무선인지 애드 혹 네트워크를 위한 순차적 협력 스펙트럼 센싱 기법[☆]

An contention-aware ordered sequential collaborative spectrum sensing scheme for CRAHN

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요 약

최근 들어 무선인지 애드 혹 네트워크(CRAHN)는 임시적으로 활용되지 않은 라이선스 스펙트럼을 기회주의적 방법으로 사용하여 통신하는 차세대 애드 혹 네트워크로 각광받고 있다. 여타 무선인지 시스템에서와 같이, 정확한 스펙트럼 센싱은 무선인지 애드 혹 네트워크 구현을 위한 필수 요소 기술이다. 중앙 제어국 중심의 협력 스펙트럼 센싱 기법은 센싱 성능을 향상 시킬 수 있으나, 무선인지 애드 혹 네트워크와 같은 비인프라망에서는 중앙 제어국이 없어 협력 센싱 구현이 어렵다. 본 논문에서는 무선인지 애드 혹 네트워크를 위한 새로운 순차적 협력 스펙트럼 센싱 기법을 제안한다. 제안된 기법에서는 Dempster Shafer 이론 기반으로 국부 스펙트럼 센싱 데이터의 신뢰도가 가장 높은 인지 노드가 임시 중앙국이 되어 주변 센서 노드로부터 스펙트럼 센싱값을 수집하여 스펙트럼 사용 유무에 대한 최종 결정을 만들고 그 최종 결정을 이웃 노드들에게 전송한다. 또한 본 논문에서는 분산 방법으로 개별 인지 노드들이 자신의 센싱 데이터를 효율적으로 교환하기 위한, 센싱데이터 신뢰도 순서 기반의 전송 메커니즘을 제안하였다. 시뮬레이션을 통해 제안된 방식은 기존 중앙 제어국 중심의 협력 스펙트럼 센싱 기법과 유사한 스펙트럼 센싱 성능을 제공하는 동시에, 최종 스펙트럼 결정 까지 소요되는 센싱 데이터 수집 시간 및 교환되는 센싱 데이터 량을 현저히 줄일 수 있음을 보였다.

ABSTRACT

Cognitive Radio (CR) ad hoc network is highly considered as one of promising future ad hoc networks, which enables opportunistic access to under-utilized licensed spectrum. Similarly to other CR networks, the spectrum sensing is a prerequisite in CR ad hoc network. Collaborative spectrum sensing can help increasing sensing performance. For such an infrastructureless network, however the coordination for the sensing collaboration is really complicated due to the lack of a central controller. In this paper, we propose a novel collaborative spectrum sensing scheme in which the final decision is made by the node with the highest data reliability based on a sequential Dempster Shafer theory. The collaboration of sensing data is also executed by the proposed contention-aware reporting mechanism which utilizes the sensing data reliability order for broadcasting spectrum sensing result. The proposed method reduces the collecting time and the overhead of the control channel due to the efficiency of the ordered sequential combination while keeping the same sensing performance in comparison with the conventional cooperative centralized spectrum sensing scheme.

☞ keyword : Cognitive radio(인지 무선), spectrum sensing(스펙트럼 센싱), collaborative spectrum sensing(협력 스펙트럼 센싱), sequential fusion(순차적 융합), Dempster Shafer theory of evidence(Dempster Shafer 증거 이론)

1. INTRODUCTION

In recent year, Cognitive Radio (CR) which enables opportunistic access to underutilized licensed spectrum

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This version is improved considerably from the previous version by including new results and features.

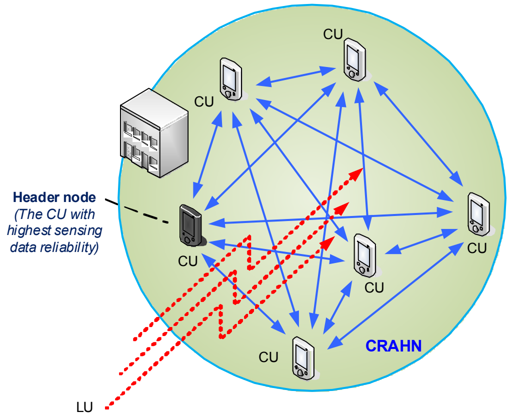
band has been considered as a promising technology. Spectrum sensing (SS) plays an essential role in CR. In order to overcome the hidden node problem in which a single sensing node cannot distinguish between an idle or a deep fade band, the cooperative [1], [2], [3] and collaborative [4] SS scheme has been considered.

A data fusion scheme for CR network based on Dempster-Shafer theory of evidence (D-S theory) was first proposed in [1] and enhanced in [2] to obtain a very high gain of combination. However, the main drawback of this method is the time and bandwidth requirement for reporting sensing data which will be extremely large when the number of CR users (CUs) increases. Ref. [3] proposes a sequential test for cooperative SS to mitigate this problem. However, the scheme does not utilize an ordered sequential test for a faster detection.

For the case of CR ad hoc network (CRAHN), due to the lack of central controller, each CU is responsible for determining its actions based on its local observation. Since the CU cannot predict the influence of its actions on the entire network only with its local observation, collaborative spectrum sensing schemes are essential [5].

In this paper, we propose a novel collaborative spectrum sensing scheme in which the final decision is made by the node with the highest data reliability based on a sequential Dempster Shafer theory. The collaboration of sensing data is also executed by the proposed contention-aware reporting mechanism which utilizes the sensing data reliability order for broadcasting spectrum sensing result.

The rest of the paper is organized as follows. Section 2 describes the system model. Section 3 introduces the proposed contention-aware reporting mechanism. Section 4 develops the proposed D-S theory and reliability broadcasting based collaborative SS scheme for CRAHN. Section 5 shows the simulation results. Finally, section 6 concludes the paper.



(Fig. 1) System model.

2. SYSTEM DESCRIPTION

We consider a single-hop CRAHN with a dedicated common control channel and multiple CUs sharing the same frequency band with a licensed system as shown in Fig. 1. In order to increase the reliability of the licensed user (LU) protection, the CUs, after sensing the spectrum band, exchange their SS information each other. Therefore, the collaborative SS model which does not require a central controller will be adopted into our CRAHN. As a result, the whole process of SS includes two phase: the individual SS phase and the collaborative phase.

The individual SS for detecting the LU's signal is essentially a binary hypotheses testing problem as follows:

$$x(t)=\begin{cases} n(t) & :H_0 \\ h(t)s(t)+n(t) & :H_1 \end{cases} \qquad (1)$$

where H_0 and H_1 are correspondent to hypotheses of the absence and presence of the LU's signal, respectively; $x(t)$ represents the received data at CU, *h(t)* denotes the channel gain, *s(t)* is the LU's signal and *n(t)* is the AWGN noise.

The individual SS on CUs will be conducted based on energy detection method due to its simple, quick and admirable performance. The output of energy detector at each CU is the received signal power which is given by following equation:

$$x_E = \sum_{j=1}^{N} \left| x_j \right|^2 \tag{2}$$

where x_j is the j-th sample of received signal and $N = 2TW$; T and W are the detection time and signal bandwidth, respectively. Due to Central limit theorem, when N is relatively large (e.g. N > 200), x_E can be well approximated as a Gaussian random variable under both hypotheses as follows [6]:

$$\begin{cases} H_0 : x_E \sim \mathrm{N}\left(\mu_0 = N, \sigma_0^2 = 2N\right) \\ H_1 : x_E \sim \mathrm{N}\left(\mu_1 = N(\gamma+1), \sigma_1^2 = 2N(2\gamma+1)\right) \end{cases}$$

where{ μ_0, μ_1} and $\{\sigma_0^2, \sigma_1^2\}$ are means and variances, respectively and is the SNR of LU's signal at CU.

Besides non-fading AWGN environment as mentioned above, the scenarios where the LU signal endures the fading channels [7]-[9] - Rayleigh fading and shadow fading - are also considered as follows.

- *Rayleigh fading*: When a signal experiences a Non-Line-of-Sight multipath channel, the LU signal's SNR at the CU follows an exponential distribution [7] whose *pdf* is given by

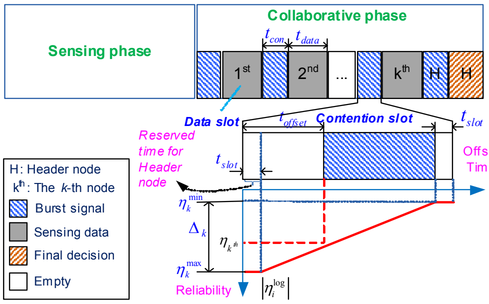
$$f_\gamma(\gamma) = 1/\bar{\gamma} \exp\left(-\gamma/\bar{\gamma}\right), \quad \gamma > 0 \tag{4}$$

where $\bar{\gamma}$ is a mean SNR value.

- *Shadow fading*: Empirical measurements show that the attenuation due to shadowing on a log scale follows a zero mean Gaussian distribution [10]. Subsequently, the LU signal's SNR at the CU under the shadow fading follows a Log-normal distribution whose *pdf* is given by

$$f_\gamma(\gamma) = \frac{10}{\sqrt{2\pi}\sigma_\gamma \ln(10)\gamma} \exp\left(-\frac{10\log_{10}\gamma - \mu_\gamma}{2\sigma_\gamma^2}\right) \tag{5}$$

where μ_γ and σ_γ is the mean and standard deviation value of the primary signal's SNR in decibels, respectively.



(Fig. 2) Contention-aware reporting mechanism.

3. THE PROPOSED CONTENTION-AWARE REPORTING MECHANISM

We propose a contention-aware reporting mechanism for collaborative spectrum sensing scheme based on the order of sensing data reliability, as shown in Fig. 2. The scheme is operated based on the sensing data's reliability which can be interpreted as the contribution level to the final decision. The main idea is that the node with the higher current sensing data's reliability will broadcast the sensing data to other CUs earlier. Instead of locally making the final decision, we propose that the node with the highest sensing data reliability, which is free after broadcasting its sensing data, will become the header node and made a final decision.

In this method, each CU will self-determine an offset time which is dependent on the reliability value of its current sensing data. This offset time is used for competing the transmission turn with other nodes in the next data time slot. Therefore, the node should have a contention-aware based on its sensing data reliability before reporting. The period of the node's contention is defined as a contention slots which is performed before every data slot. In the k-th contention slot, the value of the offset time t_{offset} is calculated as follows:

$$t_{offset} = \frac{t_{con} - 2t_{slot}}{\left(\eta_k^{\max} - \eta_k^{\min}\right)}\left(\eta_k^{\max} - \eta_k^{log}\right) + t_{slot} \tag{3}$$

where t_{con} is the length of the contention slot, t_{slot} is the slot time corresponding to the time required by the radio layer for functioning the carrier sensing. $\eta_k^{\max}$ and $\eta_k^{\min}$ are the maximum and minimum value of the data sensing reliability at the k-th contention slot, respectively.

The values of $\eta_k^{\max}$, $\eta_k^{\min}$ and $\Delta_k = \eta_k^{\max} - \eta_k^{\min}$ are firstly defined by the header node of previous sensing time, and then are automatically updated at each CU after every data slot as follows:

- If the (k - 1)-th contention slot is empty then

$$\begin{cases} \eta_k^{\max} = \eta_{k-1}^{\min} \\ \Delta_k = \Delta_{k-1} + \theta \end{cases} \tag{4}$$

where θ is the step of reliability range which is defined by the previous header node.

- If a node successfully reports in the (k - 1)-th contention slot then

$$\begin{cases} \eta_k^{\max} = \eta_{(k-1)}^{log} \\ \Delta_k = \Delta_{k-1}. \end{cases} \tag{5}$$

- If the (k - 1)-th data slot is collided then

$$\begin{cases} \eta_k^{\max} = \eta_{k-1}^{\max} \\ \Delta_k = \Delta_{k-1} - \theta. \end{cases} \tag{6}$$

At the beginning of the contention slot, the CU node will listen to the control channel. If there is no signal until the CU's offset time t_{offset} it is supposed that the CU wins the contention slot and generates its own burst signal to make a reservation for the next sensing data slot. In addition, it is worth noting that the offset time is in the range of $t_{slot} < t_{offset} < t_{con} - t_{slot}$. The first t_{slot} period is reserved for the higher priority for transmission of the current header node. Whenever the header node can make a final decision it will generate the burst signal in all the length of contention slot for obtaining the reservation to transmit the final decision in the next reporting slot.

4. THE COLLABORATIVE SPECTRUM SENSING SCHEME BASED ON ORDERED SEQUENTIAL D-S THEORY COMBINATION

After sensing time, each CU will estimate the basic probability assignment (BPA) which is defined as a form of the cumulative density function [2] as follows:

$$m_i\left(H_0\right) = \int_{x_{E_i}}^{+\infty} \frac{1}{\sqrt{2\pi}\sigma_{0i}} \exp\left(-\frac{\left(x - \mu_{0i}\right)^2}{2\sigma_{0i}^2}\right) dx \tag{7}$$

$$m_i\left(H_1\right) = \int_{-\infty}^{x_{E_i}} \frac{1}{\sqrt{2\pi}\sigma_{1i}} \exp\left(-\frac{\left(x - \mu_{1i}\right)^2}{2\sigma_{1i}^2}\right) dx \tag{8}$$

$$m_i(\Omega) = 1 - m_i\left(H_1\right) - m_i\left(H_0\right) \tag{9}$$

where $\{\mu_{0i}, \mu_{1i}\}$ and $\{\sigma_{0i}, \sigma_{1i}\}$ are means and variances of x_E under H_0 and H_1, respectively and denotes the case that either hypotheses is true. Two of the set $\{m_i(H_0),\ m_i(H_1),\ m_i(\Omega)\}$ are broadcasted.

For broadcasting the sensing result in the sequence of the data reliability, the *i*-th CU will make its self-assessed credibility ratio which is defined by:

$$\eta_i^{\log} = \left|\log\left(m_i\left(H_1\right)/m_i\left(H_0\right)\right)\right|. \tag{10}$$

Through the mechanism described in previous section, the sensing data can be broadcasted in the descending sequence of its reliability. At the header node the broadcasted BPA is immediately combined in the sequence as follows:

$$m_{combined}^{k}\left(H_j\right) = m_{combined}^{k-1} \oplus m_k\left(H_j\right) \tag{11}$$

where j = 0,1; k = 1 ,..., M; $m_{combined}^{k-1}\left(H_j\right)$ and $m_{combined}^{k}\left(H_j\right)$ are the *(k-1)*-th and *k*-th combined BPA of hypothesis H_j, M is the total number of CUs in the network and the combination operator $\oplus$ is defined based on D-S theory as follows:

$$\begin{aligned} & m_a \oplus m_b\left(H_j\right) = \\ & \frac{m_a\left(H_j\right)m_b(\Omega) + m_a\left(H_j\right)m_b\left(H_j\right) + m_a(\Omega)m_b\left(H_j\right)}{1-\left[m_a\left(H_j\right)m_b\left(H_{1-j}\right) + m_a\left(H_{1-j}\right)m_b\left(H_j\right)\right]} \end{aligned} \tag{12}$$

where a and b denotes the two arbitrary combining sources.

Finally, the sequential fusion strategy is as follows:

■ If k < M then

$$D_{final} = \begin{cases} H_1 & \text{if } \eta_{combined}^{k} > \delta \\ \text{no decision} & \text{if } -\delta < \eta_{combined}^{k} < \delta \\ H_0 & \text{if } \eta_{combined}^{k} < -\delta \end{cases} \tag{13}$$

where D_{final} denotes the final decision, δ is the decision threshold, and $-\delta < \eta_{combined}^{k} < \delta$ is global decision credibility ratio at the *k*-th report which is given by:

$$\eta_{combined}^{k} = \log\left(\frac{m_{combined}^{k}\left(H_1\right)}{m_{combined}^{k}\left(H_0\right)}\right). \tag{14}$$

In the case that $-\delta < \eta_{combined}^{k} < \delta$, the node with highest sensing data reliability will wait for the next broadcasting sensing data from another node.

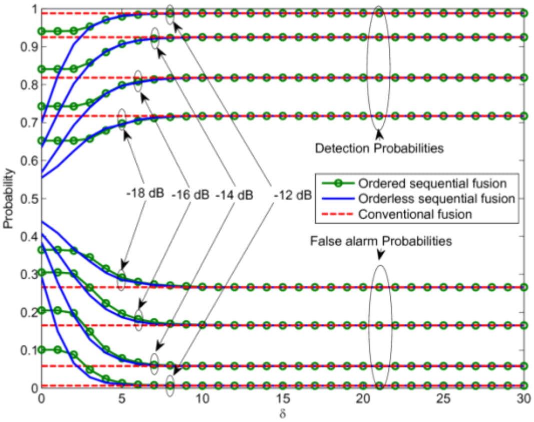
■ If k = M then

$$D_{final} = \begin{cases} H_1 & \text{if } \eta_{combined}^{k} > 0 \\ H_0 & \text{if } \eta_{combined}^{k} < 0\,. \end{cases} \tag{15}$$

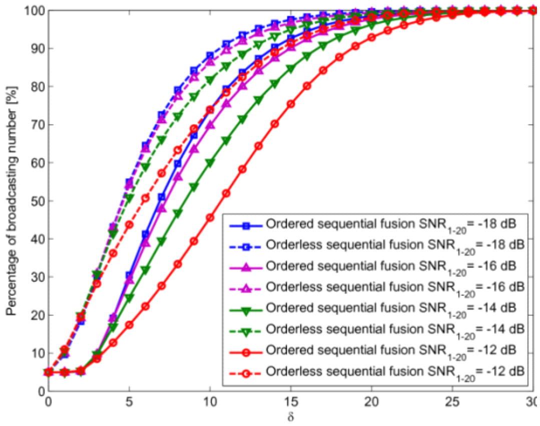
5. SIMULATION RESULTS

For simulation, we assume that the LU signal is DTV signal whose bandwidth is 6 MHz. 20 sensing nodes which receive the same LU signal's SNR are considered in the network. The local sensing time is 50 µs.

In the simulation, beside the proposed DS-theory based ordered sequential fusion schemes, we also consider the DS-theory based conventional (i.e., without sequential) and orderless sequential data fusion scheme under different situations of SNR. Fig. 3 shows the relation between threshold and the global detection and false alarm probabilities As shown in Fig. 3, it is obvious that the sensing performances (i.e., P_d and P_f) of both the orderless and ordered sequential fusion schemes are converged to the conventional case if the threshold value is large enough (i.e., $\delta \geq 8$). In addition, Fig. 4 shows the relation between threshold δ and average reporting number of nodes. As shown in Fig. 4, the proposed ordered sequential fusion can reduce the percentage of



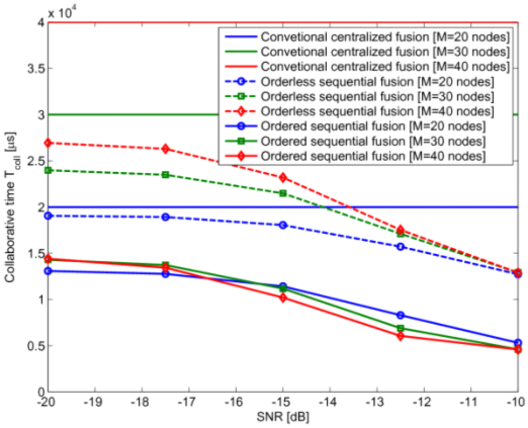
(Fig. 3) The probabilities of detection and false alarm vs. the threshold value of sequential fusion under difference SNR scenarios.



(Fig. 4) The average of node report number vs. the threshold value of sequential fusion under difference SNR scenarios.

broadcasting numbers compared with the orderless case. This means that the proposed scheme reduce the communication overhead for collaborating sensing data in CRAHN.

For a further evaluation, the proposed scheme is simulated with multiple values of LU signal's SNR and network node while keeping the same threshold $\delta = 8$ for ensuring the convergence of sensing performance. The CR network is assumed to use the some parameters similar to the IEEE 802.11 standard where t_{slot} is equal to 20s. The results are illustrated in Fig. 5 where the orderless sequential fusion is assumed to use the centralized polling method and the conventional non-sequential fusion scheme is assumed to use a fixed predefined slot model. The total collecting time is calculated as follows:



(Fig. 5) The collaborative time vs. SNR under difference number of nodes with $\delta = 8$.

- Conventional fusion case:

$$T_{coll} = M \times t_{data} \tag{16}$$

where t_{data} is the timeslot length for transmitting sensing data. It is assumed to be equal to $50 \times t_{slot}$ in this simulation.

- Orderless sequential fusion case:

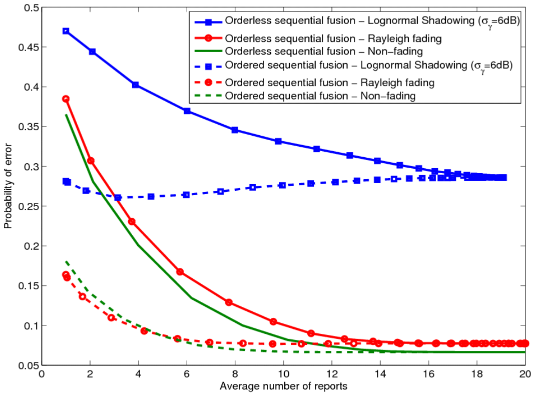
$$T_{coll} = M \times P_{orderless} \times (t_{data} + t_{poll}) \tag{17}$$

where t_{poll} is the polling time and is assumed to be $10 \times t_{slot}$ and $P_{orderless}$ is the percentage of broadcasting number of the orderless sequential fusion scheme.

Ordered fusion case:

$$T_{coll} = M \times P_{ordered} \times (t_{data} + t_{con}) \tag{18}$$

where $P_{ordered}$ is the percentage of broadcasting



(Fig. 6) The probability of error vs. the average number of report under difference fading environments with M=20 nodes and the average LU signal's SNR= -14dB.

number of the proposed ordered sequential fusion scheme.

As shown in Fig. 5, the proposed ordered sensing data reliability collaborative mechanism outperforms both the orderless sequential fusion scheme and the conventional non-sequential fusion scheme.

For giving a more practical view, the simulation is lastly conducted with a 20 CUs network which receives the average LU signal's SNR at each CU of -14dB and endures the non-fading, the Rayleigh fading and the Log normal shadowing with $\sigma_\gamma = 6dB$ environments. The performances of the proposed ordered and the orderless sequential fusion schemes are evaluated in term of the probability of sensing error. As shown in the Fig. 6, there are small and large performance gaps of the converged sensing errors for the both considered schemes when the environment is suffered from the Rayleigh fading and the Log normal shadowing, respectively. However, the sensing errors of the proposed scheme at a low value of average reporting numbers are even lower than those of the non-fading case. This shows the effectiveness of the contention-aware reporting mechanism. Further, the error probabilities of the proposed ordered sequential fusion scheme are always less than or equal to those of the orderless case for the same average reporting number under any fading environment. In addition, the error probabilities of the both schemes are converged to an identical value when the average number of reporting is large. However, the minimum value of average reporting number for sensing error convergence of the proposed ordered sequential fusion scheme is lower than that of the orderless case, i.e., 8 vs. 14 for non-fading, 7 vs. 14 for Rayleigh fading and 14 vs. 18 for Log normal shadowing. These mean that for a specific value of the error probability, the proposed collaborative SS scheme always requires a lower reporting number in any fading environment.

6. CONCLUSIONS

In the paper, a D-S theory and contention-aware reporting mechanism based collaborative SS scheme for CRAHN has been proposed. The proposed scheme reduces collaborative time and the overhead of control channel while keeping the same sensing performance compared with the conventional cooperative centralized SS scheme.

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