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Abstract—In this paper, we consider the problem of using three sensors to detect whether a certain spectrum is occupied or not. Each sensor sends its binary decision to the data fusion center through a wireless fading channel. The data fusion center combines the outcomes for an overall decision. Our analysis shows that a basic sensor network does not result in a high enough correct probability of the overall decision when the wireless fading channels experience low SNR. Then, we observe that this probability could be significantly increased with the deployment of relays in the network. However, a sensor network with relays still suffers from energy and spectral inefficiency.

The sensor network with an intermediate fusion helper was recently proposed to reduce the traffic load at the data fusion center. Our evaluation establishes that a sensor network with an intermediate fusion helper performs almost as good as the sensor network with relays, but with energy and spectral advantages.

I. INTRODUCTION

Cognitive radio (CR) is a potential technology for increasing spectral efficiency in wireless communications systems. In a cognitive radio system, secondary users temporarily use spectrum that is not utilized, as long as negligible impact is caused to primary licensed users. In order to opportunistically access temporarily unused spectrum, the spectrum in an area needs to be sensed from time to time. In a simple scenario, a secondary user acts as a sensory node; it senses and uses the available spectrum. The spectrum sensing techniques include energy detector-based sensing, waveform-based sensing, cyclostationarity-based sensing, radio identification-based sensing, matched-filtering, etc [21].

Due to noise uncertainty and wireless channel fading, the sensing decision made by a single sensor is sometimes unreliable. Cooperative sensing among multiple sensors is an efficient approach to addressing this issue, because it provides multiple measurements and, hence, increases the diversity. Additionally, having sensors cooperating over a wide area also provides a possible solution to the hidden-terminal problem. This is because sensors, separated by a distance larger than the correlation distance of shadow fading, are unlikely to be shadowed simultaneously from the primary user.

In cooperative sensing, after performing the spectrum sensing operations, each sensor sends its sensing results to a data fusion center, which makes an overall decision about the spectrum occupancy. The process of making an overall decision based on multiple sensing results is called data fusion or information combining. Depending on the type of sensing results sent from the sensors to the data fusion center, the information combining can be classified into three categories: hard combining (cf. e.g., [14]), hard combining with side information (cf. e.g., [2], [6], [14]), and soft combining (cf. e.g., [6], [12], [13], [15], [18], [22]).

In the above work, the sensing results from all the sensors are assumed to be delivered to the data fusion center without error. In other words, the fusion channels, i.e., the channels from sensors to the data fusion center, are error-free and bandwidth unlimited. There are many applications (e.g., [17]) for large scale sensor networks, with power limited sensors wirelessly connected to the data fusion center. The fusion channels are noisy and experience wireless fading. Much work [3], [4], [7], [20] has been devoted to examine the information combining rules under the condition of rate-constrained fusion channels. The optimal information combining rules were extensively studied in [5], [8]–[11], [16], [19], when the fusion channels are noisy channels or wireless fading channels. Furthermore, it was proposed in [9], [10] to use relays for reliable transmissions on the noisy fusion channels. It should be mentioned that most of the efforts, in the presence of the noisy or rate-constrained fusion channels, are focused on the optimal information combining rules.

It was recently proposed in [1] to reduce the traffic load at the data fusion center by using an intermediate fusion helper in a sensor network. Specifically, the intermediate fusion helper combines the decisions it receives from several sensors, and transmits the (combined) intermediate decision to the data fusion center. Although the spectral advantage of the sensor network with an intermediate fusion helper is obvious, its detection performance, especially in the noisy fusion channel environment, is unclear.

The contribution of this paper is two-fold:

i). We establish a system model to incorporate the practical
situations of wireless fading fusion channels. Within this model, we analyze the performance of a basic sensor network, a sensor network with relays, and a sensor network with an intermediate fusion helper. It is shown that the basic sensor network does not perform well, in terms of the correct probability of the overall decision at the data fusion center. This probability is significantly increased with the deployment of relays in the network. Our analysis shows that the correct probability of the overall decision in the sensor network with an intermediate fusion helper is almost as good as that in the sensor network with relays, and is much higher than that in the basic sensor network. Subsequently, to achieve the same detection probability, the sensor network with an intermediate fusion helper consumes the least transmission energy. This is because only a single transmission is needed from the intermediate fusion helper, compared with one transmission per relay in the sensor network with relays.

ii). In the sensor networks with relays or an intermediate fusion helper, we study the locations of the relays or the intermediate fusion helper for the optimal network performance. Specifically, the optimal relay location is the middle of the sensors and the data fusion center, while the optimal location of the intermediate fusion helper should be a bit closer to the data fusion center. Such examination facilitates the design of sensor networks.

The rest of this paper is organized as follows. The problem formulation is given in Section II. Section III discusses the sensor network with relays. The sensor network with an intermediate fusion helper is introduced in Section IV. The performance of all these sensor networks is analyzed in the separate sections. Simulation results are provided in Section V. Section VI contains conclusions and discussions.

II. PROBLEM FORMULATION

Consider a wireless sensor network (cf. Figure 1) deployed with three sensors to detect whether a spectrum is occupied or not. The detection problem can be stated in terms of a binary hypothesis test: hypothesis $H_0$ is the signal absence or spectrum unoccupied, and hypothesis $H_1$ is the signal presence or spectrum occupied. The \textit{a priori} probabilities of the two hypotheses are $\Pr(H_0) = \pi_0$ and $\Pr(H_1) = \pi_1$. Suppose each sensor listens to a certain spectrum and applies some spectrum sensing technique. Let $S_i$, $1 \leq i \leq 3$, denote the decision made by the $i^{th}$ sensor, where

$$S_i = \begin{cases} 
-1, & \text{if } H_0 \text{ is declared,} \\
1, & \text{if } H_1 \text{ is declared.}
\end{cases}$$

The probability $A_i$ that the decision $S_i$ is true is given by

$$A_i = \Pr(S_i = -1|H_0)\pi_0 + \Pr(S_i = 1|H_1)\pi_1.$$  

The observations and decisions made by the three sensors are assumed to be statistically independent conditioned on either hypothesis, i.e.,

$$\Pr(S_1, S_2, S_3|H_j) = \prod_{i=1}^{3} \Pr(S_i|H_j), \quad j = 0, 1.$$  

After the spectrum sensing operations, each sensor sends its decision to the data fusion center through its own fusion channel. The three fusion channels are mutually independent wireless fading channels. Let $X_i$ and $Y_i$ be the input and the output of the $i^{th}$ fusion channel. Then,

$$Y_i = h_i X_i + N_i,$$  

where $h_i$ is the channel fading and $N_i$ is the additive white Gaussian noise with distribution $\mathcal{N}(0, \sigma_i^2)$. Before transmission, the $i^{th}$ sensor modulates its decision $S_i$ to $X_i$, using the BPSK scheme with transmission power $P_i$. Hence, we have $X_i = \sqrt{P_i} S_i$.

The data fusion center demodulates the received signal $Y_i$ to $T_i \in \{-1, 1\}$. It then applies the majority combining rule (cf. e.g., [14]) to make an overall decision. Specifically, if at least two of the demodulated decisions are 1, then the data fusion center declares the presence of the signal. Otherwise, it declares the absence of the signal. The overall decision at the data fusion center can be expressed as

$$U = \begin{cases} 
-1, & \text{if } \sum_{i=1}^{3} T_i < 0, \\
1, & \text{if } \sum_{i=1}^{3} T_i \geq 0.
\end{cases}$$  

The probability $P_e$ that the overall decision $U$ matches the true hypothesis is defined as

$$P_e = \pi_0 \Pr(U = -1|H_0) + \pi_1 \Pr(U = 1|H_1).$$  

Next, we shall characterize this probability. To simplify our calculations, we make the following symmetry assumptions in the rest of this paper.

i). For each sensor: $\Pr(S_i = -1|H_0) = \Pr(S_i = 1|H_1)$. Hence, $A_1$ is equal to the detection probability $\Pr(S_i = 1|H_1)$.

ii). All the sensors have the same detection probability: $A_1 = A_2 = A_3 = A$.

iii). All the sensors have the same transmission power: $P_1 = P_2 = P_3 = P$.

iv). The noise powers of all the fusion channels are identical: $\sigma_1^2 = \sigma_2^2 = \sigma_3^2 = \sigma^2$.

With these simplifications, we define the signal to noise ratio as $\text{SNR} = P/\sigma^2$.

\footnote{Throughout this paper, we ignore error-correction coding as it would have the same effects in all of the discussions.}
To further facilitate our computations, we ignore the fast fading of the fusion channels at this moment, and only take the path loss into account. Hence, the channel fading $h_i$ in (1) has $|h_i|^2 = d_i^{-eta}$, where $d_i$ is the distance from the $i^{th}$ sensor to the data fusion center and $\beta$ is the path loss exponent. We assume of the equal distance from all the sensors to the data fusion center, i.e., $d_1 = d_2 = d_3 = d$.

Let $P_c$ be the probability that a transmission on a fusion channel is demodulated correctly at the data fusion center. Then, it follows from the BPSK modulation scheme that

$$P_c = \Pr(T_i = S_i) = 1 - Q\left(\sqrt{\frac{|h_i|^2 P}{\sigma^2}}\right) = 1 - Q\left(\sqrt{d^{-\beta} \text{SNR}}\right),$$

(4)

where $Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-\frac{t^2}{2}} \, dt$ is the usual Gaussian tail function. It follows from the Markov chain and (4) that

$$\Pr(T_i = -1|H_0) = \Pr(T_i = 1|H_1)$$

$$= \Pr(T_i = -1, S_i = -1|H_0) + \Pr(T_i = -1, S_i = 1|H_0)$$

$$= AP_t(1 - A)(1 - P_t) \triangleq P_B.$$ 

According the majority combining rule (2), we have

$$\Pr(U = -1|H_0) = \Pr\left(\sum_{i=1}^{3} T_i = -1|H_0\right) + \Pr\left(\sum_{i=1}^{3} T_i = -3|H_0\right)$$

$$= 3P_B^2(1 - P_B) + P_B^3 = \Pr(U = 1|H_1).$$

Hence, it follows from (3) that

$$P_c = 3P_B^2(1 - P_B) + P_B^3.$$ 

This probability vs. SNR is illustrated using the square curve in Figure 2. In plotting this curve, we set $A = 0.9$, $\beta = 3.5$, and $d = 10$. Even though the correct probability of the individual decision is as high as 0.9, we observe from the figure that the correct probability of the overall decision is quite small in the low SNR region. In order to achieve a correct probability of the overall decision higher than $A = 0.9$, the SNR of each fusion channel needs to be no less than 36 dB.

It follows from the majority combining rule that the correct probability of the overall decision is upper bounded by $3A^2(1 - A) + A^3$. This upper bound is achieved when the fusion channels are noiseless. For $A = 0.9$, this upper bound is equal to 0.972, as seen in the figure.

III. SENSOR NETWORK WITH RELAYS

As discussed, the basic sensor network does not perform well at low SNRs. A natural way to increase $P_c$ is via enhancing the sensors’ transmission power $P_t$, and hence the SNR. This approach may be infeasible due to the power limitation of the sensors, as well as the potential interference caused. An approach to improving the transmission reliability without enhancing the sensors’ transmission power is by means of relays. The usage of relays for reliable transmissions and throughput increment has been widely studied, while its application for reliable transmissions on the fusion channels has been adopted in [9], [10].

Consider the sensor network in Figure 1, but with a relay located between every sensor and the data fusion center. It is known that the usual relaying schemes include the demodulate-and-forward scheme, and the amplify-and-forward scheme. We shall characterize the correct probability of the overall decision $P_c$ in the sensor network with relays, using either of these two relaying schemes.

Here, we assume that the distance from a sensor to its serving relay is $od$, $0 < \alpha < 1$, and the distance from a relay to the data fusion center is $(1 - \alpha)d$. All the relays have the same transmission power as the sensors.

A. Demodulate-and-Forward Relays

For the demodulate-and-forward scheme, a relay first demodulates the transmission from a sensor. It then re-modulates the binary decision and transmits it to the data fusion center. Note that all the channels to and from the relays are wireless fading channels. The data fusion center demodulates the transmissions from the relays, and applies the majority combining rule to make an overall decision.

Denote by $R_i$ the demodulated decision at the $i^{th}$ relay. Let $P_{t_1}$ be the probability that a transmission from a sensor is demodulated correctly at the corresponding relay. Let $P_{t_2}$ be the probability that a transmission from a relay is demodulated correctly at the data fusion center. Then, we have

$$P_{t_1} = \Pr(R_i = S_i) = 1 - Q\left(\sqrt{(\alpha d)^{-\beta} \text{SNR}}\right),$$

(5)

and

$$P_{t_2} = \Pr(T_i = R_i) = 1 - Q\left(\sqrt{[(1 - \alpha)d]^{-\beta} \text{SNR}}\right).$$

(6)

It can be derived that

$$\Pr(T_i = -1|H_0) = \Pr(T_i = 1|H_1)$$

$$= AP_{t_1}P_{t_2} + A(1 - P_{t_1})(1 - P_{t_2})$$

$$+ (1 - A)(1 - P_{t_1})P_{t_2} + (1 - A)P_{t_1}(1 - P_{t_2})$$

$$\triangleq P_R.$$
Therefore,  
\[ P_c = 3P_R^2(1 - P_R) + P_R^3. \]  

**B. Amplify-and-Forward Relays**

Let \( X_{i,1} \) and \( Y_{i,1} \) denote the inputs and the outputs of the channel from the \( i^{th} \) sensor to its serving relay. Let \( X_{i,2} \) and \( Y_{i,2} \) denote the inputs and the outputs of the channel from the \( i^{th} \) relay to the data fusion center. Then, we have
\[
Y_{i,1} = h_{i,1}X_{i,1} + N_{i,1} = h_{i,1}\sqrt{P}S_i + N_{i,1},
\]
and
\[
Y_{i,2} = h_{i,2}X_{i,2} + N_{i,2},
\]
where \( h_{i,1} \) and \( h_{i,2} \) represent the fading on the respective channel, and \( N_{i,1} \) and \( N_{i,2} \) represent the additive white Gaussian noise with distribution \( \mathcal{N}(0, \sigma^2) \) on the respective channel. It follows from the path loss model that \( |h_{i,1}|^2 = (\alpha d)^{-\beta} \) and \( |h_{i,2}|^2 = [(1 - \alpha)d]^{-\beta} \).

For the amplify-and-forward scheme, a relay amplifies its received signal \( Y_{i,1} \) by a factor of \( K \) before transmitting it to the data fusion center, i.e.,
\[
X_{i,2} = KY_{i,1} = Kh_{i,1}\sqrt{P}S_i + KN_{i,1}.
\]  
Since the transmission power of a relay is equal to \( P \), we obtain that
\[
K = \sqrt{\frac{P}{(\alpha d)^{-\beta}P + \sigma^2}} = \sqrt{\frac{SNR}{(\alpha d)^{-\beta}SNR + 1}}. 
\]  

Denote by \( ESNR \) the equivalent SNR for the transmissions from the sensor to the data fusion center. Then, it follows from (8), (9) and (10) that
\[
ESNR = \frac{SNR^2(\alpha d)^{-\beta}}{SNR(\alpha d)^{-\beta} + SNR[(1 - \alpha)d]^{-\beta} + 1}. 
\]

Let \( P_{t,A} \) be the probability that a transmission from a sensor is demodulated correctly at the data fusion center. Then, we have
\[
P_{t,A} = 1 - Q\left(\sqrt{\frac{SNR^2(\alpha d)^{-\beta}}{SNR(\alpha d)^{-\beta} + SNR[(1 - \alpha)d]^{-\beta} + 1}}\right). 
\]
By the similar arguments as in Section II, we derive that
\[
P_c = 3P_A^2(1 - P_A) + P_A^3, 
\]
where \( P_A = AP_{t,A} + (1 - A)(1 - P_{t,A}) \).

The probability (7) is plotted as the circle curve in Figure 2 and the probability (11) is plotted as the star curve in Figure 2. In plotting these curves, we adopt the same parameters as before, i.e., \( A = 0.9, \beta = 3.5, d = 10 \). Moreover, the parameter \( \alpha \) is set as 0.5. It is seen from the figure that the sensor network with relays (either demodulate-and-forward or amplify-and-forward) significantly outperforms the basic sensor network. Furthermore, the sensor network with demodulate-and-forward relays performs better than that with amplify-and-forward relays in the operational SNR region (though such conclusion may be contrary at lower SNRs).

Hence, we shall focus on the demodulate-and-forward relays in the remaining discussions of this paper.

The sensor network with relays achieves the desired correct probability of the overall decision, in the cost of three additional relays. A simplified version [9] of this network is a single relay taking all the relaying functionalities. In other words, the single relay repeats the operations for each of the sensors. Note that the relay makes three transmissions, one for each sensor. This consumes much energy, and may be infeasible for low-power relays. Moreover, the multiple transmissions may become a communication bottleneck at the data fusion center if the number of sensors in the network is large.

**IV. SENSOR NETWORK WITH INTERMEDIATE FUSION HELPER**

Consider the sensor network in Figure 1, but with a single intermediate fusion helper located between all the sensors and the data fusion center. The intermediate fusion helper receives and demodulates the transmissions from all the sensors, and then applies the majority combining rule to make an intermediate decision on whether the signal is present or not. It sends this binary decision to the data fusion center. Subsequently, the data fusion center simply demodulates this message and declares the same decision.

The channels to and from the intermediate fusion helper are wireless fading channels. We assume that the distances from the sensors to the intermediate fusion helper are \( \alpha d \) and the distance from the intermediate fusion helper to the data fusion center is \( (1 - \alpha)d \). The intermediate fusion helper has the same transmission power as the sensors.

Let \( P_{t,1} \) be the probability that a transmission from a sensor is demodulated correctly at the intermediate fusion helper. Let \( P_{t,2} \) be the probability that a transmission from the intermediate fusion helper is demodulated correctly at the data fusion center. Then, these probabilities follow from (5) and (6).

Denote by \( F_i \) the demodulated decision from the \( i^{th} \) sensor at the intermediate fusion helper, and denote by \( U_F \) the intermediate fusion decision made at the intermediate fusion helper. Then, by the majority combining rule,
\[
U_F = \begin{cases} 
-1, & \text{if } \sum_{i=1}^{3} F_i < 0, \\
1, & \text{if } \sum_{i=1}^{3} F_i \geq 0.
\end{cases}
\]

It is not difficult to derive
\[
\Pr(F_i = -1 | H_0) = \Pr(F_i = 1 | H_1) = AP_{t,1} + (1 - A)(1 - P_{t,1}) \triangleq P_{F,i}, 
\]
and
\[
\Pr(U_F = -1 | H_0) = \Pr(U_F = 1 | H_1) = 3P_{F,i}^2(1 - P_{F,i}) + P_{F,i}^3 \triangleq P_F. 
\]
Therefore, the correct probability of the overall decision is obtained as
\[
P_c = P_F P_{t,2} + (1 - P_F)(1 - P_{t,2}).
\]
Using the same parameters as before, we plot the probability \( P_c \) of the sensor network with an intermediate fusion helper as the diamond curve in Figure 2. It is seen from the figure that the sensor network with an intermediate fusion helper performs almost as good as the sensor network with relays. However, only a single message is transmitted from the intermediate fusion helper to the data fusion center. This saves two thirds of the overall bandwidth at the data fusion center, and the energy consumption by the intermediate fusion helper is approximately one third of that used by the relays in the sensor networks with relays.

A. Optimal Location of the Intermediate Fusion Helper

In drawing the diamond curve in Figure 2, we locate the intermediate fusion helper in the middle of the sensors and the data fusion center, i.e., \( \alpha = 0.5 \). However, such a location may not be optimal for maximizing \( P_c \). In this sub-section, we shall examine the optimal location of the intermediate fusion helper.

It is not difficult to derive from (5) and (6) that

\[
\frac{\partial P_{t_1}}{\partial \alpha} = -\sqrt{\frac{\beta^2 d^{-\beta} \text{SNR}}{8\pi}} e^{-(\alpha d)^{-\beta} \text{SNR}} (1-\alpha)^{-\frac{d}{2}} - 1,
\]

(15)

\[
\frac{\partial P_{t_2}}{\partial \alpha} = \sqrt{\frac{\beta^2 d^{-\beta} \text{SNR}}{8\pi}} e^{-[(1-\alpha) d^{-\beta} \text{SNR}](1-\alpha)^{-\frac{d}{2}} - 1}.
\]

(16)

It follows from (12) and (13) that

\[
\frac{\partial P_F}{\partial \alpha} = 6P_{F_i}(1-P_{F_i})(2A-1) \frac{\partial P_{t_1}}{\partial \alpha}.
\]

(17)

Finally, we obtain from (14) that

\[
\frac{\partial P_c}{\partial \alpha} = -\frac{\partial P_{t_1}}{\partial \alpha} + \frac{\partial P_F}{\partial \alpha} + 2P_F \frac{\partial P_{t_2}}{\partial \alpha} + 2P_{t_2} \frac{\partial P_F}{\partial \alpha}.
\]

(18)

By inserting (6), (13), (15), (16) and (17) into (18), and setting it to zero, we obtain the optimal location \( \alpha^* \) as a function of \((A, \text{SNR}, \beta, d)^2\).

Figure 3 shows the optimal location \( \alpha^* \) vs. SNR for different values of \( A \) and for fixed \( \beta = 3.5 \) and \( d = 10 \). It is observed from the figure that \( \alpha^* \) is, in general, larger than 0.5. This indicates that for the best performance, the intermediate fusion helper should be closer to the data fusion center than to the sensors. With the increase of SNR, the optimal location tends to \( \alpha^* = 0.5 \). The \( P_c \) of the sensor network with the optimally located intermediate fusion helper is shown as the dot curve in Figure 2. A few performance gains of the sensor network with optimized intermediate fusion helper location over that with a fixed \( \alpha = 0.5 \) can be observed from the figure.

Following similar arguments, we find, as expected, that the optimal relay location for the sensor network with either demodulate-and-forward relays or amplify-and-forward relays is always at \( \alpha^* = 0.5 \). Hence, the circle curve and the star curve in Figure 2 already illustrate the largest achievable \( P_c \) of the sensor network with demodulate-and-forward relays or amplify-and-forward relays.

2Note that \( P_c \) is not a concave function of \( \alpha \) at low SNRs. For simplicity, we focus only on the medium-high SNR range (i.e., \( \text{SNR} \geq 23 \text{ dB} \)), which insures a concave \( P_c \) function.

B. Transmission Energy of the Sensor Networks

As mentioned, the basic sensor network, as well as the sensor network with relays, is not energy and spectrally efficient. In the basic sensor network, in order to achieve a desired correct probability of the overall decision, the transmission energy of each sensor needs to be very large. In the sensor network with relays, each relay will consume the same amount of transmission energy as a sensor. Since the network with intermediate fusion helper requires a single transmission from the intermediate fusion helper, its total consumed transmission energy is less than that of the sensor network with relays.

Figure 4 shows the total transmission energy used in the three networks. It is seen that to achieve the same correct probability of the overall decision, the network with intermediate fusion helper consumes the least transmission energy.

V. SIMULATION RESULTS

In the analytical analysis above, we omit the fast fading of the fusion channels for simplicity. In this section, we simulate
the performance of different sensor networks, where the fusion channels experience both path loss and Rayleigh fading. The other parameters used in our simulations are the same as those for Figure 2. A total of $5 \times 10^3$ sensing operations is executed, and the correct probability of the overall decision is averaged over these trials. The average correct probability of the overall decision is shown in Figure 5. By comparing Figure 2 and Figure 5, we observe that our simulation results manifest the same trend as the analytical conclusions.

VI. CONCLUSIONS AND DISCUSSIONS

We have considered the problem of using three sensors for cooperative spectrum sensing, in which the fusion channels from the sensors to the data fusion center are wireless fading channels. We examined the performance of sensor networks with or without relays. Then, we considered a sensor network deploying an intermediate fusion helper to combine the sensing decisions from the sensors before transmitting them to the data fusion center. The performance of all sensor networks was compared. Our analysis and simulations establish the performance advantage of the sensor network with an intermediate fusion helper.

Though this paper focused on sensor networks with only three sensors, we have generalized our performance evaluation to sensor networks with an arbitrary number of sensors. In summary, we reached the similar conclusions in general sensor networks as in the 3-sensor networks, viz., we observed the performance advantage of the sensor network with an intermediate fusion helper. Further, to alleviate the potential communication bottleneck at the intermediate fusion helper when the number of sensors in a network is large, we have also proposed to deploy multiple intermediate fusion helpers.

In this paper, we based our analysis on the majority combining rule at either the data fusion center or the intermediate fusion helper. We have also considered the AND combining rule and the OR combining rule. Our analysis shows that under these combining rules, the sensor network with an intermediate fusion helper even outperforms the sensor network with relays, in terms of the correct probability of the overall decision. Moreover, we have attempted to extend our analysis beyond hard combining rules. Due to the length limitation, we did not present the details of these results in this paper.

REFERENCES