Cooperative detection of moving target in wireless sensor network based on Adaptive Learning Decision Fusion

Yee Ming Chen and Chi-Li Tsai

Abstract**—**Detection of a target occurrence is one of the main tasks of wireless sensor network in many applications. This paper has proposed a novel method of decision fusion based on simple reinforcement learning using the past experience for cooperative target detection. Simulations show that the proposed adaptive learning algorithm for fusion of weighted decisions could improve the detect probability effectively against 'OR', 'AND' and 'K-out-of-N' fusion rules. Monte Carlo Simulation results also show that proposed method achieves both better target detection and lower detection miss performance.

Keywords—Energy detector; Decision fusion; Spectrum sensing

I. Introduction

DISTRIBUTED target detection in wireless sensor network(WSN) is the process of observing and evaluating an event using multiple sensor nodes using cooperative detection mechanism mainly includes centralized control, distributed and relay mode three kinds of approaches [1]. Current approaches to target detection in sensor node of WSN transmit raw data to an external target for evaluation or rely on simplistic pattern recognition schemes. This implies either high communication overhead or low target detection accuracy, especially for complex multiple targets. Therefore, this paper adopts the centralized control approach due to low communication overhead. In the centralized control approach, every node distributed in the different position detects the target signal independently, and the detection result is transmitted to the fusion node. The fusion techniques are further classified as data fusion and decision fusion techniques [2]. In data fusion techniques, all the sensor nodes share their detected raw information like detected energy or other statistical information while in decision fusion technique all the sensor nodes take their local decisions and generally share the decision by sending '0' or '1' corresponding to absence and presence of target's signal respectively. The conventional decision fusion rules generally used at fusion node are AND, OR and K-out-of-N rules. For decision fusion rule, the fusion node makes final decision according to the number of sensor nodes claiming the presence of the target's signal. In conventional decision fusion rules, all the sensor nodes are assumed to the same average SNR. However, this assumption is unrealistic. That in practical, the collaborative sensor nodes are likely to experience the different fading due to their variable environments [3]. Consequently, average SNR must be different from node to node. We assume that each collaborative node has different average SNR denoted by $w_i = \frac{SNR_i}{\sum_{i=1}^{n} SNR_i}$. Censored sensor node's weight factor can be measured by dividing SNR value of that censored sensor node with the sum of SNRs of remaining censored sensor node. The weight factor of a censored each sensor node is measured at fusion node using SNR value of that censored sensor node and SNR values of other censored sensor nodes. The concept of 'weight' in this paper is a number assigned to a resource, and the number reflects the importance of the resource to a certain sensor node. Therefore, WSN's nodes select spectrum resources to use based on the weights assigned to the spectral resources. Resources with higher weights are considered higher priority.

Reinforcement learning is a computational approach of learning used to maximize some notion of long-term reward. Moreover, this learning process does not require training examples when any prior information about the signal is not available [4].

In this paper, a novel method of decision fusion by simple reinforcement learning is proposed in which the sensors' decisions are weighted based on their estimated signal-to-noise ratios (SNR) and the fusion threshold is not necessarily fixed. The method called adaptive learning algorithm for fusion of weighted decisions. In each round, weight depends on the presence /absence of the target in previous round. In other words, it can be said that the presence /absence of the target signal can be detected by the weights in each round. Two modules are included in the framework. In the first module, the signal is transmitted to sensor node which individually energy detector performs spectrum sensing and provide binary decision. In the second module, instead of just providing the

This work was supported This research work was sponsored by the Ministry of Science and Technology, R.O.C., under project number MOST 106-2221-E-155-028.

Yee Ming Chen is with the Department of Industrial Engineering and Management, Yuan Ze University, Taiwan, R.O.C. (Tel: 886-3-4638800 ext 2515; Fax: 886-3-4638907; e-mail: chenyeeming@saturn.yzu.edu.tw).

Chi-Li Tsai is with the Department of Industrial Engineering and Management, Yuan Ze University, Taiwan, R.O.C. (e-mail: fenikace@yahoo.com.tw).

binary decision the sum of products of weights with detection information is sent to the fusion node which helps is making final decision. The best aspect of proposed research is that in each round, value of weight is increased /decreased depending on the presence/absence of the binary decision at each sensor node in the previous round. In each round with update in weight, the probability of detection also changes which enables efficient usage of spectrum by exploiting sensor nodes' past experience.

II. Decision Fusion Approaches

For decision fusion rule, the fusion node makes final decision according to the number of sensor nodes claiming the presence of the target's signal. Let L denote the number of sensor nodes claiming the presence of target signal. In fusion node, F, the final decision is given by

$$F = \begin{cases} H_0 & \text{if } L < K \\ H_1 & \text{if } L \geq K \end{cases} \quad (1)$$

where K = 1, K = N and 1< K < N are corresponding to OR rule, AND rule and K-out-of-N rule respectively [6].

(1) OR rule:

Like in logical OR operation, the target exists if there is one or more sensor nodes detecting the presence of target signal. We assume that there are N sensor nodes, the detection probability P_d and the false alarm probability P_f in the "OR" rule can be expressed as

$$P_d = \sum_{k=1}^{N} \binom{N}{k} P_d^k (1 - P_d)^{N-k} \quad (2)$$

$$P_f = \sum_{k=1}^{N} \binom{N}{k} P_f^k (1 - P_f)^{N-k} \quad (3)$$

(2) AND rule

The target exists if all the sensor nodes detect the presence of target signal. The probability of detection and false alarm detection for AND rule is given as:

$$P_d = P_d^N \quad (4)$$

$$P_f = P_f^N \quad (5)$$

(3) K-out-of-N rule

The fusion node declares presence of the target's signal if at least K out of N sensor nodes report presence of the signal. The probability of detection and false alarm detection for K-out-of-N rule are given as:

$$P_d = \sum_{k=K}^{N} \binom{N}{k} P_d^k (1 - P_d)^{N-k} \quad (6)$$

$$P_f = \sum_{k=K}^{N} \binom{N}{k} P_f^k (1 - P_f)^{N-k} \quad (7)$$

III. Fusion of Weighted Decisions

This section deals with the idea of fusion of weighted decisions in Section I. Basic steps carried to decision fusion in cooperative fashion are described as follows:

(1) The signal from the target is transmitted through the channel to N number of sensor nodes. The channel considered is a Rayleigh fading channel [7] and noise is AWGN noise.

(2) At each sensor node, spectrum sensing is performed individually using an energy detector.

(3) Now, the sum of the product of weight with the result of individual detection at each individual sensor node is forwarded to the fusion node.

(4) The fusion node applies proposed adaptive learning algorithm or some conventional fusion rule and thus provides the final result about the presence/absence of the signal.

The basic flow chart that shows how the whole process of spectrum sensing is carried out is shown in Figure. 1.

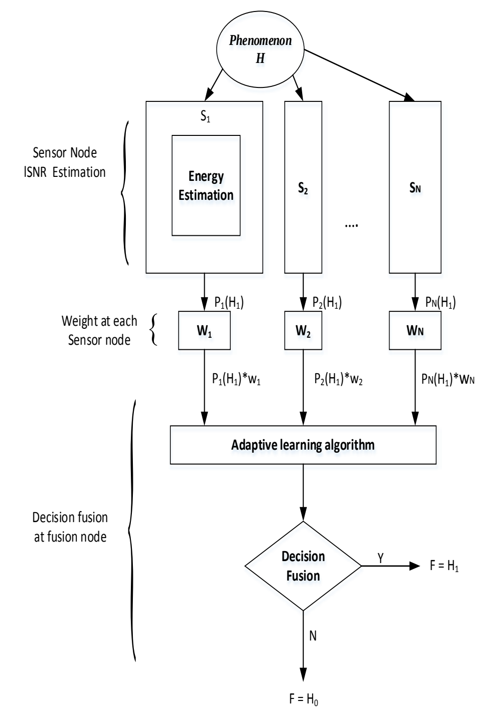


Fig. 1. Adaptive learning algorithm flow chart

(1) Weight Initialization

Initially, weights are assigned to each sensor node depending on different conditions to view which sensor node is performing better. A much practical way of weight initialization is depending on SNR. Lower the value of SNR better is the performance and so higher is the value of weight for such sensor node.

$$w_i(1) = \frac{SNR_i}{\sum_{i=1}^{n} SNR_i} \quad (8)$$

where SNR_i is signal to noise ratio at i-*th* sensor node.

(2) Weight assignment in succeeding rounds

In this paper, it is considered that weight was updated at each sensor node in each round. Weight assigned to each individual sensor node depends upon the spectrum sensing result of each individual sensor node of previous round.

$$w_i(k+1) = \begin{cases} w_i(k) + \Delta w, & d_i = 1 \\ w_i(k) - \Delta w, & d_i = 0 \end{cases} \quad (9)$$

where d_i sensor node decision at i*th* sensor node about the presence/absence of the target signal.

$$P_d = 1 - \prod_{i=1}^{n} w_i(k) \times [1 - P_{d,i}(k)] \quad (10)$$

The reason to update weights and in this way is to increase the weight of the i-*th* node gradually when it has much contribution to the final decision. On the other hand, if a user experiences deep fading, with lower SNR, its weight should be decreased to reduce the influence on the final collaborative decision.

IV. Simulation Results and Analysis

We consider N sensor nodes random deployed in a region of interest (ROI) as shown in Figure. 2. WSN operate in distributed cooperative manner; that divide population into groups, each of group which select the node with the best reporting channel gain as a fusion node. The candidate fusion node then computes the final decision (according to (1)), from the outputs of the sensor node within their ROI.

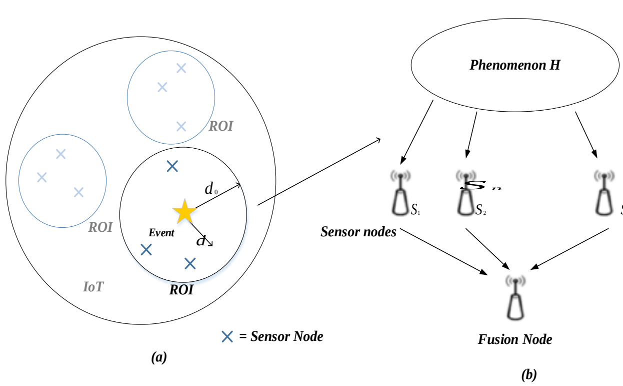


Fig. 2. Cooperative target detection over WSN

From Figure 2(b) scenario, Mont Carlo simulation results are presented based on the proposed fusion of weighted decisions scheme , and some conventional decision fusion rules such as OR, AND, and K-out-of-N. The Mont Carlo simulation model is developed using MATLAB.

We consider a group of N = 5 sensor nodes that cooperate together to sense target. We assume that the received signal to noise ratios (SNR) for each SU is different. Spectrum sensing is performed using energy detection technique, where decision thresholds are all set identical for each sensor node. Sensing performance at each sensor node is evaluated by the probability of detection corresponding to hypothesis H_1 and the probability of false alarm corresponding to H_0. These performances depend on the SNR determined at each sensor node. We have chosen N = 5 sensor nodes with SNR= -10 dB for sensor node 1 ~3 and SNR=-20 dB for sensor node 4, respectively. Sensor node 5 assigned as the fusion node. The channel between sensor nodes and fusion node is assumed to be Additive White Gaussian Noise (AWGN) channel. In this simulation, we evaluate the proposed adaptive learning algorithm in terms of convergence rapidity and correct weights estimation. In Figure 3, the update weights of 5 samples of sensor nodes are given in Figure 2(a). Obviously, we can see that the weights of high SNR (sensor node 1 ~3), during the number of time slot, are increased and the weights of low SNR (sensor node 4) is decreased. It could be seen that the weights of sensor nodes with high SNR are not same, because they encounter different fading channel during time slots.

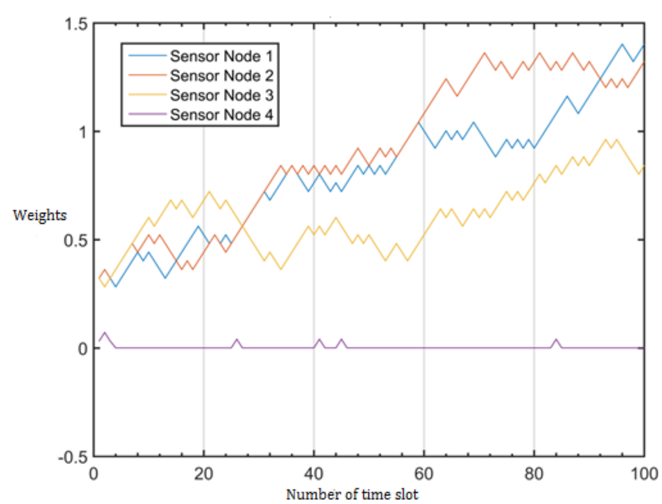
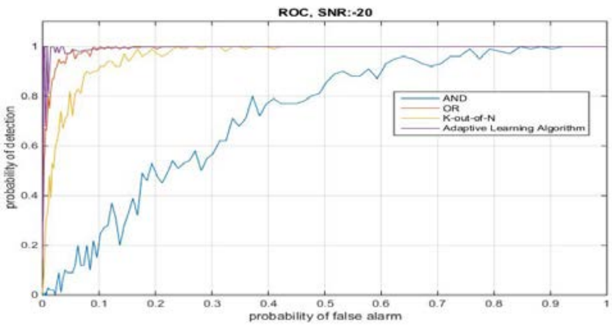
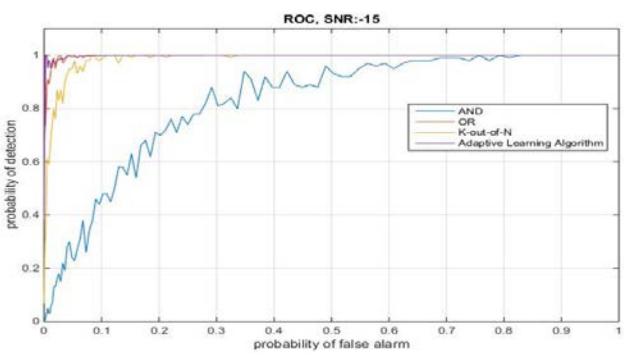


Fig. 3. Update weight of four sample of sensor nodes

Furthermore, fusion of weighted decisions schemes for cooperative event detection the effect on the performance of the proposed adaptive learning algorithm. In distributed detection, some conventional fusion algorithms such as OR, AND, and K-out-of-N rules were simply combining hard local decisions sent from sensor nodes does not appear to be optimal when the sensors are localized in different environment conditions. In the following results, the performance of the various decision fusion methods is obtained from Monte Carlo simulations. Figure 4 shows the simulation receiver operating characteristic (ROC) curves for comparison of proposed adaptive learning algorithm for fusion of weighted decisions with OR, AND, and K-out-of-N fusion rules, respectively.



(a) Low SNR

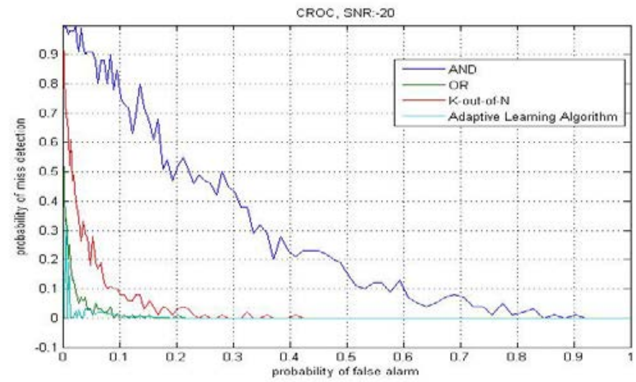


(b) High SNR

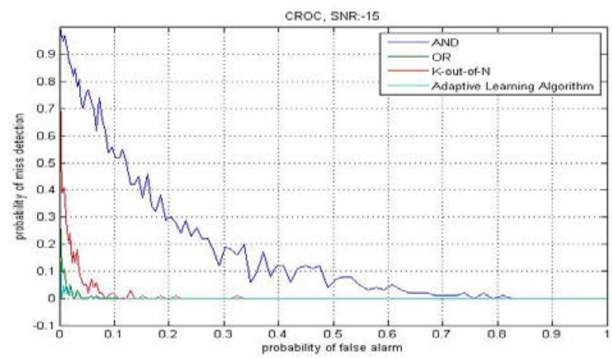
Fig. 4. Comparative analysis of ROC

We can observe the detection performance in these figures (Fig. 4) that proposed adaptive learning algorithm outperformed by conventional decision fusion rules under SNR=-20 dB, or -15 dB. For adaptive learning algorithm, the probability of detection of fusion node increases rapidly from $P_d = 0$ to 1 between $P_f = 0$ and 0.05. For AND rule, the detection performance significantly deterioration. The probability of detection of the fusion node for K-out-of-N rule falls between the probabilities of the OR rule and the AND rule.

Figure 5 depicts complementary ROC (CROC) curves under the event probability of miss detection, in which the proposed adaptive learning algorithm has the lowest probability of miss detection (Pm) against conventional decision fusion rules such as OR, AND, and K-out-of-N.



(a) Low SNR



(b) High SNR

Fig 5. Comparative analysis of CROC

V. Conclusions

In this paper we have proposed a novel method of decision fusion by simple reinforcement learning of cooperative target detection. The contributions of our proposed method is can be concluded that weight assignment depending individual sensor node of SNR provides a good detection information as compared to other conventional fusion rules. Also, this method provides higher probability of detection (P_d) and lower probability of miss (P_m) performance. In the future, this work can be extended to reduce the overhead incurred in achieving spectrum sensing reliability.

References

[1] B. Wang, K.J. Ray Liu, "Advances in cognitive radio networks: a survey", *IEEE Journal of Selected Topics in Signal Processing* , vol.5 , no.1 ,2011, pp. 5–23.

[2] M.M. Abdullahi, S.M. Sani, and M.B. Mu'azu, " Cooperative Spectrum Sensing and Determination of Optimum Threshold in Cognitive Radio System", *International Journal of Computer Applications*,vol.122, no.23, 2015, pp. 32-38.

[3] F. Akyildiz, B. F. Lo and R. Balakrishnan, "Cooperative Spectrum Sensing in Cognitive Radio Networks: A Survey", *Physical Communication (Elsevier) Journal*, vol. 4, no. 1, ,2011, pp. 40-62.

[4] Kenta Umebayashi, Janne J. Lehtomäki, Takanao Yazawa, Yasuo Suzuki, "Efficient Decision Fusion for Cooperative Spectrum Sensing Based on OR-rule", *IEEE Transaction on wireless communications*, vol. 11, no.7,2012, pp.2585-2595.

[5] Pankaj Verma, Brahmjit Singh," Overcoming sensing failure problem in double threshold based cooperative spectrum sensing", *Optik* , No. 127, 2016, pp 4200–4204.

[6] I. F. Akyildiz, B. F. Lo, and R. Balakrishnan, "Cooperative spectrum sensing in cognitive radio networks: A survey," *Physical Communication*, vol. 4, no. 1, 2011, pp. 40–62.

[7] S. M. Dima, C. Panagiotou, D. Tsitsipis, C. Antonopoulos, J. Gialelis, and S. Koubias, "Performance evaluation of a WSN system for distributed event detection using fuzzy logic," *Ad Hoc Networks*, vol. 23, 2014, pp. 87–108.

[8] D. Triwicaksono and S. Y. Shin, "Energy detector and matched filter as cascaded clear channel assessment in wireless network," in *Proc. IET International Conference on Information and Communications Technologies*, 2013, pp. 551–556.

Yee Ming Chen is a professor in the Department of Industrial Engineering and Management at Yuan Ze University, where he carries out basic and applied research in agent-based computing. His current research interests include soft computing, supply chain management, and system diagnosis/prognosis.

Chi-Li Tsai received the Master degree in the Department of Industrial Engineering and Management at Yuan Ze University, where he has worked ever since as a research assistant, developing multi-agent system. Since 2014, he has also been studying for the Ph.D. degree at Yuan Ze University. His research interests include soft computing, multi-agent simulation, and signal processing.