph; others schemes are put forward indirectly in designing the protocols about cognitive radio that are also called oriented-object scheme, such as literatures (Cheng *et al*., 2007; Ma *et al*., 2007). In a word, above schemes is not advantage in the rapid application for urgency surrounding.

MODEL

A CR networks can be mapped to an undirected connected graph $G(V,E)$. The number of path which goes through some node x is τx.When the occurrence probability of each path is ρ , the un-conflict time delay index is below:

Corresponding Author: Liyan Sun, School of Management Science and Engineer, Anhui University of Finance and Economics, Bengbu, R.P. China

$$\omega_x(G,\rho)=\sum_{i=1}^{|\tau_x|} p_i(|f_x-f_s|+|f_x-f_r|) \tag{1}$$

The un-conflict time delay index of whole network is below $(0 \le h_{ji}, h_{js}, h_{jr} \le H)$:

$$\omega(G,\rho)=\frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{|\tau_i|} p_{ij}(|f_{ji}-f_{js}|+|f_{ji}-f_{jr}|)$$

$$=\frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{|\tau_i|} p_{ij}\Delta h(|h_{ji}-h_{js}|+|h_{ji}-h_{jr}|) \tag{2}$$

In above formula, the parameters hji,hjs and hjr is random value from 1 to H, Δh is the bandwidth of frequency. When $|\tau_i|$ and ρ_{ij} are unchanged, more is the range of spectrum, more is the max value of un-conflict time delay. etc, when h_{ji} = H, h_{js} = h_{jr} = 1 or h_{ji} = 0 h_{js} = h_{jr} = H the max value in below:

$$Max(\omega(G,\rho))=\sum_{i=1}^{N}\sum_{j=1}^{\tau_{ix}} p_{ij}\Delta h(H-1) \tag{3}$$

The forwarding conflict index of node x is below:

$$\gamma_x(G,\rho)=\sum_{i=1}^{\tau_x} p_i(\frac{\prod_{j=0}^{d_x} C_H^1-\prod_{j=0}^{d_x} C_{H-j}^1}{\prod_{j=0}^{d_x} C_H^1}) \tag{4}$$

And the forwarding conflict index of whole network is below:

$$\gamma(G,\rho)=\sum_{i=1}^{N}\sum_{j=0}^{|\tau_i|} p_{ij}(\frac{\prod_{j=0}^{d_i} C_H^1-\prod_{j=0}^{d_i} C_{H-j}^1}{\prod_{j=0}^{d_i} C_H^1}) \tag{5}$$

The conflict time delay index of node x is below:

$$T_d=\sum_{i=0}^{|\tau_x|}\begin{pmatrix} p_i(|f_x-f_s|+|f_x-f_r|)(1-\gamma_x(1-\gamma_x)^{n-1} \\ -\gamma_x^2(1-\gamma_x)^{n-2}-\dots\dots-\gamma_x^{n-1}(1-\gamma_x)-(1-\gamma_x)^n)^{-1}\end{pmatrix}$$

$$=\sum_{i=0}^{|\tau_x|}(\frac{p_i(|f_x-f_s|+|f_x-f_r|)}{(\frac{1-\gamma_x^{n-1}}{1-\gamma_x})}) \tag{6}$$

And take the limit of T_d:

$$\lim_{n\to\infty} T_d=\sum_{i=0}^{|\tau_x|}(\frac{p_i(|f_x-f_s|+|f_x-f_r|)}{(\frac{\prod_{j=0}^{d_x}(C_{H-j}^1)}{\prod_{j=0}^{d_x}(C_H^1)})}) \tag{7}$$

And the range of T_d is given:

$$\lim_{n\to\infty} T_d \ge \sum_{i=0}^{|\tau_x|}(\frac{p_i(|f_x-f_s|+|f_x-f_r|)}{(1-\frac{1}{H})^d}) \quad \text{and} \tag{8}$$

$$\lim_{n\to\infty} T_d \le \sum_{i=0}^{|\tau_x|}(\frac{p_i(|f_x-f_s|+|f_x-f_r|)}{(1-\frac{d}{H})^d})$$

So there are two ways to improve the efficiency:

- Raise the number of frequency to reduce the confliction index
- Reduce the time delay of switching frequency

THE PROPOSED ALGORITHM

Few nodes have small degree or great degree if the degree distribution of network is the Poisson distribution; most of nodes are in the center of degree distribution. Some considerations are given below for designing the spectrum management scheme based on degree in view of degree distribution.

As the Fig. 1 shows, there are some characteristics about layering spectrum.

- The spectrum is divided into multi layers by node degree and each degree correspond to one layer, the maximal degree is correspond to the center layer l (d_{max}), the minimal degree is correspond to the edge layer l (d_{rmin}) and l (d_{lmin}), corresponding to the layer $l(d_{ri})$ and $l(d_{li})$ the degree whose value is di
- Each level is divided into two parts which are left interval and right interval except the layer of maximal degree has only one interval. They are symmetrical to the central axis [H +1)/2], the number of frequency in left interval is same to the right interval
- The amount of frequencies in each layer $l(d_i)$ is decided by the node degree distribution of network, as the fellow formula: $|l(d_i)|=H*F(d_i)$, the distribution range of each layer is below; the parameter H is the number of frequency and the function F(d) give the number of node whose degree is di. So the range of each layer is given below:

$$\begin{cases} [1,\left[F(d_{\min})H/2\right]]\cup[H-\left[F(d_{\min})H/2\right],H], d_l=d_{\min} \\ [\left[(H-F(d_{\max})H)/2\right],\left[(H+F(d_{\max})H)/2\right]], d_l=d_{\max} \\ [\left[(1-\sum_{j=\min}^{i-1}F(d_j))H/2\right],\left[(1-\sum_{j=\min}^{i}F(d_j))H/2\right]] \\ \cup[\left[(2-\sum_{j=\min}^{i}F(d_j))H/2\right],\left[(2-\sum_{j=\min}^{i-1}F(d_j))H/2\right]], d_l=d_i \end{cases} \tag{9}$$

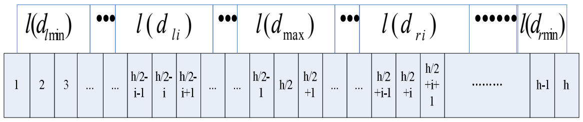


Fig. 1: Layer spectrum resource

$input: float\ F(d_{node_i}), \text{int}\ d_{\max}, \text{int}\ H$

$output: \text{int}\ f_{node_i},\ range_{il\max}, range_{il\min}$

$\quad range_{ir\max}, range_{ir\min}$

$1.\text{int}\ |l_{d_i}| = F(d_{node_i}) \times H;$

$2.\text{int}\ f_{node_i} = 0, \text{space} = 0;$

$3.IF((d_{node_i} != d_{\min})and(d_{node_i} != d_{\max}))\{$

$$range_{il\max} = [H \sum_{j=d_{\min}}^{d_{i-1}} F(d_j)/2];$$

$$range_{il\min} = [H \sum_{j=d_{\min}}^{d_i} F(d_j)/2];$$

$$range_{ir\max} = H - [H \sum_{j=d_{\min}}^{d_{i-1}} F(d_j)/2];$$

$$range_{ir\min} = H - [H \sum_{j=d_{\min}}^{d_i} F(d_j)/2];$$

$if(rand()\%2 == 1)\{$

$$\text{space} = [H \sum_{j=d_{\min}}^{d_{i-1}} F(d_j)/2];$$

$f_{node_i} = \text{space} + (rand()\%[|l_{d_i}|/2]);$

$\}else\{$

$$\text{space} = H - [H \sum_{j=d_{\min}}^{d_i} F(d_j)];$$

$f_{node_i} = \text{space} + (rand()\%[|l_{d_i}|/2]);\ \}$

$3.1\}elseif(d_{node_i} == d_{\max})\{$

$range_{il\max} = range_{ir\max} = [H(1 - F(d_{\max}))/2];$

$range_{il\min} = range_{ir\min} = [H(1 + F(d_{\max}))/2];$

$$\text{space} = [H \sum_{j=d_{\min}}^{d_{\max}-1} F(d_j)];$$

$f_{node_i} = \text{space} + (rand()\%|l_{d_i}|);$

$3.2\}elseif(d_{node_i} == d_{\min})\{$

$$range_{il\max} = \left[(2 - \sum_{j=\min}^{i} F(d_j))H/2\right];$$

$$range_{ir\max} = \left[(2 - \sum_{j=\min}^{i-1} F(d_j))H/2\right];$$

$$range_{il\min} = \left[(1 - \sum_{j=\min}^{i-1} F(d_j))H/2\right];$$

$$range_{ir\min} = \left[(2 - \sum_{j=\min}^{i} F(d_j))H/2\right];$$

$if(rand()\%2 == 1)\{$

$f_{node_i} = \text{space} + (rand()\%[|l_{d_i}|/2]);$

$\}else\{$

$f_{node_i} = H - (rand()\%[|l_{d_i}|/2]);$

$\}\}$

$4\ return\ f_{node_i}, range_{il\max}, range_{il\min}, range_{ir\max}, range_{ir\min}$

Fig. 2: Select frequency

$input: NE_i = \{node_j \mid distance(node_j, node_i) < radius\};$

$NF_i = \{f_j \mid\}; d(node_i); CF_i = \varnothing;$

$\forall node_j, node_j \in NE_i, node_j.f_j \in NF;$

$SF_i = \{f_k\}, \forall f_k \in SF_i, range_{il\min} \le f_k \le range_{il\max}$

$or\ range_{ir\min} \le f_k \le range_{ir\max}$

$output: f_i$

$1.label = false;$

$2.for(\forall node_j, node_j \in NE_i)\{$

$for(\forall f_j, f_j \in NF_i)\{$

$if(f_j == f_i)\{$

$label = true;$

$CF_i = CF + f_j;$

$\}\}\}$

$3.if(label == true)\{$

$select\ f_i\ from\ SF_i - CF_i;$

$\}$

$4.return\ f_i;$

Fig. 3: Avoid conflicting

In order to get the suitable frequency based on the scheme, each node in network carries out fellow three algorithms which include select-frequency and avoid-conflict.

The frequencies having different position in spectrum resource take on different dominance in transmission, so cognitive nodes should use the dominance frequency if they undertake more duty in network transmission.

The dominant frequency is that some frequency has less time delay and confliction than other frequencies with same strategy of selecting frequency. The spectrum resources are divided into a number of non-overlapping frequency band, each frequency band has same bandwidth. The frequencies whose take on dominance location spend less time delay in switching frequency, such as the cognitive node whose frequency location is middle in spectrum resource wastes less time from the frequency to another than nodes whose frequency location is in edge of spectrum resource. And this conclusion has been proved by the below formula. In the formula, the parameter p is the probability of switching from one frequent to another and all value of p is same; the parameter w is the minimal value of time delay; the parameter x is the frequency location in spectrum resource.

As the Fig. 2 shows, the function of algorithm selecting frequency helps node select suitable frequency with node degree. Firstly cognitive node computes the range of layer which corresponds to its degree and then node chooses the right interval or left interval of layer, finally node takes on some frequency at random which belong to the selected layer.

As the Fig. 3 shows, the function of algorithm avoid conflicting is to prevent cognitive nodes from

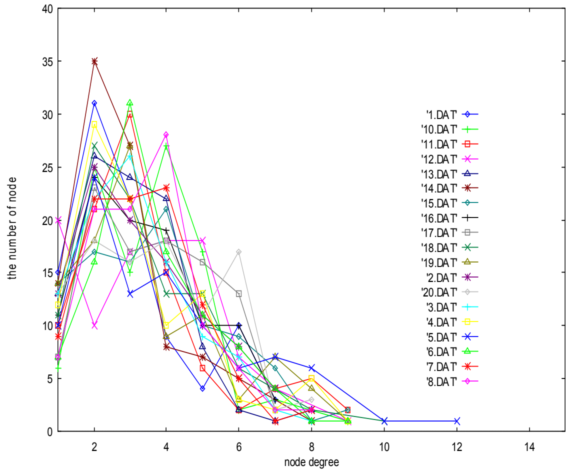


Fig. 4: The degree distribution

using same frequencies; those nodes are neighbor and happen to select same frequency.

EXPERIMENTS

In this section, we verified that the proposed scheme can reduce time delay and confliction in selecting spectrum. The parameters of experiment are fellows: the cognitive radio network is a connected graph, nodes are distributed in area whose width is100m and length is100 m, the number of nodes is100 in network, the transmission radius of node is10 m, the number of frequency is less than 500. The test data is got from the longest path which include node that has maximal degree. The degree distribution and scene of networks show as the Fig. 4.

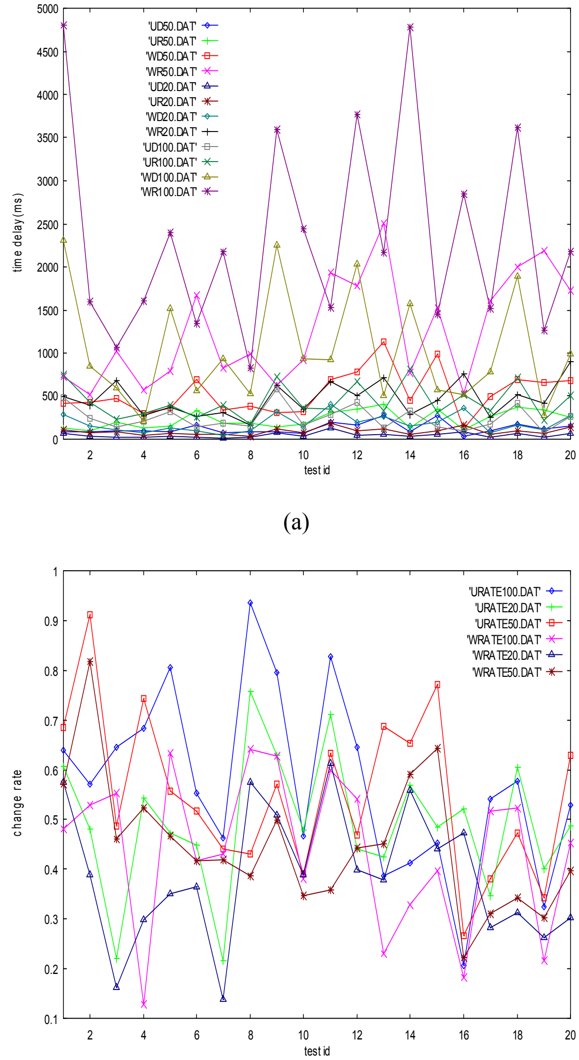
We also consider case that node have different impaction on forwarding data, in other words node have different weight in transmission. The Fig. 5, 6, 7 and 8 give the result of experiments with comparing the case that node has different weight with the case that node has same weight. The mean of alphabet and numbers in document name is same to former and "U" represents the test with same weight, "W" represents the test with different weight.

The data of figures is from below formulas. We also give the assumption that there is a linear relationship between node degree and forwarding data, so the weight of node is the node degree. The time delay of path is got by the formula

$$t_{time\_delay} = \sum_{i=1}^{l} w_{node_i} \times | f_{i-1} - f_i |$$

The average time delay is got by the formula:

$$\overline{t_{time\_delay}} = \sum_{20} t_{time\_delay} / 20$$



(a)

(b)

Fig. 5: The steady with different weight

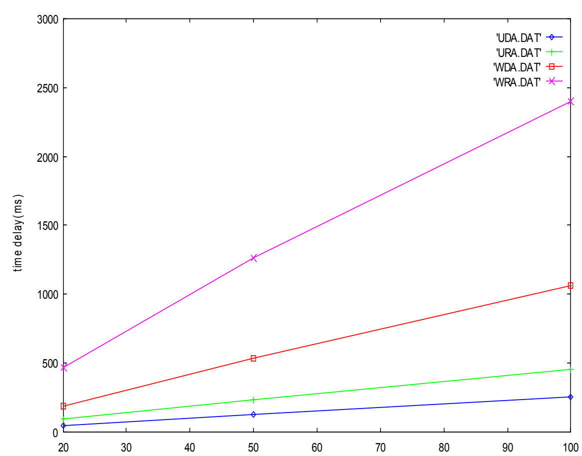


Fig. 6: The time delay

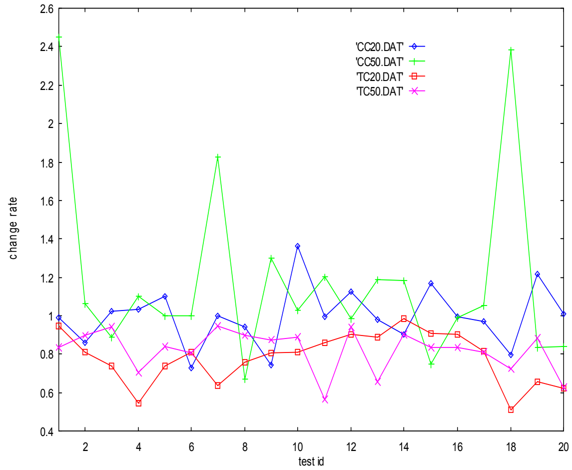
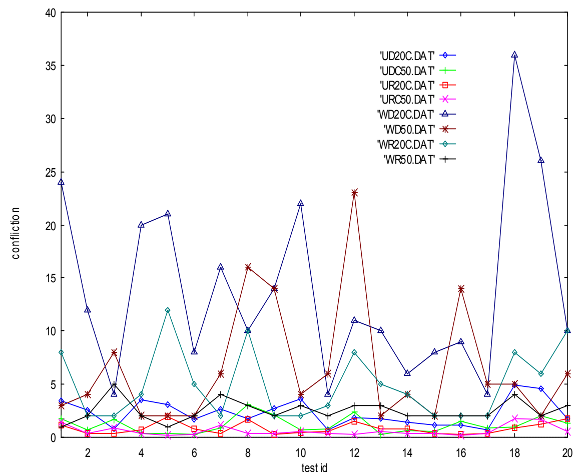
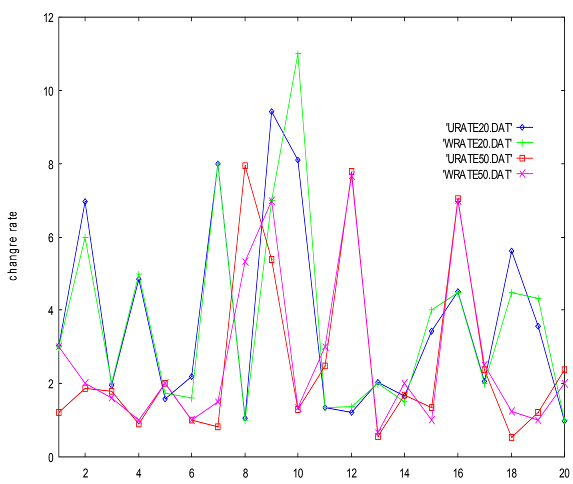


Fig. 7: The confliction



(a)



(b)

Fig. 8: Compare with the scene with same weight on confliction

The confliction is got by the formula

$$C = \sum_{i=1}^{l} \left(\frac{w_{node_i} c_i}{d(n_i)}\right)$$

and

$$w_{node_i} = d(node_i)$$

The performance of case that node has different weight is analyzed as fellows:

- Steady, from the Fig. 5 shows, reducing the time delay of node having more degree improve is necessary, as the amplitude range of scheme 1 is also great larger than the scheme based on degree in Fig. 5(a) and the gap between two scheme becomes larger than the case 1 with same weight in Fig. 5(b), such as the maximal rate is less than 0.7 between the case 2 and the scheme 1, but the maximal rate is more than 0.9 between the case1 and the scheme1.
- Time delay, from the Fig. 6 shows, the time delay of proposed scheme is less than the scheme 1 and its value is more than the case 1. So the result further prove node having more degree bring more time delay than the node having less degree.
- Confliction, the confliction is not increased as the Fig. 7 shows. And we also compare the confliction between the case 1 and case 2, they have almost same confliction, such as in Fig. 8 the curve of test "WRATE20" almost overlaps the curve of test "URATE20" and the same is to the curve of test "WRATE50" and the curve of "URATE50".

CONCLUSION

In this study, a novel spectrum management scheme based on degree is proposed, which can be applied to the rapid deploy application. In the proposed scheme, firstly the spectrum is divided into multiple layers with the degree distribution, secondly nodes select some suitable frequency from some layer, the algorithms of selecting suitable frequency is designed to improve the efficiency of selecting frequency and avoiding conflict. In view of nodes having more degree taken on dominance frequencies and they also forward much data in transmission, with this scheme the time delay of whole network could be reduced without adding the confliction. Finally the efficiency of scheme is verified by experiments. In the research, we found that the density of nodes also affects the efficiency of spectrum management, so the issue has become a target of our next research.

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