Geometric Analysis-Based Cluster Head Selection for Sectorized Wireless Powered Sensor Networks

Hyun-Ho Choi, *Senior Member, IEEE*, Sengly Muy, and Jung-Ryun Lee, *Senior Member, IEEE*

***Abstract*—In this letter, we consider a sectorized wireless powered sensor network (WPSN), wherein sensor nodes, which are clustered based on sectors, transmit data to the cluster head (CH) using energy harvested from a hybrid access point. We construct a system model for this sectorized WPSN and formulate an optimization problem to obtain an optimal CH that maximizes the achievable transmission rate of sensing data. To obtain the optimal CH with low overhead and complexity, we perform an asymptotic geometric analysis (GA) that determines the optimal coordinates of the CH in the considered area of the sector such that only a small number of sensor nodes near this optimal coordinates need to be investigated. Simulation results show that the performance of the proposed GA-based CH selection method is close to the optimal performance exhibited by exhaustive search; moreover, the proposed method substantially reduces the channel feedback overhead.**

***Index Terms*—Wireless powered sensor networks, wireless energy transfer, cluster head selection, geometric analysis.**

I. INTRODUCTION

ONE OF the major challenges in wireless sensor networks (WSNs) is the limited battery lifetime of sensor nodes. To overcome this problem, Wireless energy transfer (WET) technology has received increasing attention as a promising technology because it can transfer electrical energy via wireless media from a power transmitter to multiple receivers equipped with energy harvesting (EH) functionality [1].

WET technology was initially applied to a cellular network called the wireless powered communication network (WPCN) where a hybrid access point (HAP) broadcasts wireless energy to EH nodes in the cell and the EH nodes transmit data to the HAP using the harvested energy [2]. However, the WPCN has a doubly near-far problem. That is, far users from the HAP receive less wireless energy than near users in the downlink; however, they are required to transmit data with more power in the uplink. To solve this problem, various techniques such as scheduling [3], user cooperation [4], and backscatter [5] have been investigated. Particularly, for WSN environments, the clustered wireless powered sensor network (WPSN) has been presented to address this problem [6]–[9]. In this network, the sensor nodes transmit data to the cluster head (CH) using the energy harvested from the HAP, and the CH forwards the aggregated sensing data to the HAP. In [6], the HAP exploited energy beamforming to transfer more power to the CH because the performance was limited by the high energy consumption of the CH. In [7], numerous sensor nodes transferred their remaining energy to the CH while transmitting data simultaneously such that the CH would acquire more energy. In [8], cluster cooperation was proposed such that the sensors in the energy-surplus cluster can facilitate the sensors in the energy-deficient cluster to relay sensing data to the HAP. Furthermore, a WPSN was divided into several layers to alleviate the doubly near-far problem and the optimal border of each layer was analyzed [9].

The performance of the clustered WPSN is dominated by the cluster configurations, such as the number of clusters, the member nodes in each cluster, and the selection of CH in each cluster. However, it has been challenging to create appropriate clusters and select the optimal CH because previous studies used exhaustive search (ES) [8] or heuristic algorithms such as k-means clustering [7], and these methods require considerable channel information and computational complexity as the number of participating nodes increases. Although the CH selection problem has been addressed in wireless network environment, to the best of our knowledge, any practical approach for optimal CH selection in the WPSN network has not been presented yet.

In this letter, we assume a sector-based cluster for the WPSN, considering the practical WET application in which energy beamforming is used to increase the EH level at receivers [10]. Hence, the radio coverage becomes a sector instead of a circular cell. In this sectorized WPSN, the sensor nodes are clustered based on the sector, and they transmit sensing data to the CH using the energy harvested from the HAP. We construct a system model for this sectorized WPSN and formulate an optimization problem to obtain an optimal CH that maximizes the achievable transmission rate of the sensing data. This corresponds to a combinatorial optimization problem; therefore, ES entails a significant overhead and complexity as the number of sensing nodes increases. Hence, to reduce the search space, we perform an asymptotic geometric analysis (GA), which theoretically determines the optimal coordinates of the CH in the considered area of the sector such that only a small number of sensor nodes near this optimal coordinates need to be investigated. The simulation results show that the proposed GA-based CH selection method approaches the optimal performance of the ES while significantly reducing the channel feedback overhead.

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II. System Model and Problem Description

Fig. 1 illustrates the system model and the frame structure for the considered sectorized WPSN, where one HAP and *N* sensor nodes exist. The HAP serves as a sink node to collect sensing information from all sensor nodes and supplies wireless energy for the sensor nodes (i.e., performs WET) as a stable energy source. The sensor nodes harvest energy from the HAP and use this energy to transmit data to the CH (i.e., perform wireless information transmission (WIT)). The CH aggregates all of the sensing information received from the sensor nodes as well as its own sensing information (i.e., performs data fusion) and then transmits the aggregated data to the HAP using the harvested energy [11].

The frame is based on time division multiple access, and scheduling-based resource allocation is performed for a conflict-free transmission in compliance with the harvest-then-transmit protocol [3]. First, a beacon (B) signal is broadcasted for frame synchronization and to provide both the frame configuration and scheduling information for all nodes. Thereafter, the HAP transmits energy and the sensor nodes harvest energy during the WET slot with a length of T_e. The remainder of the frame comprises *N* WIT slots, which are used for the sensor nodes and the CH to transmit data. It is assumed that all sensors perform the same sensing task, such as temperature, humidity, or fire sensing [11]; therefore, the bit sizes of the sensing data are the same, and the WIT slots have the same length of T_d. Each WIT slot is reserved for each sensor node through prescheduling, and the last WIT slot is dedicated to the CH.

Let $\mathcal{N}$ be the set of sensor nodes in the sector, i.e., $\mathcal{N} = \{1, 2, \ldots, N\}$. We denote the selected CH node as *i*, where $\exists i \in \mathcal{N}$, and we denote the other sensor nodes as *j*, where $\forall j \in \mathcal{N} \setminus \{i\}$. As shown in Fig. 1, h_j denotes the channel power gain between the HAP and node *j*, and g_{ij} denotes the channel power gain between sensor node *j* and CH *i*. For simplicity, we assume channel reciprocity between any two nodes. First, the energy harvested by sensor node *j* from the HAP is expressed as

$$E_j = \zeta G_1 h_j P T_e \quad \text{[Joule]}, \quad \forall j \in \mathcal{N}, \tag{1}$$

where $0 < \zeta < 1$ is the EH efficiency of the sensor nodes, assuming that all sensor nodes are homogeneous and have the same ζ value. G_1 denotes the antenna gain from the HAP to the sensor nodes, and *P* is the constant transmission power of the HAP. Subsequently, the transmission power of node *j* for transmitting data to the CH during its WIT slot is determined as follows:

$$P_j = \frac{\eta E_j}{T_d} = \frac{\eta\zeta G_1 h_j P T_e}{T_d}, \ \forall j \in \mathcal{N} \setminus \{i\}, \tag{2}$$

where $0 < \eta < 1$ is the ratio of the energy used only for transmission (i.e., we exclude the energy used for reception, processing, and circuit operations) to the total energy harvested from the HAP. Based on the Shannon capacity, the achievable rate of transmission from sensor node *j* to CH *i* is expressed as

$$\begin{aligned} R_{ij} &= \log_2\left(1 + \frac{G_2 g_{ij} P_j}{\sigma^2}\right) \quad \text{[b/s/Hz]} \\ &= \log_2\left(1 + \frac{\eta\zeta G_1 G_2 g_{ij} h_j P T_e}{\sigma^2 T_d}\right), \ \forall j \in \mathcal{N} \setminus \{i\}, \end{aligned} \tag{3}$$

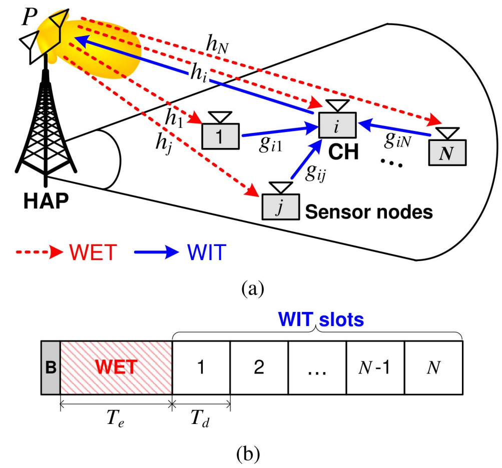


Fig. 1. Sectorized WPSN: (a) system model and (b) frame structure.

where G_2 denotes the antenna gain of the sensor node, and σ^2 is the noise power at the receiving side. The transmission power of CH *i* for transmitting data to the HAP during its WIT slot is expressed as

$$P_i = \frac{\eta E_i}{T_d} = \frac{\eta\zeta G_1 h_i P T_e}{T_d}. \tag{4}$$

Subsequently, the achievable rate of transmission from CH *i* to the HAP is calculated as

$$\begin{aligned} R_i &= \log_2\left(1 + \frac{G_2 h_i P_i}{\sigma^2}\right) \\ &= \log_2\left(1 + \frac{\eta\zeta G_1 G_2 h_i^2 P T_e}{\sigma^2 T_d}\right) \quad \text{[b/s/Hz]}. \end{aligned} \tag{5}$$

When all sensor nodes perform the same sensing task, the maximum transmission rate of sensing data that can be collected in the WSNs is limited by the minimum rate of all the transmission links [12]. Therefore, the achievable transmission rate of sensing data in the considered WPSN is represented as

$$\mathcal{R} = \min\left[\min_{j \in \mathcal{N}\setminus\{i\}} \{R_{ij}\}, R_i\right]. \tag{6}$$

Consequently, the optimal CH i^* that maximizes the sensing data rate is determined by solving the following optimization problem:

$$\begin{aligned} \textbf{(P1):}\ i^* &= \arg\max_{i \in \mathcal{N}} \mathcal{R} \\ &= \arg\max_{i \in \mathcal{N}} \min\left[\min_{j \in \mathcal{N}\setminus\{i\}} \{R_{ij}\}, R_i\right] \\ &= \arg\max_{i \in \mathcal{N}} \min\left[\min_{j \in \mathcal{N}\setminus\{i\}} \left\{\log_2\left(1 + \frac{\eta\zeta G_1 G_2 g_{ij} h_j P T_e}{\sigma^2 T_d}\right)\right\}, \right. \\ &\qquad \left. \log_2\left(1 + \frac{\eta\zeta G_1 G_2 h_i^2 P T_e}{\sigma^2 T_d}\right)\right] \\ &= \arg\max_{i \in \mathcal{N}} \min\left[\min_{j \in \mathcal{N}\setminus\{i\}} \{g_{ij} h_j\}, h_i^2\right]. \end{aligned} \tag{7}$$

III. Geometric Analysis

The considered problem (**P1**) is a combinatorial optimization problem; hence, it is necessary for the ES to know all channel state information (i.e., h_i and g_{ij} for

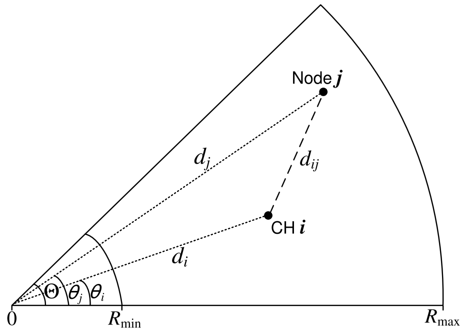


Fig. 2. System representation for geometric analysis.

$\forall i, j \in \mathcal{N}$). This induces a large feedback overhead and computational complexity as N increases. To reduce the search space, we perform an asymptotic GA assuming that a large number of sensor nodes are uniformly distributed in the sector. Fig. 2 illustrates the system representation for the GA. We denote d_{ij} as the distance between nodes *i* and *j*, and d_j as the distance between the HAP and node *j*. If we assume that the channel fading effect is averaged over time, we can use a simple distance-dependent path loss model expressed as $g_{ij} = \mathcal{G} d_{ij}^{-\alpha}$ and $h_j = \mathcal{G} d_j^{-\alpha}$, where $\mathcal{G}$ is the average power attenuation at a reference distance of 1 m, and α is the path loss exponent [3]. Applying these channel power gains, (**P2**) is converted to

$$(\mathbf{P2}):\ i^* = \arg\min_{i\in\mathcal{N}} \max\left[\max_{j\in\mathcal{N}\setminus\{i\}}\{d_{ij}d_j\}, d_i^2\right]. \quad (8)$$

For a specific CH *i*, we first consider the subproblem $\max_{j\in\mathcal{N}\setminus\{i\}}\{d_{ij}d_j\}$ in (8). Using the polar coordinate system, we represent $i = r_i\angle\theta_i$ and $j = r_j\angle\theta_j$. Subsequently, we obtain $d_{ij} = \sqrt{r_i^2 + r_j^2 - 2r_ir_j\cos(\theta_i-\theta_j)}$ and $d_j = r_j$. Assuming that many sensor nodes are uniformly distributed and node *j* can exist anywhere in the sector area, we can transform the problem of finding the optimal node *j* into the problem of finding the optimal location of node *j*, as follows:

$$(\mathbf{P3}):\ \max_{j\in\mathcal{N}\setminus\{i\}} \ \{d_{ij}d_j\} \quad (9)$$

$$= \max_{\{r_j,\theta_j\}}\left\{r_j\sqrt{r_i^2 + r_j^2 - 2r_ir_j\cos(\theta_i-\theta_j)}\right\}, \quad (10)$$

$$\text{s.t.}\ R_{min} \le r_j \le R_{max}, \quad (11)$$

$$0 \le \theta_j \le \Theta, \quad (12)$$

where R_{min} and R_{max} are the minimum and maximum radii of the sector, respectively, and Θ is the angle of the sector. Its Lagrangian is expressed as

$$\begin{aligned}\mathcal{L}\big(r_j,\theta_j,\vec{\mu}\big) &= r_j\sqrt{r_i^2 + r_j^2 - 2r_ir_j\cos(\theta_i-\theta_j)} \\ &\quad + \mu_1(r_j - R_{min}) + \mu_2\big(R_{max} - r_j\big) \\ &\quad + \mu_3\theta_j + \mu_4\big(\Theta - \theta_j\big). \end{aligned} \quad (13)$$

The partial derivatives of the Lagrangian are calculated as

$$\begin{aligned}\frac{\partial\mathcal{L}}{\partial r_j} &= \sqrt{r_i^2 + r_j^2 - 2r_ir_j\cos(\theta_i-\theta_j)} \\ &\quad + \frac{r_j(r_j - r_i\cos(\theta_i-\theta_j))}{\sqrt{r_i^2 + r_j^2 - 2r_ir_j\cos(\theta_i-\theta_j)}} + \mu_1 - \mu_2, \end{aligned} \quad (14)$$

$$\frac{\partial\mathcal{L}}{\partial\theta_j} = -\frac{r_ir_j^2\sin(\theta_i-\theta_j)}{\sqrt{r_i^2 + r_j^2 - 2r_ir_j\cos(\theta_i-\theta_j)}} + \mu_3 - \mu_4. \quad (15)$$

By solving $\frac{\partial\mathcal{L}}{\partial d_j} = 0$ and $\frac{\partial\mathcal{L}}{\partial\theta_j} = 0$ with Karush-Kuhn-Tucker conditions, we can express the object function in (10) as f_k for $k = 1, 2, \ldots, 6$, according to the given conditions, as follows:

1) When $r_j = R_{max}$ and $\theta_j = 0$,

$$f_1 = R_{max}\sqrt{r_i^2 + R_{max}^2 - 2r_iR_{max}\cos\theta_i}. \quad (16)$$

2) When $r_j = R_{max}$ and $\theta_j = \Theta$,

$$f_2 = R_{max}\sqrt{r_i^2 + R_{max}^2 - 2r_iR_{max}\cos(\Theta-\theta_i)}. \quad (17)$$

3) When $r_j = R_{min}$ and $\theta_j = 0$,

$$f_3 = R_{min}\sqrt{r_i^2 + R_{min}^2 - 2r_iR_{min}\cos\theta_i}. \quad (18)$$

4) When $r_j = R_{min}$ and $\theta_j = \Theta$,

$$f_4 = R_{min}\sqrt{r_i^2 + R_{min}^2 - 2r_iR_{min}\cos(\Theta-\theta_i)}. \quad (19)$$

5) When $r_j = \frac{r_i}{4}(3\cos\theta_i \pm \sqrt{9\cos^2\theta_i - 8})$ and $\theta_j = 0$ subject to $\cos\theta_i \ge \sqrt{\frac{8}{9}}$,

$$f_5 = r_j\sqrt{r_i^2 + {r_j}^2 - 2r_ir_j\cos\theta_i}. \quad (20)$$

6) When $r_j = \frac{r_i}{4}(3\cos(\Theta-\theta_i) \pm \sqrt{9\cos^2(\Theta-\theta_i) - 8})$ and $\theta_j = \Theta$ subject to $\cos(\Theta-\theta_i) \ge \sqrt{\frac{8}{9}}$,

$$f_6 = r_j\sqrt{r_i^2 + {r_j}^2 - 2r_ir_j\cos(\Theta-\theta_i)}. \quad (21)$$

It is note worthy that f_1 and f_2, f_3 and f_4, and f_5 and f_6 are symmetrical with respect to θ. Moreover, the original problem (**P2**) is a min-max problem; therefore, $\max_j\{d_{ij}d_j\}$ is minimized when $f_1 = f_2$, $f_3 = f_4$, and $f_5 = f_6$. Hence, we obtain the optimal $\theta_i^* = \frac{\Theta}{2}$. By applying this, the objective function can be summarized as follows:

$$f_1(r_i) = R_{max}\sqrt{r_i^2 + R_{max}^2 - 2r_iR_{max}\cos\frac{\Theta}{2}}, \quad (22)$$

$$f_2(r_i) = R_{min}\sqrt{r_i^2 + R_{min}^2 - 2r_iR_{min}\cos\frac{\Theta}{2}}, \quad (23)$$

$$f_3(r_i) = r_j^*\sqrt{r_i^2 + {r_j^*}^2 - 2r_ir_j^*\cos\frac{\Theta}{2}}, \quad (24)$$

where $r_j^* = \frac{r_i}{4}(3\cos\frac{\Theta}{2} \pm \sqrt{9\cos^2\frac{\Theta}{2} - 8})$ only if $\Theta \le 2\cos^{-1}\sqrt{\frac{8}{9}} = 38.9°$. Equation (22)–(24) are the local optimal solutions of (10), so we apply them to the original problem (**P2**) in (8) and (**P2**) is re-expressed as

$$(\mathbf{P4}):\ \min_{r_i}\max\left\{f_1, f_2, f_3, r_i^2\right\} \quad (25)$$

$$\text{s.t.}\ R_{min} \le r_i \le R_{max}. \quad (26)$$

We discover that $f_2 < r_i^2$ is satisfied if $\Theta < 120°$ from the inequality $f_2 < R_{min}^2$. Moreover, $f_3 < r_i^2$ is satisfied if $\Theta < 120°$ because $r_j^* < r_i$. However, f_3 is feasible only when $\Theta \le 38.9°$; therefore, $f_3 < r_i^2$ is always satisfied.

Consequently, when the sector angle is smaller than $120°$, **(P4)** can be simplified as

$$\textbf{(P5)}: \min_{r_i} \max\left\{f_1, r_i^2\right\} \tag{27}$$

$$\text{s.t.} \;\; R_{min} \le r_i \le R_{max}. \tag{28}$$

Here, the derivative of $f_1(r_i)$ with respect to r_i is expressed as

$$f_1' = 2R_{max}\frac{r_i - R_{max}\cos\frac{\Theta}{2}}{\sqrt{r_i^2 + R_{max}^2 - 2r_iR_{max}\cos\frac{\Theta}{2}}}. \tag{29}$$

Therefore, $f_1' < 0$ when $r_i < R_{max}\cos\frac{\Theta}{2}$ and $f_1' > 0$ when $r_i > R_{max}\cos\frac{\Theta}{2}$, such that f_1 is minimum when $r_i = R_{max}\cos\frac{\Theta}{2}$.

Another minimum point can be obtained using the condition $f_1 = r_i^2$, i.e., $R_{max}\sqrt{r_i^2 + R_{max}^2 - 2r_iR_{max}\cos\frac{\Theta}{2}} = r_i^2$. This is a quartic equation with respect to r_i, which is expressed as

$$r_i^4 - R_{max}^2 r_i^2 + 2R_{max}^3\cos\frac{\Theta}{2}r_i - R_{max}^4 = 0. \tag{30}$$

This equation has a unique solution via the following proposition.

Proposition 1: Define $g(r_i) = r_i^4 - R_{max}^2 r_i^2 + 2R_{max}^3\cos\frac{\Theta}{2}r_i - R_{max}^4$. A unique solution r_i^* exists within the range $[R_{min}, R_{max}]$ satisfying $g(r_i) = 0$ if and only if $0 < \Theta < 120°$.

Proof: First, we verify the following:

$$\begin{aligned} g(R_{min}) &= R_{min}^4 - R_{max}^2R_{min}^2 + 2R_{max}^3R_{min}\cos\frac{\Theta}{2} \\ &\quad - R_{max}^4 < 0, \end{aligned} \tag{31}$$

$$\begin{aligned} g(R_{max}) &= R_{max}^4\left(2\cos\frac{\Theta}{2} - 1\right) > 0, \\ &\quad \text{if } \Theta < 2\cos^{-1}\frac{1}{2} = 120°. \end{aligned} \tag{32}$$

The first derivative of $g(r_i)$ is obtained as

$$g'(r_i) = 4r_i^3 - 2R_{max}^2 r_i + 2R_{max}^3\cos\frac{\Theta}{2}. \tag{33}$$

Subsequently, we verify the following:

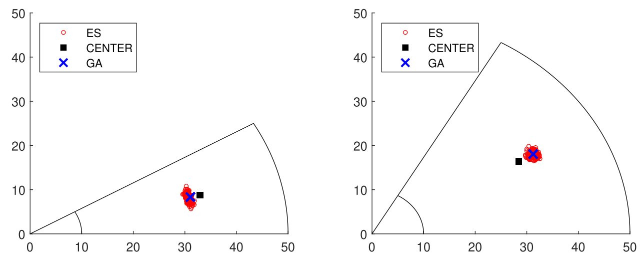
$$g'(R_{min}) = 4R_{min}^3 - 2R_{max}^2R_{min} + 2R_{max}^3\cos\frac{\Theta}{2} > 0, \tag{34}$$

$$g'(R_{max}) = 2R_{max}^3\left(1 + \cos\frac{\Theta}{2}\right) \ge 0. \tag{35}$$

Next, we find the minimum of $g'(r_i)$ when $r_i \in [R_{min}, R_{max}]$. From the second derivative $g''(r_i) = 12r_i^2 - 2R_{max}^2 = 0$, $g'(r_i)$ has a minimum value when $r_i = \frac{R_{max}}{\sqrt{6}}$. Therefore, the minimum value of $g'(r_i)$ is expressed as

$$\begin{aligned} g'\left(\frac{R_{max}}{\sqrt{6}}\right) &= 2R_{max}^3\left(\cos\frac{\Theta}{2} - \frac{\sqrt{6}}{9}\right) > 0 \\ &\quad \text{if } \Theta < 2\cos^{-1}\left(\frac{\sqrt{6}}{9}\right) = 148°. \end{aligned} \tag{36}$$

From (34)-(36), $g'(r_i)$ is an increasing function when $r_i \in [R_{min}, R_{max}]$ and $\Theta < 148°$. In addition, $g(0) < 0$ and $g(R)$



(a) (b)

Fig. 3. Distribution of optimal CH when (a) $\Theta = 30°$ and (b) $\Theta = 60°$.

> 0 if $\Theta < 120°$. Therefore, a unique solution, $R_{min} < r_i^* < R_{max}$ satisfying $g(r_i^*) = 0$ exists. ∎

Finally, the optimal coordinates of the CH are determined as follows:

$$i^* = \begin{cases} r_i^*\angle\frac{\Theta}{2}, & \text{if } r_i^* < R_{max}\cos\frac{\Theta}{2} \\ R_{max}\cos\frac{\Theta}{2}\angle\frac{\Theta}{2}, & \text{otherwise} \end{cases} \tag{37}$$

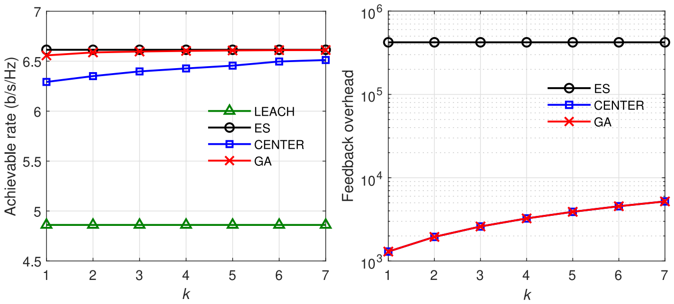
where r_i^* is a solution of (30).

IV. Result and Discussion

For performance evaluation, we assume a sector with $R_{min} = 10$ m and $R_{max} = 50$ m and vary the sector angle from $10°$ to $60°$, considering an environment where the sensors experience sufficient EH level [13]. We randomly distribute the sensor nodes in the sector region and change the number of sensor nodes in the sector according to the node density in the range of 0.2 to $2/m^2$. The default values of the sector angle of $30°$ and the node density of $1/m^2$ are used unless stated otherwise. Regarding the constants, we set $\zeta = 0.5$, $\eta = 0.9$, $\mathcal{G} = -3$ dB, $\alpha = 2.7$, $G_1 = 20$ dB, G_2 =3 dB, $T_e = 5$ s, and $T_d = 0.1$ s [7]. We compare the proposed GA-based CH selection method (simply denoted herein as GA) with the conventional methods of ES, low-energy adaptive clustering hierarchy (LEACH), and CENTER. LEACH is a typical clustering algorithm in which the CH is selected randomly based on the stochastic threshold algorithm [14]. CENTER regards the CH as the node closest to the centroid of the sector [7]. In CENTER and GA methods, we search only the k nodes closest to the centroid and the optimal coordinates obtained using GA, respectively.

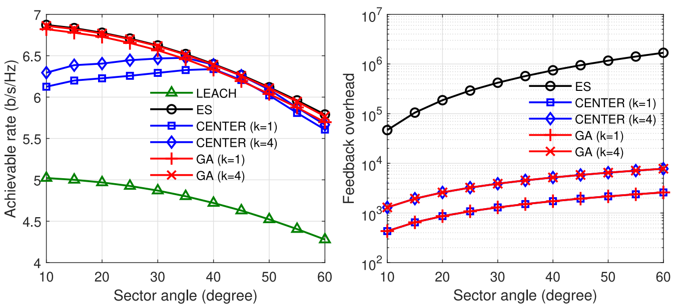
Fig. 3 shows the position of the CHs obtained by ES, CENTER, and GA when $\Theta = 30°$ and $60°$ for 300 random deployments. The square indicates the centroid of the sector, the X-mark indicates the coordinates of the optimal CH obtained by GA, and the circle represents the actual position of the optimal CH obtained by ES in each deployment. As shown, the optimal CHs obtained by ES are distributed near the optimal point of GA rather than that of CENTER; this means that GA finds a point closer to the optimal CH according to the sector angle.

Fig. 4 shows the achievable rate of sensing data and feedback overhead versus the number of search nodes (k) in the CENTER and GA methods. As k increases, the proposed GA approaches the optimal performance of ES, but the conventional CENTER method still exhibits performance differences. In terms of feedback overhead, which is defined as the amount of channel information (i.e., h_i and g_{ij}) required for the



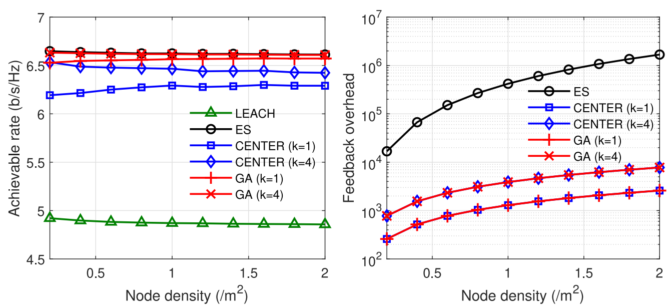
(a) (b)

Fig. 4. (a) Achievable rate and (b) feedback overhead vs. number of search nodes (k).



(a) (b)

Fig. 5. (a) Achievable rate and (b) feedback overhead vs. sector angle (Θ).



(a) (b)

Fig. 6. (a) Achievable rate and (b) feedback overhead vs. node density.

feedback to determine the optimal, the overhead of ES is proportional to N^2 because it considers all combinations of (i, j). Furthermore, the overheads of both CENTER and GA are proportional to k N because they only need to investigate the k nearest nodes. Therefore, the overheads of both GA and CENTER increase with k but are significantly lower compared to that of ES. LEACH exhibits the lowest rate because it selects the CH randomly without considering the channel information among the nodes [14]. Hence, LEACH does not require channel feedback and so we omit its overhead performance herein.

Fig. 5 shows the achievable rate and feedback overhead versus the sector angle (Θ). As Θ increases, the achievable rate decreases because the sector coverage increases and the wireless channel between the nodes deteriorates. The performance of the proposed GA is close to the optimal performance of ES regardless of the sector angle; however, CENTER does not exhibit such performances as the sector angle gets smaller or larger. As shown, the rates of GA and CENTER increase for a larger k (i.e., $k = 4$) but their overheads increase accordingly.

Fig. 6 shows the achievable rate and feedback overhead versus the node density. In all methods, the rate is not significantly affected by the node density because the achievable rate is governed by the minimum rate of the transmission links. Similarly, the proposed GA approaches the optimal performance of ES while significantly reducing the feedback overhead.

V. Conclusion

In this letter, we considered a sectorized WPSN and formulated an optimization problem to obtain the optimal CH that maximizes the sensing data rate. To obtain the optimal CH with low overhead, we performed an asymptotic GA that determined the optimal coordinates of the CH in the sector area analytically. The simulation results showed that the optimal CHs were in fact distributed near the optimal coordinates obtained by GA, and that the proposed GA-based CH selection method maximized the sensing data rate while reducing the feedback overhead significantly. We expect our GA approach to be applicable for optimal CH selection with low overhead in the future WPSN environment where WET technology is practically used.

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