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Data-Gathering and Aggregation Protocol for Networked Carrier Ad Hoc Networks: The Optimal and Heuristic Approach

Chao Gao, Guorong Zhao and Jianhua Lu

Additional information is available at the end of the chapter

Abstract

In this chapter, we address the problem of data-gathering and aggregation (DGA) in navigation carrier ad hoc networks (NC-NET), in order to reduce energy consumption and enhance network scalability and lifetime. Several clustering algorithms have been presented for vehicle ad hoc network (VANET) and other mobile ad hoc network (MANET). However, DGA approach in harsh environments, in terms of long-range transmission, high dynamic topology and three-dimensional monitor region, is still an open issue. In this chapter, we propose a novel clustering-based DGA approach, namely, distributed multiple-weight data-gathering and aggregation (DMDG) protocol, to guarantee quality of service (QoS)-aware DGA for heterogeneous services in above harsh environments. Our approach is explored by the synthesis of three kernel features. First, the network model is addressed according to specific conditions of networked carrier ad hoc networks (NC-NET), and several performance indicators are selected. Second, a distributed multiple-weight data-gathering and aggregation protocol (DMDG) is proposed, which contains all-sided active clustering scheme and realizes long-range real-time communication by tactical data link under a time-division multiple access/carrier sense multiple access (TDMA/CSMA) channel sharing mechanism. Third, an analytical paradigm facilitating the most appropriate choice of the next relay is proposed. Experimental results have shown that DMDG scheme can balance the energy consumption and extend the network lifetime notably and outperform LEACH, PEACH and DEEC in terms of network lifetime and coverage rate, especially in sparse node density or anisotropic topologies.

Keywords: navigation carrier ad hoc networks (NC-NET), clustering protocol, data-gathering and aggregation (DGA), QoS aware

1. Introduction

The emerging advantages of wireless network inspire other technical fields to solve their own bottlenecks through the network approach [1]. In our researches, we devote to put forward a network-aware solution for a bottleneck of modern navigation technology, which restricts it from stage of a higher level [2]. That is, the level of navigation efficiency is closely related to self-contained degree of navigation system; on one hand, the upgrade of its integrity will increase the burdens on economic investment and physical load; on the other hand, if we simplify the complexity of navigation equipment to alleviate the above burdens, its navigation capacity will be degraded accordingly. In previous works [2–6], we have proposed a novel network architecture, namely, navigation carrier ad hoc networks (NC-NET), to handle the navigation-related issues, in terms of cooperative navigation, localization, target tracking and multimedia data exchange, through a network approach. The proposed NC-NET, which is essentially ad hoc network between navigation carriers (NCs), is surveyed as a new network family. Hereinto, navigation carrier is defined as the carrier that has the demands of localization and/or navigation, such as aircraft, car, ship, submarine, buoyage system, satellite or pseudo satellite, etc. In Refs. [2, 3], we have finished partial protocols and mechanisms as follows: (i) the protocol framework and the models in physical layer [2]; (ii) a diffserv-based dynamic cooperative MAC protocol, i.e., DDC-MAC [3]; and (iii) the network-based localization mechanisms [4–6]. As part of a series of research work, the main objective of this chapter is to develop a data-gathering and aggregation (DGA) protocol with full account of the unique challenges in NC-NET.

In previous literature, the DGA problem has been investigated extensively [7–12], to prioritize and manage the resource sharing according to the unique requirements of each traffic class. However, in DGA of NC-NET, we should integrate into account several unique challenges that never handled in existing work, including (i) coexistence of multiple traffic services with heterogeneous QoS requests; (ii) coexistence of short-range and long-range traffic requests; and (iii) harsh routing environment, i.e., sparse network density, long-range transmission and high dynamic topology.

Several clustering algorithms are presented for VANET such as [13–26]. However, these algorithms do not show how the routing is performed according to their clustering algorithms after the cluster formation. Hence, they do not guarantee the network topology during the routing process. Their clustering algorithms ignore as well the quality of service requirements important for safety, emergency and multimedia services. On the other hand, QoS-based clustering algorithms take into consideration the quality of service metrics such as bandwidth, energy and end-to-end delay to group the nodes. However, they ignore the high speed mobility metrics which makes them inefficient to deal with NC-NET. The optimized link state routing (OLSR) [15] is a proactive routing protocol that has been modeled to cope with mobile ad hoc networks (MANETs). Its basic idea is to elect a cluster head for each group of neighbour nodes and divide hence the network into clusters. These heads then select a set of specialized nodes called multipoint relays (MPRs). The function of the MPR nodes is to reduce the overhead of flooding messages by minimizing the duplicate transmissions within the same zone. QoS-OLSR [17] is an enhanced version of OLSR that extends the MANET network lifetime taking into consideration the available bandwidth and the residual energy per node during cluster head election and MPR node selection. Nonetheless, this protocol does not

consider the mobility of nodes while computing the QoS. Thus, nodes with high bandwidth, energy and mobility may be elected as cluster heads which leads to recurrent disconnections. Likewise, the MPRs selected according to this protocol do not satisfy both mobility constraints and routing parameters (end-to-end delay and packet delivery ratio). Moreover, the MPR selection algorithm according to QoS-OLSR is vulnerable to cheating in the sense that some nodes may claim bogus QoS values in order to ensure being selected as MPRs. Furthermore, QoS-OLSR does not advance any MPR recovery algorithm able to select quick alternatives and keep the network connected in case of link failures.

With these comparisons, it is clear that the results on challenge (i), challenge (ii) and their hybrid are extensive; however, in harsh environment that of challenge (iii), the integrated investigates on challenges (i) and (ii) are quite limited. From above analysis, we identify the missing properties in the existing work for QoS provisioning in NC-NET and introduce the design and implementation of a new distributed multiple-weight data-gathering and aggregation protocol (DMDG) protocol for NC-NET. DMDG is designed with key features to support the above three challenges. These features include the following: first, the network model is addressed according to specific conditions of networked carrier ad hoc networks (NC-NET), and several performance indicators are selected. Second, a distributed multiple-weight data-gathering and aggregation protocol (DMDG) is proposed, which contains all-sided active clustering scheme and realizes long-range real-time communication by tactical data link under a TDMA/CSMA channel sharing mechanism. Third, an analytical paradigm facilitating the most appropriate choice of the next relay is proposed. To optimize the performance of DMDG, the aforementioned contributions are theoretically analysed and evaluated. Finally, the results demonstrate the efficiency of our protocol by comparing to other contemporary MANET routing protocols. Experimental results have shown that DMDG scheme can balance the energy consumption and extend the network lifetime notably and outperform LEACH, PEACH and DEEC in terms of network lifetime and coverage rate, especially in sparse node density or anisotropic topologies.

The remainder of this chapter is organized as follows. Section 2 introduces the network model and evaluates indicators of NC-NET. Section 3 presents the details of the proposed DMDG protocol, including the clustering algorithm, data aggregation and communication scheme and the three-dimensional routing algorithm. Section 4 presents the numerical analysis and simulation of our scheme, along with the corresponding results. Finally, in Section 5, we summarize this chapter with conclusions and prospect.

2. Network model and problem formulations

In the area of cluster-based wireless sensor networks, the previous research is quite extensive, with energy efficiency and scalability being the main focus of many of the clustering protocols proposed so far [6–10]. Meanwhile, much research has been done on sensor activation protocols, which focus on selecting a subset of the active sensor nodes that are sufficient to satisfy the network's coverage requirements. Compare to traditional ad hoc network, NC-NET has special characters in a couple of aspects, including high-powered links, high-speed nodes and sparse and very-large-scale working range. In this section, we discuss the related work that has been done taking into account these points.

2.1. Network model

In this subsection, we first introduce the characteristics of ad hoc network and then define the network model of navigation carrier ad hoc network. We model the ad hoc network as a graph, $G = (C, E, R_c)$, which consists of a set of mobile nodes, $C = \{C_1, C_2, \cdots, C_m\}$, and a set of wireless links, E; each sensor node consists of components of sensing, computing and wireless transmission. Assume that each node has the same transmission radius R_t and the same sensing radius R_s. The notations used in this chapter are defined in **Table 1**.

Before discussing the nature of this problem, we give the following assumptions for the feasibility of the NC-NET, which include monitor area, transmission channel and communication environment.

Assumption 1 (Monitor area). The monitor area of NC-NET A_c is a cylinder, which is equivalent with the tradition definition of monitoring area.

$$A_c = \left\{(x, y, z) | x^2 + y^2 \leq R_{\text{cov}}, 0 \leq z \leq h_{\text{cov}}\right\} \tag{1}$$

where R_{cov} is monitor radius and h_{cov} is monitor height.

Assumption 2 (Signal link). The transmission path adopts tactical data link. To meet the requirement of real-time performance and reliability, R_c is defined as 1/3 – 1/5 ratio to the effective transmission radius of the link and assumed that the bit error rate (BER) is invariable.

Assumption 3 (Communication environment). The statistical property of the NLOS propagation accords with exponential distribution, while the time delay accords with Bernoulli distribution. The coupling and interference in electromagnetic environment are mutually independent white noise with zero mean.

Figure 1 is an example of NC-NET, in which the type of area coverage A_{c-1} is considered. $A_{c-1} \subset A_c$ and d_{ch-ch}, d_{ch-M}, d_{ch-unk}, d_{ch-ag} represent the distance between neighbour cluster heads, cluster head to cluster member, cluster head to uncertain node and cluster head to agent

Notation	Definition
A_c	Work area of the NC-NET
$C = \{C_1, C_2, \cdots, C_m\}$	Set of NC-NET mobile nodes
$E = \{(i, j) \mid s(i, j) \leq 2R_c\}$	Set of wireless links
$C_{Msg} \in G$	Structure message of NC-NET nodes $C = (ID, HD, Type, XYcord, Nbn, CP, Nbs[])$
$Link_j^i(\tau)$	Signal links between node i and j at time τ
$Type_k^i$	Type of the node i in cluster $k, Type_k^i \in \{Memb, CH, agent, NR, toCH, toNR\}$
$R_{msg}(i)$	Maximum transmission range of node i
$R_c(i)$	Sensing radius of node i
$T_{life}(i)$	Lifetime of network sensor i

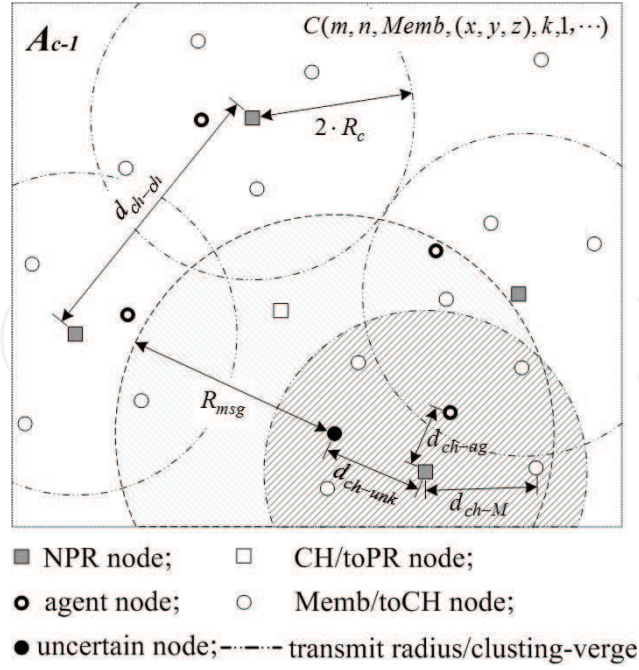**Table 1.** Notation and definition in NC-NET.

Figure 1. Sketch map of NC-NET model.

node, respectively. $2R_c$ is the cluster radius, and R_{msg} is the searching radius of uncertain node. Each interested grid has at least one sensor node within it, or the grid can be sensed by neighbour sensors.

2.2. Evaluating indicators

2.2.1. Coverage relevant model

Coverage is an important issue of ad hoc networks and is closely related to energy saving, connectivity and network reconfiguration [11–14]. The following is the main methods, which is adopted to assess coverage, comprising 3D k-coverage model and the necessary and sufficient condition (NSC) (**Table 2**).

Definition 1 (3D k-covered problem). Given a set of N sensors in area P, the radius of sensor node is R_c, if there is $C_{i1}, …, C_{ik} \in \{C_1, …, C_N\}$, $k \geq 1$. In this case, every position v in area P can meet the following formula.

$$v \in \bigcap_{j=1}^{k} \left\{ x \big| dist(x, C_{ij}) \leq R_c \right\} \tag{2}$$

Then area P is 3D k-coverage by $\{C_1, C_2, ···, C_N\}$.

Theorem 1 is the necessary and sufficient condition used to determine the connected coverage set, which has been proved by Zhang and Hou in literature [23].

Theorem 1. Given a set of N sensors C in three-dimensional area P, $C = \{C_1, C_2, ···, C_N\}$, the communicating radius of sensor node is R_c; the sensing radius of sensor node is $R_c \geq 2R_s$.

Input: Sensing range R_s, maximum transmission range R_t, sensor nodes set V, and ε_0.

Output: *agent*, C_{CH}, C_{PR}.

1.	for all $u,v \in V(G)$, $i \in NEW(G)$ do
2.	while round==1//NC-NET initialization
3.	C[v].{ID, Type} ←sensor[i].{PRI, Power}
4.	Subprogram GetFirst_CHs();
5.	end-while
6.	while round==0//NC-NET regular circuit
7.	if(C.new∩V(G)=Ø‖C[i]∩V(G)=Ø)
8.	Subprogram NEW_DEAD();
9.	elseif(toCH[v]∪toAgent[v]≠Ø)
10.	Subprogram RENEW_agent();
11.	Subprogram RENEW_CHs();
12.	CHs[v]←NEW_CHs[v]; AGs[v]←NEW_AGs[v];
13.	end-if
14.	CHs[u] ←CHs[v]; AGs[u] ←AGs[v];
15.	CHs.{} ⇌ Ags.{};
16.	BroadcastMsg(Ags[u].{ID,nbn,*Level*,CP});
17.	BroadcastMsg(CHs[u].{ID,nbn,*Level*,CP});
18.	while(toPR[v]≠Ø&round==0)
19.	Subprogram RENEW_PRs();
20.	BroadcastMsg(C[i].{ID,nbn,*Level*,CP})
21.	end-while
22.	BroadcastMsg(C[i].{ID,nbn,*Level*,CP});
23.	end-for

Table 2. Main clustering procedure pseudo-code.

$\exists$ $C_i \subset C$, $C_i = \{C_{i1}, \cdots, C_{ik}\}$. If sensing area of C_i can complete cover P, the set $C_i = \{C_{i1}, C_{i2}, \cdots, C_{ik}\}$ is a connected coverage set.

2.2.2. Link consumption indicator

Link quality is one of the key factors which affected the application of ad hoc network technique. In this chapter, we adopt tactical data link to extend it to solving the fleet-network-build-up problem, in which the following link consumption model is adopted.

In relatively short distances, the propagation loss problem is modelled as being inversely proportional to d^2, whereas for longer distance, it is inversely proportional to the propagation to d^4. Power control can be used to invert this loss by setting the power amplifier to ensure a

certain power at the receiver [15–17]. Therefore, to transmit and to receive an l-bit packet in distance d, the radio expends the following energy, respectively:

$$
\begin{aligned}
E_{Tx}(l,d) &= l \cdot E_{Tx-elec} + E_{Tx-amp}(l,d) \\
&= \begin{cases} l \times E_{elec} + l \times \varepsilon_{ft} \times d^2 & d < d_0 \\ l \times E_{elec} + l \times \varepsilon_{amp} \times d^4 & d \geq d_0 \end{cases}
\end{aligned}
\tag{3}
$$

$$
E_{Rx}(l,d) = E_{Rx-elec}(l) = l \times E_{elec} \tag{4}
$$

where d_0 is the free space model and multipath fading model. $E_{Tx-elec}$ is the electronics energy and depends on factors such as digital coding, modulation, and filtering of the signal before it is sent to the transmit amplifier. The parameters ε_{ft} and ε_{amp} depend on the required sensitivity and the noise figure of the receiver [12].

For the experiments described in this chapter, we adopted the parameters of the radio chips similar to those in [2] to determine the parameter values in (1) and (2). Then we have the representative values of the parameters ε_{amp} = 0.0013 pJ/bit/m^4, E_{elec} = 50 nJ/bit and ε_{ft} = 10 pJ/bit/m^2.

3. Distributed multi-weight data-gathering and aggregation protocol

In this section, we present the distributed multiple-weight data-gathering and aggregation protocol (DMDG) after describing the network model and evaluating indicator adopted, which consists of three parts as described in the following subsection.

3.1. Clustering algorithm

The hierarchical clustered sensor network is composed of a number of clusters. The following are some important definitions used in the clustering algorithm.

Definition 2 (Initial probability for cluster head)

$$
p_{init} = \beta \cdot ID_i/ID_{max} + (1-\beta) \cdot GDOP_i/GDOP_{max} \tag{5}
$$

where ID_i is the initial priority of sensor node i, ID_{max} is the maximum priority within the spherical radius r_c, $GDOP_i$ is the geometric distribution of position (GDOP) of sensor node i, $GDOP_{max}$ is the optimum GDOP within the spherical radius r_c, and β is a self-adapting weighing factor.

Definition 3 (Electing factor for cluster head, EFCH)

$$
W_i = \alpha \cdot \left(E_{ij}/\overline{E}^r \right) + (1-\alpha)/2 \cdot \frac{d_{max} - d_{toBS}^i}{d_{max} - d_{toBS}} + (1-\alpha)/2 \cdot GDP_k \tag{6}
$$

where α is a self-adapting weighing factor, $\alpha = 1/(2 + \beta)$, $(\beta = E_{ij}/\bar{E}^r)$. E_{ij} is the mean energy value of communicated consumption between sensor node C_i and other nodes in the same cluster,

$\bar{E}^r = E_{total}(r)/m$. d^i_{toBS} is the distance between C_i and cluster head node CH_k. d_{toBS} is the distance between CH_k and the cluster centre, $d_{toBS} = \sum\limits_{i=1}^{m} d^i_{toBS}/m$. GDP_k is the GDOP of cluster head node CH_k.

Definition 4 (Correlation among sensor nodes). $\forall$ C_i, $C_j \in G(V)$, $\exists$ $R(C_i, C_j) \in R^+$, $i \neq j$, if $\|D(C_i, C_j)\| \leq r$, $\|R(C_i, C_j)\| = 1$; else if $\|D(C_i, C_j)\| > r$, $\|R(C_i, C_j)\| = n + 1$, where n is the sensor number between C_i and C_j, r is the average 1-hop distance, and then $R(C_i, C_j)$ is called as the correlation between node C_i and C_j.

Now we describe our cluster formation algorithm in detail. The algorithm consists of three stages. In the initial stage, NC-NET nodes initiate the clustering procedure (Lines 2–5), round=1; NC-NCT nodes *sensor*[i] join into the network and obtain their own *ID*s and *Type*s, which are proportional to *PRI* and *power* of their link terminal; then run the subprogram *GetFirst_CHs*() to elect the first cluster head and agent, which is direct ratio to *ID* and *Type*.

When NC-NET is formed, round = 0, the program of regular circuit (Lines 7–21) will be performed. In the beginning of every cycle, cluster heads should judge whether there are new-coming requisitions *C.new* or new-dead node and judge whether there are new requisition for cluster head to *CH*[v] and for agent to *Agent*[v] and then execute relative treating subprograms *NEW_DEAD*(), *RENEW_agent*() and *RENEW_CHs*(), in which the first one is related to *ID*s and *Type*s and the last two subprograms are mainly determined by p_{init} and W_i which is defined in Definition 2 and Definition 3. When CHs[i] is selected as a cluster head, it broadcasts message *Msg*() to all other nodes to indicate its identity and adjust TDMA format. The agent and cluster head also communicate every cycle to back up information to preserve robustness and stability of the network. The procedure also handles the request for reference nodes *RENEW_PRs*() to realize renew of the network and assure load balance of the clustering protocol.

3.2. Data aggregation and communication scheme

This subsection presents the data aggregation mechanism and the communication mode among NC-NET nodes. The data transmitted among network members mainly has four portions, including the communication between reference nodes C_{PR} and cluster head C_{CH}, cluster head C_{CH} and the neighbour cluster head, cluster head C_{CH} and the cluster member C_{CM} and cluster member C_{CM} and the 2-hop neighbour node. Each transmission process has its own packet mode, including broadcast, data-centric, local transmission and multicast. The data packets have a unified scheme, main portions of which are shown in **Table 3**. Mainly composed of synchronous head, node's structural information C_{Msg}, sphere coordinate coefficient TS_{CA}, relative velocity V_C, heading angle φ_C and system time t_A. The received variables should accord with transmission demand and uniform formats, and the redundant information should be neglected.

- **NR-CH**: The data packet between reference node and cluster head node C_{CH} has three kinds of process: (i) the position reference nodes C_{PR} broadcast global coordinate information and the network distributing variable to cluster head nodes C_{CH}; (ii) the time reference

Packet	head	C_{Msg}	TS_{CA}	V_C	ϕ_C	t_A
NR-CH	√	√	√	–	√	√
CH-CH	√	√	–	–	–	√
CH-CM	√	√	√	–	–	√
CM-CM	√	√	–	√	√	–

Table 3. The format of data packet.

nodes C_{TR} broadcast system time t_A to C_{CH} and other network member; (iii) C_{CH} uploads its own sensing parameter and cluster member dynamic information to neighbour C_{PR}, which can be used for the next reference nodes' election.

- **CH-CH**: This transmitting process is to modify localization information for each other, which is used to define cluster verge. It is also used to acquire *ID* of neighbour cluster head node, which can be a relay node for multi-hop transmission.

- **CH-CM**: In this process, cluster head C_{CH} collects sensing information from its own cluster members C_{CM}, which is used for data aggregation and fusion. Then C_{CH} transmits system time t_A, transition matrix TS_{CA} and other information to C_{CM} under a TDMA channel sharing mechanism.

- **CM-CM**: In this process, cluster head C_{CH} broadcast sensing information to neighbour cluster heads in its own TDMA-based time slot. This information is mainly used to correct navigation parameters including position, velocity (or relative velocity) and heading angle. Other information is calculated into evaluating indicators, which are defined in Sections 2.2 and 3.1, for the next cluster head election.

3.3. Three-dimensional routing algorithm

When the network is clustered, specific methods for intra-cluster and intercluster communications depend on applications. For intra-cluster communication, the nodes can directly send data to the cluster head using time-division multiple-access (TDMA) schedule, just as in LEACH [7].

As shown in **Figure 2**, when node *B* broadcasts a packet, all the one-hop neighbours receive that packet. In order to avoid recipient ambiguity in a local broadcast, the incoming label of a node must be unique at least in its 2-hop neighbours. In the label assignment phase, the cluster head must execute an algorithm to ensure that each node is allocated a unique incoming label. A 3D heuristic routing algorithm is proposed for this purpose, which can be expatiated in the following example.

- **Step 1**: When node *A* receives the request packet from the node *B*, firstly, estimate whether the distance between nodes *B* and *A* (d_{AB}) satisfies the responding condition, $d_{AB} \leq 2 \cdot R_c$, and calculate the number of optimum hops (K_{hop}) if the condition is satisfied; if not, ignore the request. As shown in **Figure 2**, $K_{hop} = 3$.
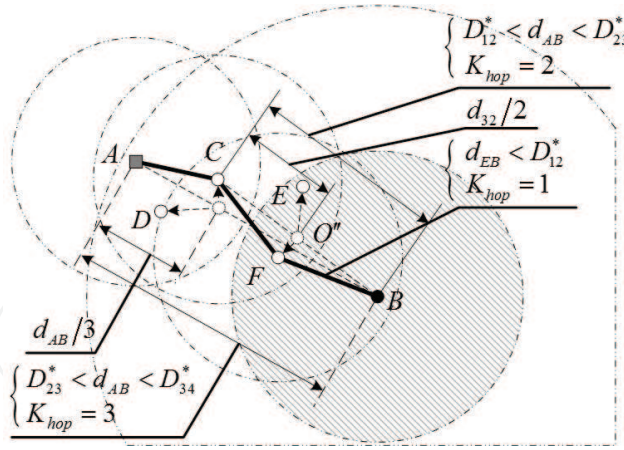
Figure 2. Geographic routing algorithm in NC-NET.

- **Step 2**: Node A computes the first trisection point O' between A and B based on geographic position got from the request packet, and then confirm point O' as the ideal next-hop position.

- **Step 3**: Node A compares all the distance between one-hop neighbour (nodes C and D) and point O'; then choose the next-hop node with the following equation, $Hop_i = \min_i \{|P_i - P_{opt}|\}$, in which i is ID of one-hop neighbours. So in the case of Step 2, the next-hop neighbour of node A is C, which obtains the information packet.

- **Step 4**: Node C repeats the steps (Steps (1)–(3)), and confirm the next-hop relay E, where $K_{hop} = 2$; then the node F obtains its next-hop relay B, where $K_{hop} = 1$. So the route is confirmed and the information transmitted through the route A-C-F to B; the routing procedure is finished.

4. Performance evaluation and simulation

To evaluate the performance of our scheme and compare it to both the association sponsor and central angle method, a set of simulations have been carried out, which are described in the following section.

4.1. Simulation setup

In our simulations, the NC-NET nodes are distributed schematically in a cubic region, and the number of nodes is varying from 5 to 50. In each simulation experiment, the deployment of sensor nodes is with a sparse setting and is in clusters based on DMDG. The default parameters used in both the simulations and the analysis are summarized in **Table 4**.

The proposed DMDG protocols were evaluated by extensive computer simulations by Matlab 2014 and compared with LEACH [7], DEEC and PEACH. The performance compared includes network lifetime, costs associated to clustering and backbone formation, as well as the

Parameters	Values
Network size ($Rcov,h$) (km)	20,2
The number of sensor nodes	5–50
Sensing range (Rc) (m)	5000 ~ 10,000
Maximum transmission range ($Rtmax$) (m)	15,000
Time interval for reporting data	30 s
MAC protocol	TDMA/CSMA
Radio frequency (MHz)	960 ~ 1206
E_{elec} in the energy model (μJ/bit)	1.16
d_0 in the energy model (km)	10
ε_{ft} in the energy model (pJ/bit/m^2)	10
ε_{amp} in the energy model (pJ/bit/m^4)	0.0013

Table 4. Main simulation parameters.

properties of generated clusters [19–24]. We assume that all the messages received from the cluster members can be aggregated into a single message.

Three kinds of scenarios are conducted in this simulation: (i) the average power consumption per node obtained by using LEACH, DEEC and DMDG; (ii) the lifetime and stable periods of the related LEACH, DEEC, PEACH and DMDG protocols; and (iii) the coverage rate versus proportion of dead nodes in different sensing range R_c = 5, 8, 10 km. We choose these scenarios because they are key factors in reflecting the efficiency of major technical points of DMDG protocol.

4.2. Performance result and analysis

As an addressing basic of the clustering process, it is critical to answer two questions before inspecting the proposed clustering protocol: (i) how does the number of nodes impact on the average power consumption, and (ii) how does the number of nodes impact on the average number of hops. The objective of the first scenario is to answer them through a simulation approach. **Figure 3** presents the average power consumption per node obtained by using LEACH, DEEC and DMDG and average number of hops versus the number of nodes when the maximum transmission range R_{msg} = 15, 000 m, and the number of the node increase from 5 to 50.

It is clear in **Figure 3(a)** that DMDG always achieves the lowest power consumption and a relative stable hop number, $N_{hop} \approx 2$, which is gradually increasing in LEACH and DEEC. The average power consumption using DMDG can be as low as 0.637 when compared to LEACH and 0.824 when compared to DEEC. The stability in average number of hops results in stable of end-to-end delay; this can prove to be an advantage since it is convenient for estimating end-to-end delay and guarantee a data synchronism.
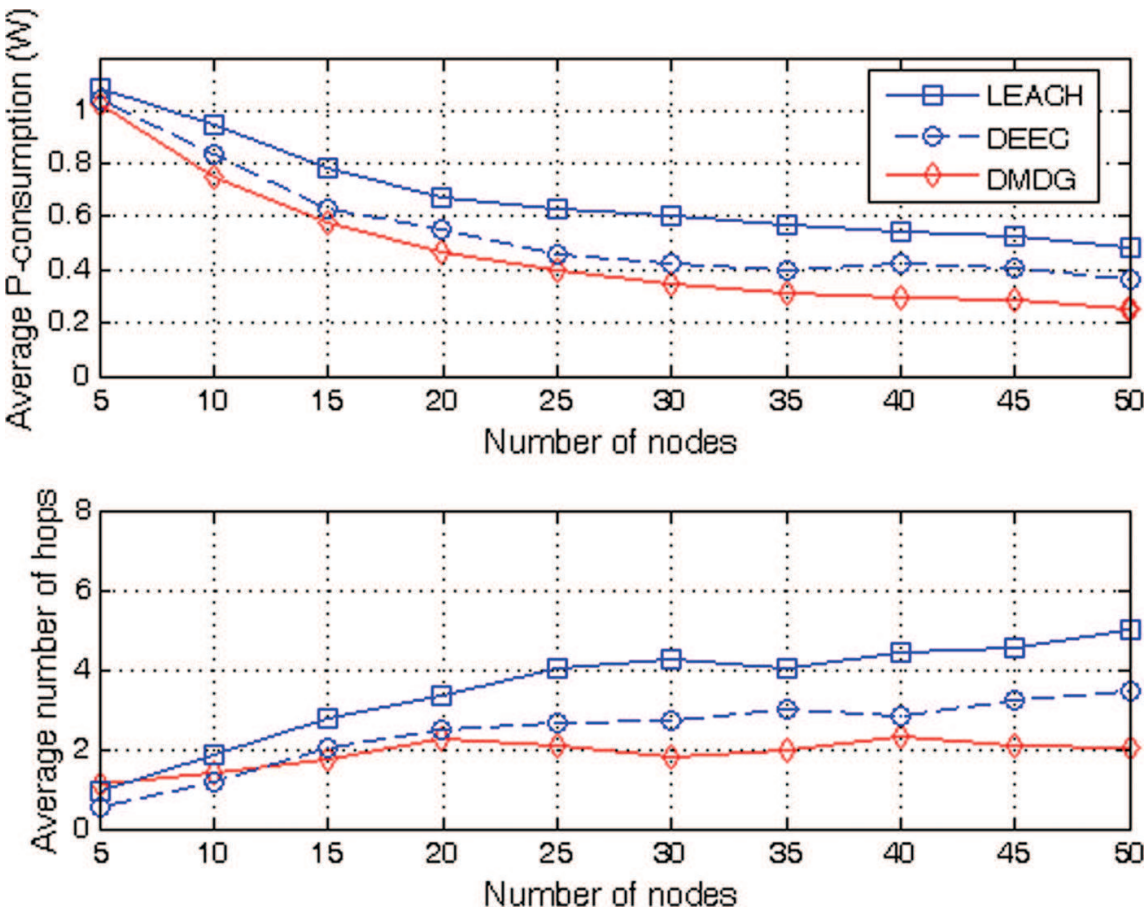
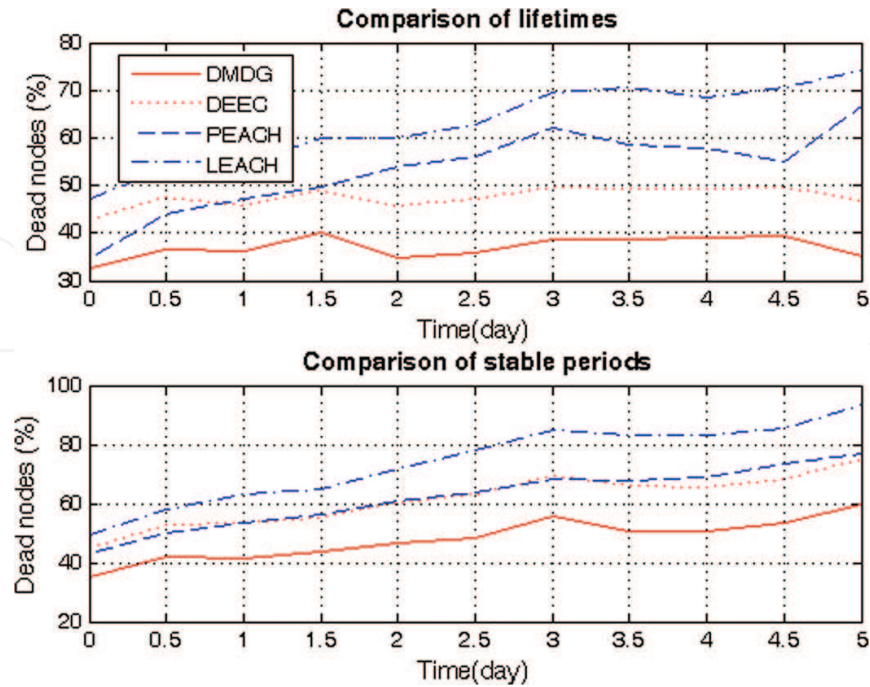**Figure 3.** Average power consumption and average number of hops versus the number of nodes, N.

Figure 4. Comparison of lifetime and stable periods between LEACH, PEACH, DEEC and DMDG.
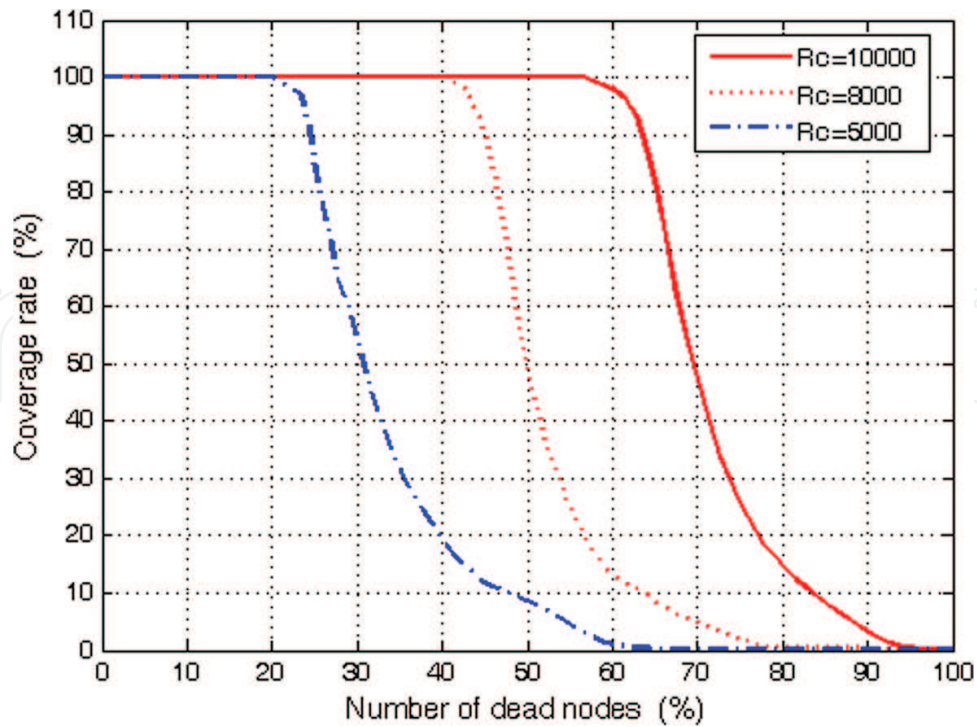
Figure 5. Coverage rate versus number of the dead nodes (R_c = 5, 8, 10 km).

Then, in the second scenario, we aim to investigate the lifetime and stable periods of the related LEACH, DEEC, PEACH and DMDG protocols, because the result is closely related with the topological balance of the NC-NET. The simulation results are presented in **Figure 4**. In the case of networks using DMDG with the maximum transmission range R_{msg} = 5000 m, the proportion of dead nodes (renew for mission) is 26% in lifetime and increases slowly in stable period (about 51% in the 4th day), which is much better than other protocols.

As the last scenario, we investigate the coverage rate performance with the increase of dead node, and the results are depicted in **Figure 5**. In this simulation, the coverage rate performance has been evaluated under three kinds of sensing range, that is, R_c = 5, 8, 10 km. The tendency curves of coverage rate have been compared with the increase of the number of dead node. Besides, DMDG protocol adopts the *3D*-coverage model, which is introduced in **Definition 1**, k = 2. The result has shown that DMDG can achieve a full two-coverage if the number of the dead nodes $n_{dead} \leq 11$ when R_c = 5 km, $n_{dead} \leq 20$ when R_c = 8 km and $n_{dead} \leq 29$ when R_c = 10 km; this conclusion approves that the DMDG protocol can guarantee a high-coverage environment in a fleet network with low-density in-motion nodes.

5. Conclusions

This chapter presented a new clustering and routing scheme, namely, the distributed multiple-weight data-gathering and aggregation protocol (DMDG), in order to work under long-distance sparse NC-NET and efficiently guarantee a long stable coverage rate through a unit circle

test. Simulation results show that DMDG protocol can significantly extend the network life-time when compared with other approaches. The NC-NET with DMDG protocol is equally applicable to the cases of three-dimensional localization and in-flight alignment for carrier-based aircraft. The detail performance evaluation of these cases will be resolved in the following research.

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