

MILEACH: An Enhanced Mobility-Aware Clustering Protocol for Continuous Communication During Emergency Situations

Ghefar Alrefai

Associate professor at the Dept. Information and Communication Engineering, Faculty of Engineering, EBLA Private University
and Lecturer at Cordoba Private University.

Abstract - Ensuring continuous communication after infrastructure damage or severe congestion remains a core requirement of public-safety networks. In such conditions, even a short-lived connection can determine whether rescue information reaches first responders in time. Fifth-generation (5G) systems, and the emerging 5G-Advanced and IMT-2030 (6G) frameworks, support Device-to-Device (D2D) / New Radio (NR) sidelink operation when a gNodeB is overloaded, partially destroyed, or out of reach. This paper presents Mobile Improved Low-Energy Adaptive Clustering Hierarchy (MILEACH), a decentralized clustering protocol designed for energy-efficient D2D communication among mobile user equipment (UE) during emergencies. Clusters are first organized as circular patches following the I-LEACH construction. A genetic algorithm then re-elects the cluster head (CH) using battery capacity, residual charge, intra-cluster distance, node mobility, and coverage intensity. Re-clustering is triggered only when the CH degrades, leaves, or the cluster collapses, rather than in every round. MATLAB simulations compare MILEACH with I-LEACH and GA-LEACH in static and mobile settings, for square and rectangular areas, and for three gNodeB placements (center, top edge, and corner). MILEACH consistently reduces the number of dead nodes and conserves residual energy; the gain is largest under the harshest coverage conditions.

Keywords: *MILEACH; Device-to-Device (D2D) communication; NR sidelink; cluster-head selection; genetic algorithm; public-safety networks; 5G-Advanced; emergency communications; energy efficiency; mobility-aware clustering.*

1. INTRODUCTION

Global mobile traffic continues to grow at a high rate even after the first wave of 5G deployment. The Ericsson Mobility Report of November 2025 estimates about 2.9 billion 5G subscriptions by the end of 2025 (approximately one-third of all mobile subscriptions) and projects that 5G will carry the majority of mobile data well before 2031 [1]. This traffic pressure, together with the International Telecommunication Union Radiocommunication Sector (ITU-R) IMT-2030 vision for 6G [2], makes resilience under infrastructure failure a first-class design goal rather than an afterthought. Several radio-access tools have been proposed to absorb demand and improve robustness, including millimeter-wave (mmWave) transmission, cell densification, massive multiple-input multiple-output (MIMO), and machine-learning-assisted clustering of D2D users [3]. Among these tools, D2D communication—standardized in 3GPP as proximity services (ProSe) and later as NR sidelink over the PC5 interface—allows nearby UEs to exchange data without traversing a failed or congested Evolved Node B (eNB) / Next-Generation Node B (gNodeB) [3], [4].

In a disaster, a minute of connectivity can decide life or death. Earthquakes, floods, tsunamis, and storms repeatedly disable terrestrial infrastructure. The February 2023 earthquakes in Türkiye and Syria illustrated how the collapse of cellular sites, power grids, and transport routes isolates survivors and delays rescue. Similar coverage holes appear after floods and storms whenever backhaul or on-site power disappears. Effective disaster management therefore requires continuity of voice and data despite damaged sites, battery drain, and coverage holes [5], [6]. Recent mission-critical designs combine D2D clustering with residual-energy-aware cluster-head selection to keep isolated UEs attached to a surviving cell-edge relay [7]. In parallel, 3GPP Release 17 introduced UE-to-Network (U2N) sidelink relay, and Release 18 added UE-to-UE (U2U) relay together with the Sidelink Relay Adaptation Protocol (SRAP) [8]. Release 18 also standardized sidelink positioning, which is directly relevant to locating victims when GNSS is unavailable [9], [10].

Short-range D2D / sidelink links can deliver high rates, yet they suffer from blockage, limited UE batteries, and rapid topology change. Energy harvesting and radio-frequency (RF) wireless power transfer have been studied as complementary supplies [5], but

they do not by themselves organize a large, mobile population. Clustering remains the practical way to improve scalability, load balance, CH lifetime, and routing support in 5G, Internet of Things (IoT), and public-safety networks [6]. Because the number of UEs is large, self-organizing methods—including genetic algorithms (GAs) and other computational-intelligence tools—are used to form clusters and elect CHs [6], [3].

This paper therefore targets continuous communication during emergencies by grouping users that share a geographic neighborhood, electing CHs with a mobility-aware fitness function, and avoiding unnecessary re-clustering. The main contributions are as follows.

- **Protocol design.** a decentralized, D2D-only clustering protocol (MILEACH) that extends I-LEACH circular patches with a GA using battery, mobility, distance, and coverage features.
- **Overhead control.** event-triggered re-clustering instead of a mandatory new CH election in every round, which is better matched to mobile disaster scenes.
- **Evaluation.** a MATLAB comparison with I-LEACH and GA-LEACH for static and mobile UEs, square and rectangular areas, and three gNodeB placements that represent good, weak, and very weak coverage.
- **Standards alignment and future path.** an updated related-work map (2022–2026) and a development roadmap that links MILEACH to Rel-17/18 sidelink relay, UAV-assisted sinks, adaptive weights, interference-aware power control, and IMT-2030 public-safety use cases.

The remainder of the paper is organized as follows. Section 2 reviews the LEACH family and its limitations in mobile D2D settings. Section 3 discusses related work. Section 4 presents the system model and the MILEACH algorithm. Section 5 reports the simulation results. Section 6 proposes developments for 5G-Advanced and 6G public-safety networks. Section 7 concludes the paper.

2. LEACH PROTOCOL AND LIMITATIONS IN MOBILE D2D NETWORKS

2.1 Overview of LEACH

Low-Energy Adaptive Clustering Hierarchy (LEACH) is the reference hierarchical routing protocol for wireless sensor networks (WSNs) [11]. It combines randomized CH rotation, local data aggregation, and time-division multiple access (TDMA) inside each cluster in order to distribute energy load and reduce the number of long-haul transmissions [11], [12]. A typical LEACH topology is shown in Fig. 1: cluster members (CMs) send data to a CH, and the CH forwards an aggregated packet toward the base station.

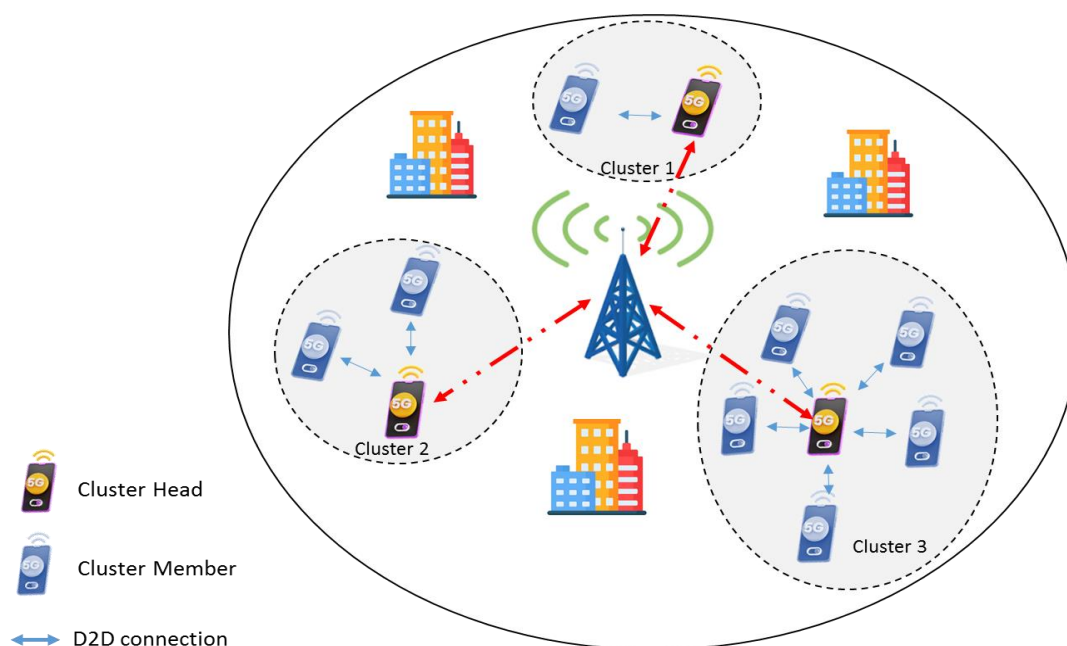


Figure 1. Hierarchical clustering architecture used by LEACH-family protocols: cluster members communicate with a cluster head, which then forwards aggregated traffic to the base station / gNodeB.

Each LEACH round has a set-up phase and a longer steady-state phase (Fig. 2) [13]. In the set-up phase, nodes elect themselves as CHs with a threshold probability and advertise their role; non-CH nodes join the strongest advertiser. In the steady-state phase, the CH issues a TDMA schedule, aggregates member packets, and uses code-division multiple access (CDMA) or an equivalent orthogonalization method to limit inter-cluster interference before forwarding data to the sink [14].

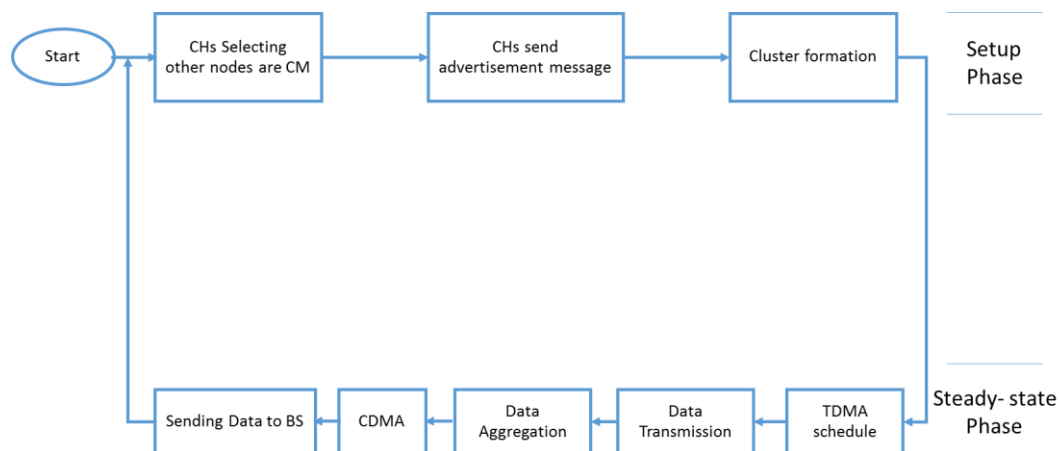


Figure 2. Flow chart of the classical LEACH round: set-up (CH advertisement and cluster formation) followed by steady-state (TDMA, aggregation, and forwarding to the base station).

2.2 Why classical LEACH is insufficient after a disaster

Disaster fields are not static WSNs with identical batteries. UEs move, batteries differ by device class, and the surviving gNodeB—if any—is rarely at the geometric center of the affected area. The following LEACH limitations become critical in mobile D2D / sidelink operation [12], [13], [14].

- CHs are elected at random, without a joint account of residual energy, distance to the sink, intra-cluster distance, or mobility. A poorly placed or already weak CH dies early and partitions the cluster.
- The number of CHs fluctuates from round to round, which produces unbalanced clusters and unpredictable uplink load on the surviving gNodeB.
- Node mobility is ignored. A CH that leaves the patch, or members that drift out of range, break the TDMA schedule long before the next scheduled re-election.
- Forced re-election every round wastes energy on control messages—an overhead that a public-safety network cannot afford when batteries cannot be recharged.

These gaps motivated a family of LEACH variants (I-LEACH, S-LEACH, SE-LEACH, LEACH-GA, and others). They improve energy accounting or geometry, yet most of them still assume static nodes and a WSN energy model. MILEACH is designed for the complementary case: mobile cellular UEs that must keep D2D clusters alive after a disaster.

3. RELATED WORK

Early applications of LEACH to cellular D2D already showed that clustering can raise spectral and energy efficiency when high-rate traffic must be exchanged among nearby users. Midasala et al. applied LEACH-style CH selection inside Long-Term Evolution (LTE) networks and reported more than 30% improvement over BPDS and OEAS in spectrum and energy efficiency under mobility [15]. Sivakumar and Radhika compared LEACH, LEACH-C, and LEACH-GA in WSNs and found that a GA-tuned CH probability extended network lifetime by more than 40% relative to LEACH and LEACH-C [16].

Mehra et al. proposed SE-LEACH, which splits each round into CH selection, cluster formation, and data dissemination, and scores candidates by residual energy, local density, and distance to the sink [17]. The protocol improved the stability period, but the nodes were assumed homogeneous, continuously powered, and immobile. Tarawneh et al. introduced I-LEACH, which partitions the field into circular patches and fixes the number of CHs from the area geometry and the target CH probability instead of drawing it at random [14]. I-LEACH is the geometric backbone of MILEACH. Mohammed et al. proposed S-LEACH, which sectors the field around the base station to shorten transmission distances and reported gains over Q-LEACH, I-LEACH, RCH-LEACH, and ME-LEACH [12]. The evaluation, however, used a small square field and static nodes, which limits transfer to a disaster city block.

Raziah et al. implemented LEACH for CH selection among battery-limited D2D devices that operate without cellular infrastructure and showed a longer lifetime through a lower dead-device count [13]. The same group later added adaptive power control on top of LEACH clustering to manage inter- and intra-cluster interference in cooperative D2D systems [19]. Haghzad Klidbary and Javadian (2024) refined LEACH with a GA whose objective includes energy and distance, and reported at least 11% more remaining energy and more alive nodes than LEACH, LEACH-E, and LEACH-EX [18]. Their GA-LEACH is used as a benchmark in this paper; its main drawbacks are computational cost and a single static topology.

Mission-critical and post-disaster studies have moved beyond generic WSN assumptions. Ali et al. combined D2D clustering with wireless power transfer for disaster management [5]. Masaracchia et al. designed an energy-efficient clustering and routing framework specifically for disaster-relief networks [23]. Hossain et al. proposed SmartDR for post-disaster D2D recovery [24]. Elshrkasi et al. introduced CFACHS, which splits each cluster into a main cluster and a sub-cluster so that every UE in the affected area can attach to a CH; MATLAB results showed about 26–28% higher power efficiency and a capacity gain of roughly 8–12% versus conventional clustering [7]. On the 5G D2D side, Aslam et al. analyzed clustering for content-sharing networks [20] and later used machine learning to decide which users should stay on the eNB rather than inside a D2D cluster [3].

The 2024–2026 literature shifts the sink itself. Gouda and Thakur (2025) combine hypergraph clustering with particle-swarm CH / ground-cluster-unit selection and ant-colony path planning for UAV-assisted D2D cells, reducing the energy of both ground UEs and the aerial base station [22]. 3GPP Rel-17/18 sidelink relay and Rel-18 sidelink positioning provide the first standardized hooks for multi-hop UE relays and GNSS-independent localization in public-safety scenes [8]–[10], [26]. Taken together, previous LEACH variants reduce energy but largely overlook joint mobility, heterogeneous UE batteries, and event-triggered re-clustering in a cellular disaster cell. MILEACH is proposed to close that gap, while Section 6 shows how it can absorb the newer UAV, sidelink-relay, and learning-based ideas without discarding the validated MATLAB results.

3.1 Positioning of MILEACH against recent protocols

Table 1 summarizes the features that distinguish MILEACH from the protocols used as direct or conceptual baselines. The table is intended as a review aid for editors and referees; the quantitative comparison in Section 5 is restricted to I-LEACH and GA-LEACH, which were implemented under the same MATLAB assumptions.

Protocol	Year	Mobile UEs	CH logic	Disaster / D2D focus	Re-clustering
LEACH [11]	2002	No	Random threshold	WSN	Every round
I-LEACH [14]	2020	No	Circular patches + energy	WSN	Every round
S-LEACH [12]	2022	No	BS-centered sectors	WSN	Every round
GA-LEACH [18]	2024	No	GA (energy, distance)	WSN	Iterative / static field
CFACHS [7]	2022	Limited	Main + sub-cluster, residual energy	Public safety / D2D	Attachment-driven
UAV-D2D [22]	2025	Yes (ground + UAV)	Hypergraph + PSO	UAV-assisted D2D	Dynamic with UAV path
MILEACH (this work)	2026	Yes	I-LEACH circles + GA (energy, mobility, coverage)	5G D2D emergency cell	Event-triggered

Table 1. Feature comparison of LEACH-family and recent disaster / D2D clustering protocols.

4. SYSTEM MODEL AND PROPOSED MILEACH PROTOCOL

4.1 Network setting

The study considers a single 5G cell in which UEs are randomly placed over a geographic area of 0.1 km² (static calibration) or 1–2 km² (mobile emergency scenarios), either close to or far from the gNodeB. In-band D2D is assumed. Underlay operation reuses cellular radio resources and is preferred here because it improves spectral efficiency when a surviving gNodeB is still present; overlay operation with orthogonal resources remains compatible with the same clustering logic. When the gNodeB fails completely, the CH-to-sink hop can be replaced by a UE-to-UE relay or an aerial sink (Section 6) without changing the intra-cluster election.

Three clustering costs must be controlled in 5G / public-safety networks [6]: (i) maintenance cost, because mobility and density changes force re-association and CH re-election; (ii) computational cost of the optimizer that chooses CHs; and (iii) bandwidth and energy wasted on discovery and control messages. MILEACH attacks (i) and (iii) by making re-clustering event-triggered, and attacks (ii) by running a compact GA only inside each circular patch rather than over the whole cell.

4.2 Protocol operation

MILEACH inherits the circular-patch construction of I-LEACH [14] and the evolutionary CH search of GA-LEACH [18], but it adds mobility and coverage genes and it stops rotating the CH until the current head is no longer fit. Each round still contains a set-up interval and a steady-state interval. The number of circular patches is a function of the field dimensions and the node density. The GA fitness uses five features: distance from the node to the gNodeB, distance from a candidate CH to its neighbors, node mobility, battery capacity, and residual charge (coverage intensity is included as a complementary term). A smartphone battery is smaller and more heterogeneous than a WSN mote, so battery genes cannot be replaced by a single residual-energy bit.

Fig. 3 summarizes the algorithm. Circles are formed and an initial CH is elected as in I-LEACH. The GA then re-selects the CH with the highest fitness inside each circle. If two nodes share the same fitness, the node with the lower medium-access-control (MAC) address is chosen in order to break ties deterministically. The CH continues to emit beacons. Re-clustering is launched only when the CH's fitness drops below a threshold, the CH announces that it is leaving, or all members have left or died.

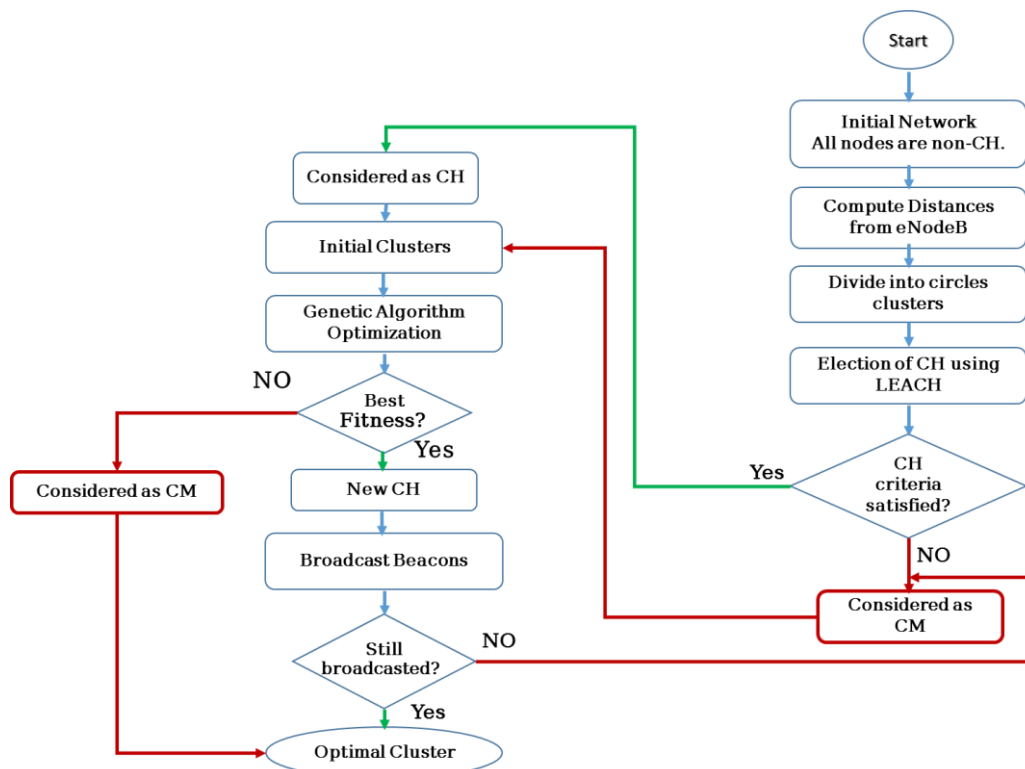


Figure 3. Flow chart of MILEACH. After I-LEACH circular construction, a genetic algorithm elects the CH; the cluster is maintained until energy, connectivity, or membership triggers a new election.

MILEACH is decentralized. Distances and channel indicators needed for clustering are obtained from D2D / sidelink peer-discovery messages that carry a device identifier and a positioning hint; no gNodeB is required for intra-cluster organization [20]. Each UE keeps a neighborhood table. This property is what makes the protocol usable after a site outage, and it is compatible with the Rel-17/18 discovery and relay procedures discussed in Section 6.

4.3 Mathematical model

The Euclidean distance between two nodes $a = (a_x, a_y)$ and $b = (b_x, b_y)$ is [14]

$$d(a, b) = \sqrt{[a_x - b_x]^2 + [a_y - b_y]^2} \quad (1)$$

Circular patches are dimensioned from the target CH probability p , the total number of nodes N , and the field sides L_x and L_y [14]:

$$\begin{aligned} N_h &= \lfloor \sqrt{(N \cdot p) \cdot L_x / \max(L_x, L_y)} \rfloor, \\ N_v &= \lfloor \sqrt{(N \cdot p) \cdot L_y / \max(L_x, L_y)} \rfloor \end{aligned} \quad (2)$$

where N_h and N_v are the numbers of circles along the horizontal and vertical sides. The circle diameter is

$$d_r = \min(L_x / N_h, L_y / N_v) \quad (3)$$

In the MILEACH set-up phase, each node draws a random number $r \in [0, 1]$ and compares it with the classical LEACH threshold $T(n)$. Let G be the set of nodes that have not been CH in the last $1/p$ rounds. Then [11], [14]

$$\begin{aligned} T(n) &= p / [1 - p \cdot (r_{\text{round}} \bmod 1/p)] \quad \text{if } n \\ &\in G; \quad T(n) = 0 \text{ otherwise} \end{aligned} \quad (4)$$

$$n \text{ is an initial CH candidate} \Leftrightarrow r < T(n) \quad (5)$$

The resulting CM / CH labeling is only the initial population of the GA. The fitness of a chromosome (candidate CH) is a weighted sum of battery capacity (BC), battery charge percentage (BCP), distance to neighboring nodes (DN; smaller is better and is therefore used in reciprocal or complementary form), mobility (MO; lower speed is preferred for CH stability), and coverage intensity (CO):

$$\begin{aligned} F &= w_1 \cdot BC + w_2 \cdot BCP + w_3 \cdot f(DN) + w_4 \cdot g(MO) \\ &+ w_5 \cdot CO, \quad \sum w_i = 1, \quad w_i \geq 0 \end{aligned} \quad (6)$$

The mapping functions $f(\cdot)$ and $g(\cdot)$ convert distance and speed into benefit terms (for example, $f(DN) = 1 / (1 + DN)$ and $g(MO) = 1 / (1 + |v|)$). Weights are chosen empirically in the present study so that they can be retuned for a given agency's priority (coverage versus battery). Section 6.4 explains how a reinforcement-learning agent can replace this manual tuning. The GA then applies selection, crossover, and mutation for a prescribed number of generations and returns the best chromosome as the CH of that circle.

The radio energy model follows the first-order amplifier model used by I-LEACH [14] and RCH-LEACH [21]. The energy required to transmit an L -bit packet over distance d is

$$E_{Tx}(L, d) = L \cdot E_{elec} + L \cdot \epsilon_{fs} \cdot d^2 \quad \text{if } d < d_0 \quad (7)$$

$$\begin{aligned} E_{Tx}(L, d) &= L \cdot E_{elec} + L \cdot \epsilon_{mp} \cdot d^4 \quad \text{if } d \geq d_0, \\ d_0 &= \sqrt{(\epsilon_{fs} / \epsilon_{mp})} \end{aligned} \quad (8)$$

Reception of an L -bit packet consumes [21]

$$E_{Rx}(L) = L \cdot E_{elec} \quad (9)$$

Here E_{elec} is the electronics energy per bit, ϵ_{fs} and ϵ_{mp} are the free-space and multipath amplifier coefficients, and d_0 is the distance threshold that switches the path-loss regime. This model is deliberately kept identical to the I-LEACH / GA-LEACH baselines so that the observed gains come from clustering decisions, not from a more optimistic radio model.

5. SIMULATION SETUP AND RESULTS

All protocols were implemented in MATLAB. I-LEACH [14] and GA-LEACH [18] are the quantitative baselines. A static-network calibration is reported first so that MILEACH can be compared fairly with algorithms that were originally designed for immobile nodes. The mobile campaign then uses 200 UEs over 1 km² (square) and 2 km × 1 km (rectangle) fields. The gNodeB is placed at the center (nominal coverage), at the top edge (weak coverage), or at a corner (very weak coverage), as drawn in Fig. 4. These three placements emulate a surviving macro site that is, respectively, inside the disaster footprint, on its boundary, or only able to illuminate a distant corner of the area.

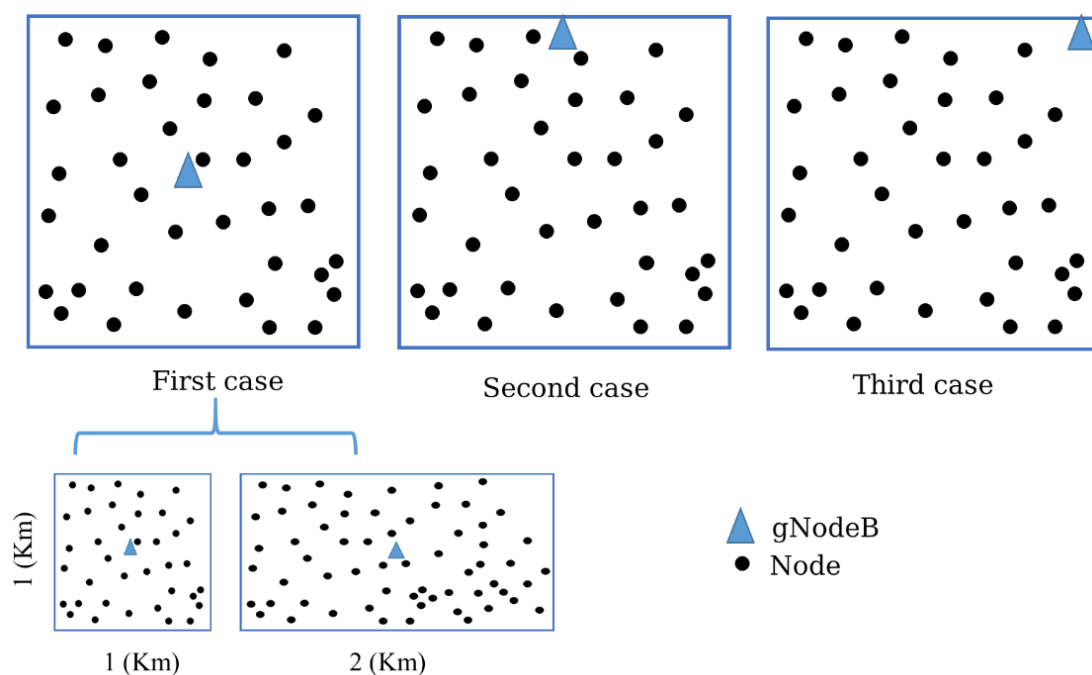


Figure 4. Evaluation geometries: gNodeB at the center, top edge, or corner of a square cell, plus a rectangular 2 km × 1 km cell used to stress longer hop distances.

Table 2 lists the simulation parameters. The number of clusters is not fixed a priori; it follows from node density and Eqs. (2)–(3). Initial energies of mobile UEs are heterogeneous (terminal-battery dependent) but are drawn once and reused for every protocol so that the comparison is fair. Weights in Eq. (6) were selected empirically and can be changed without altering the algorithm structure.

Parameter	Static calibration	Mobile emergency scenarios
Network area	0.1 km ²	1 km ² (square) and 2 km × 1 km (rectangle)
Number of nodes	150	200
gNodeB coordinates	Top of the field	Center, top edge, and corner
Reference initial energy E_0	0.5 J (homogeneous WSN-style test)	Heterogeneous; total energy stored once and reused
CH election probability p	0.1	0.1
Data packet length L	4000 bits (500 bytes)	4000 bits (500 bytes)

Electronics energy E_{elec} (E_{trans} / E_{rec})	1.0×10^{-7} J/bit	1.0×10^{-7} J/bit
Aggregation energy E_{agg}	1.0×10^{-8} J/bit	1.0×10^{-8} J/bit
Free-space amplifier ϵ_{fs} (E_{fs})	0.3400×10^{-9} J/bit/m ²	0.3400×10^{-9} J/bit/m ²
Simulation horizon	2000 rounds	2000 rounds
Mobility	None	Random speed and direction per UE
Optimizer	GA inside each circular patch	GA inside each circular patch

Table 2. MATLAB simulation parameters for the static calibration and the mobile emergency scenarios.

Fig. 5 shows one snapshot of the 1 km² mobile field with the gNodeB at the center. Live nodes are filled black circles, dead nodes are empty circles, CHs are green, and the gNodeB is blue. The circular patches of I-LEACH / MILEACH are visible as the regular tiling of the cell.

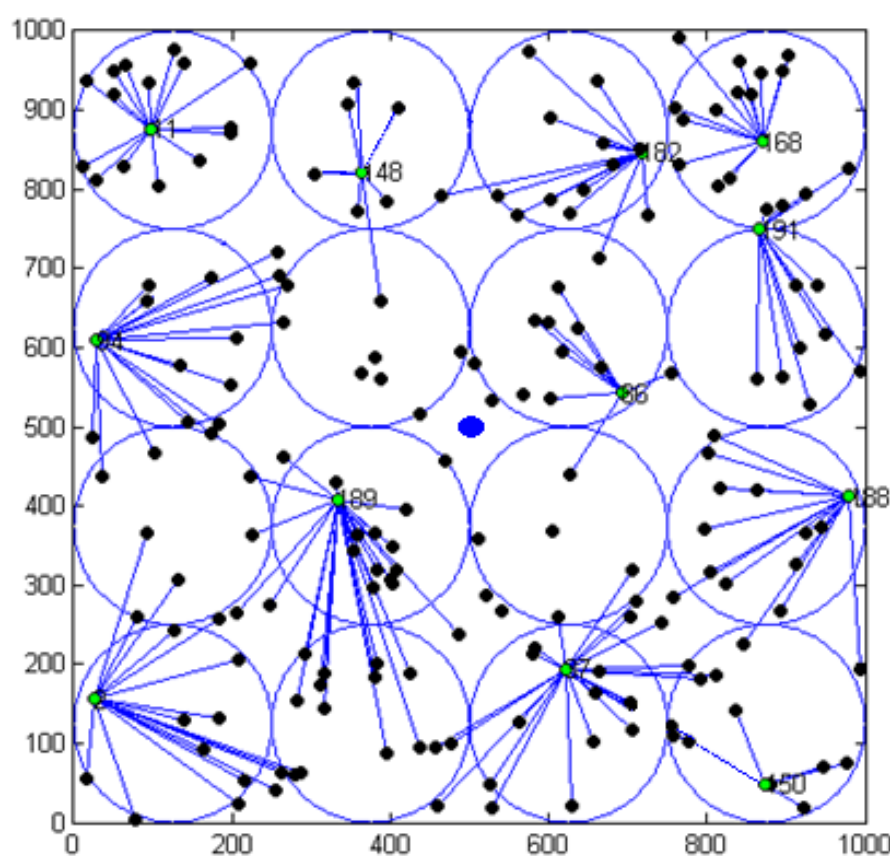


Figure 5. Example MILEACH snapshot on a 1 km² field with the gNodeB at the center: circular patches, elected CHs, and intra-cluster associations.

5.1 Static calibration

Before the mobile campaign, MILEACH was run on a static field with the gNodeB at the top (the same geometry used by several LEACH-family papers). Fig. 6(a) reports first-dead, half-dead, and last-dead rounds; Fig. 6(b) reports residual energy versus rounds. MILEACH postpones the first-node death and stretches both the half-lifetime and the full lifetime well beyond GA-LEACH and I-LEACH. Residual energy declines almost linearly and remains strictly above the two baselines until the network is exhausted. This result matters because it shows that the extra mobility and coverage genes do not harm the protocol when nodes happen to be static—an important sanity check against over-fitting the fitness function to movement.

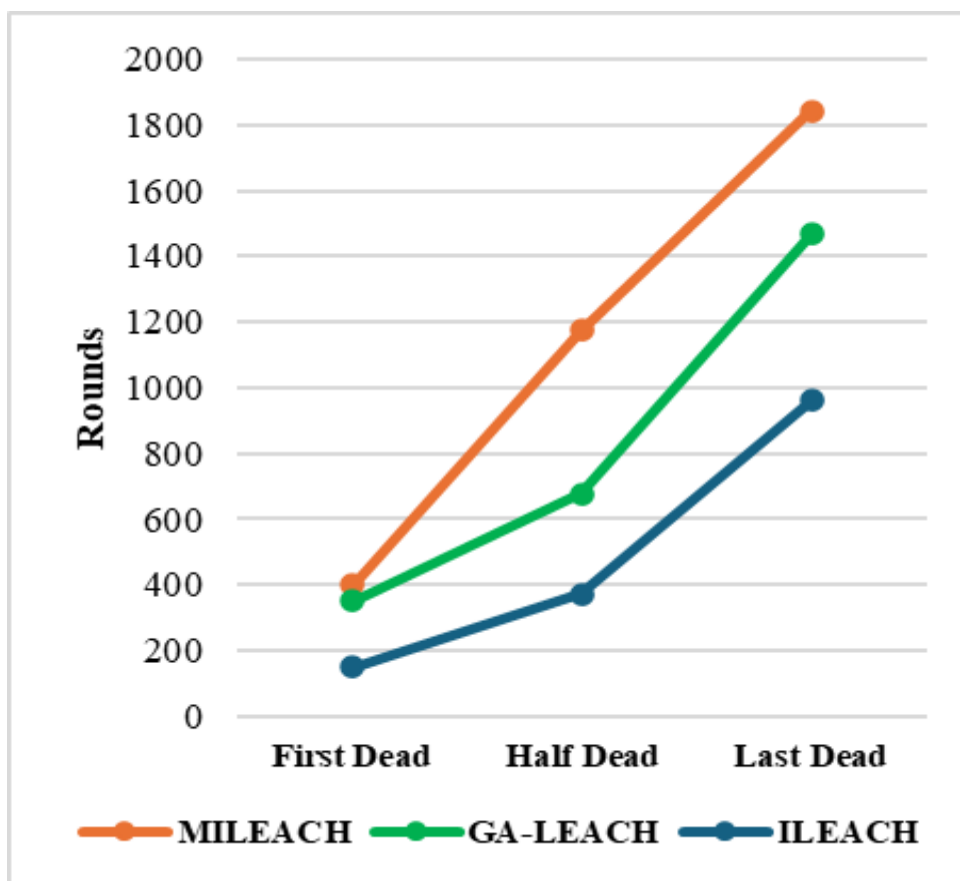


Figure 6(a). Static environment: rounds until the first, half, and last node deaths for MILEACH, GA-LEACH, and I-LEACH.

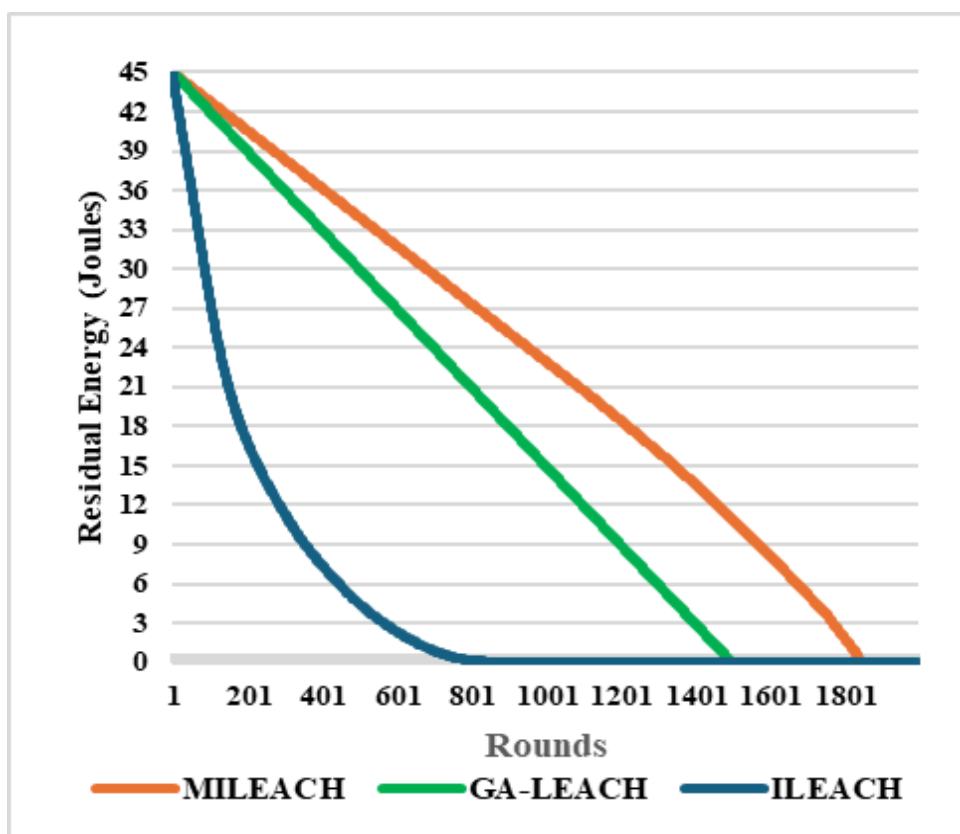


Figure 6(b). Static environment: residual network energy over the simulation horizon.

5.2 Case I — gNodeB at the center (square and rectangle)

All 200 mobile nodes start from the same random locations, speeds, and battery draws. Messages can still reach the gNodeB. Fig. 7(a)–(b) show live-node count and residual energy on the 1 km² square. After 2000 rounds the number of dead nodes is 8 with MILEACH, 14 with GA-LEACH, and 24 with I-LEACH (a threefold reduction versus I-LEACH). The common initial energy pool is 2.913×10^5 J. At round 2000 the pool is approximately 2.487×10^5 J (MILEACH), 2.365×10^5 J (GA-LEACH), and 2.145×10^5 J (I-LEACH). MILEACH therefore conserves about 3.42×10^4 J relative to I-LEACH, which is 4% of the initial pool and leaves 1.16 times the residual energy of I-LEACH.

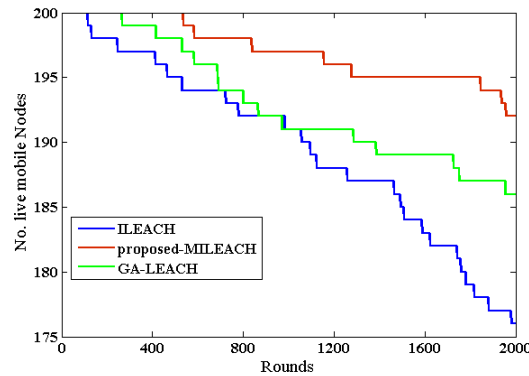


Figure 7(a). Case I, square 1 km² field: number of live mobile nodes over 2000 rounds.

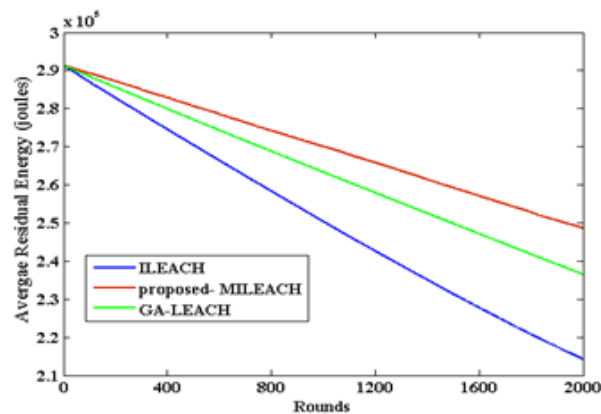


Figure 7(b). Case I, square 1 km² field: residual energy over 2000 rounds.

The rectangular 2 km × 1 km field doubles the longer-side distance and is a stricter test of CH-to-gNodeB hops. Fig. 8 shows that MILEACH still finishes with 26 dead nodes, versus 32 (GA-LEACH) and 100 (I-LEACH). I-LEACH collapses because its CH rule does not penalize mobility or poor coverage once the geometry stretches; many CHs are elected far from both their members and the sink.

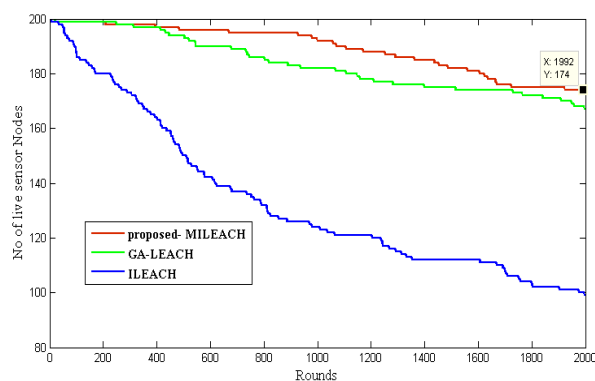


Figure 8. Case I, rectangular 2 km × 1 km field: number of live nodes over 2000 rounds. MILEACH retains 174 live nodes near the end of the run, versus a collapse of I-LEACH toward 100 live nodes.

5.3 Case II — *gNodeB* at the top edge

Moving the *gNodeB* to the top of the field increases the average CH-to-sink distance and represents a cell-edge disaster footprint. Fig. 9(a)–(b) and Table 3 show that MILEACH still limits the dead-node count to 18 after 2000 rounds, compared with 50 (GA-LEACH) and 100 (I-LEACH). Residual energy remains 2.079×10^5 J for MILEACH, 1.979×10^5 J for GA-LEACH, and 1.162×10^5 J for I-LEACH. Relative to I-LEACH this is an energy-preservation ratio of about 32% of the initial pool.

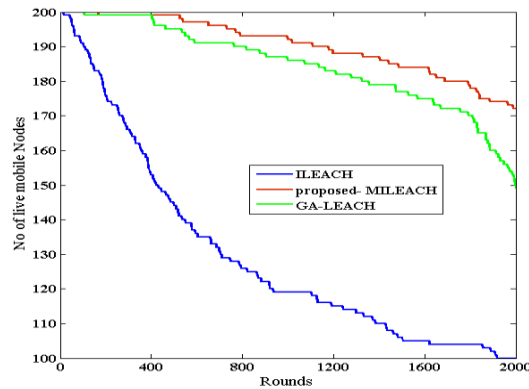


Figure 9(a). Case II (*gNodeB* at the top): live mobile nodes over 2000 rounds.

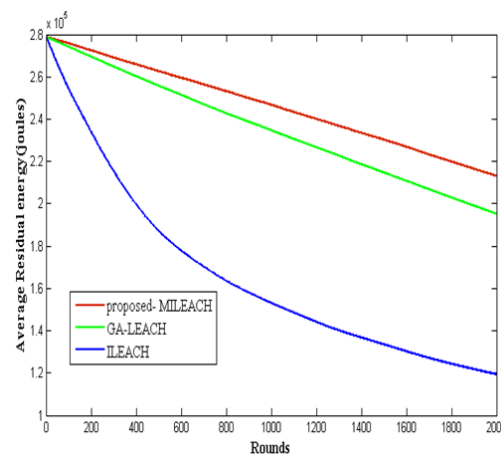


Figure 9(b). Case II (*gNodeB* at the top): residual energy over 2000 rounds.

5.4 Case III — *gNodeB* at the corner (harshes coverage)

The corner placement is the most demanding geometry: many UEs must cross almost the full diagonal to reach the sink. Fig. 10(a)–(b) show that MILEACH still keeps 150 nodes alive (50 dead), whereas GA-LEACH and I-LEACH finish with 62 and 146 dead nodes, respectively (Table 3). Starting from a common pool of 2.7×10^5 J, MILEACH conserves approximately 36% of the initial energy relative to I-LEACH. In other words, the protocol's advantage grows as coverage worsens—the regime that matters after a site outage.

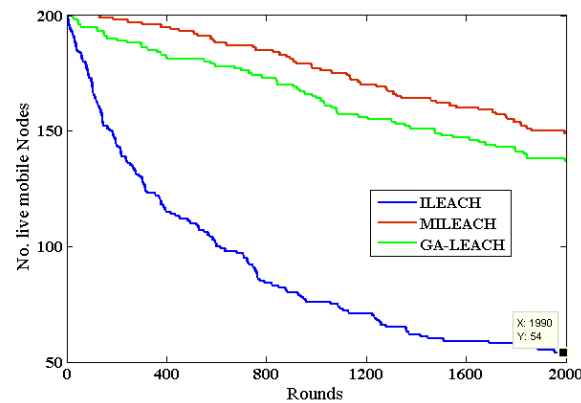


Figure 10(a). Case III (gNodeB at the corner): live mobile nodes over 2000 rounds.

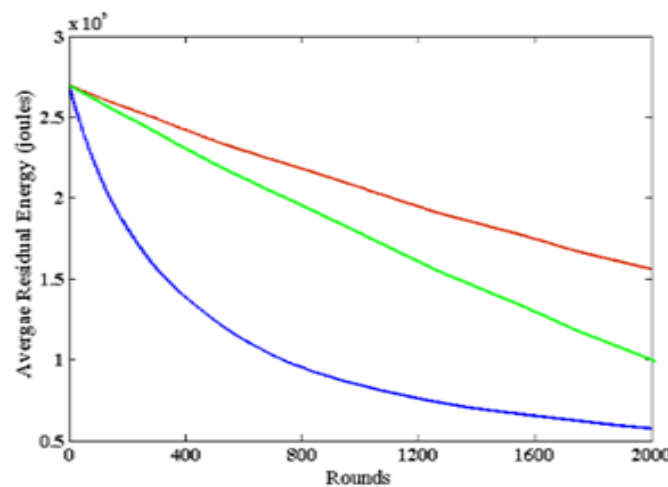


Figure 10(b). Case III (gNodeB at the corner): residual energy over 2000 rounds.

5.5 Cross-scenario summary

Table 3 collects the dead-node counts. Connectivity preservation versus I-LEACH is 8 percentage points of the node population in Case I (square), 36 points in Case II, and 48 points in Case III ($146 - 50 = 96$ nodes, i.e. 48% of 200). Versus GA-LEACH the corresponding preservation margins are 3, 16, and 6 percentage points. Energy preservation versus I-LEACH is 4%, 32%, and 36% of the initial pool in the three mobile cases. Two observations follow. First, a mobility- and coverage-aware fitness function is not a luxury: it is the difference between a usable public-safety mesh and a field that loses half of its UEs. Second, event-triggered re-clustering avoids paying the LEACH control tax every round, which compounds over a 2000-round horizon.

Algorithm	Case I square	Case I rectangle	Case II (top)	Case III (corner)
MILEACH (proposed)	8	26	18	50
GA-LEACH [18]	14	32	50	62
I-LEACH [14]	24	100	100	146

Table 3. Number of dead nodes after 2000 rounds in all mobile scenarios (lower is better).

6. PROPOSED DEVELOPMENTS FOR 5G-ADVANCED AND 6G PUBLIC-SAFETY NETWORKS

The MATLAB results in Section 5 validate MILEACH as a mobility-aware clustering core. They do not, however, exhaust the capabilities that 5G-Advanced and IMT-2030 now make available. This section proposes a development program that can be implemented incrementally on top of the present protocol. No new simulation numbers are claimed here; each subsection states the intended mechanism, the standard or paper it builds on, and the metric that a follow-up study should report.

6.1 Density-adaptive circular patches

I-LEACH / MILEACH currently compute N_h , N_v , and d_r from a single global density $N / (L_x L_y)$. After an earthquake the UE density is highly non-uniform: shelters and collapsed buildings create hot spots, while evacuated streets are almost empty. An adaptive rule should recompute a local p and a local d_r inside a sliding window, merging empty circles and splitting overloaded ones. The fitness in Eq. (6) already contains a coverage term; feeding it a local density estimate would close the loop. The evaluation metric is the coefficient of variation of cluster size, together with the CH-to-member hop energy.

6.2 Native mapping onto 3GPP Rel-17/18 sidelink relay

The present CH is a logical relay. Rel-17 U2N relay and Rel-18 U2U relay plus SRAP [8], [26] provide a standards-compliant realization: the MILEACH CH becomes an L2 relay UE, cluster members become remote UEs, and the CH-to-gNodeB hop becomes either a Uu hop (when the site survives) or a second PC5 hop toward a peer that still has coverage. Multi-path (simultaneous Uu + PC5) is already in the Rel-18 work item for public safety [8]. Implementing MILEACH on this stack would replace the abstract “beacon” with PC5 discovery and would allow QoS flows to inherit ProSe / MCX priorities. The evaluation metric is service continuity time after a gNodeB drop, measured with a 3GPP-compliant system-level simulator.

6.3 UAV / NTN aerial sinks and hypergraph clustering

When no terrestrial gNodeB remains, a UAV or a non-terrestrial network (NTN) platform can act as a mobile sink. Gouda and Thakur show that hypergraph clustering plus PSO-based ground-cluster-unit selection and ant-colony UAV path planning reduces the joint energy of UEs and the aerial station [22]. MILEACH can treat the UAV waypoint as a moving “gNodeB coordinate” in Eqs. (1) and (6), so that CHs are elected under the current UAV footprint rather than under a destroyed site. The evaluation metrics are UAV flight energy, ground residual energy, and the outage of the worst-served cluster.

6.4 Learning-based adaptation of the fitness weights

The weights $w_1 \dots w_5$ are currently static. In a long-lived incident the right trade-off changes: during the first hour, coverage (finding isolated UEs) dominates; later, residual battery dominates. A lightweight multi-armed-bandit or deep-reinforcement-learning agent running on the CH—or on an edge server when one is reachable—can treat the five weights as an action and the combination of dead-node rate, residual energy, and packet delivery ratio as a reward. Aslam et al. already showed that SVM / random-forest / DNN classifiers can decide which UEs should stay on the macro link [3]. The same feature vector (energy, mobility, geometry) can drive MILEACH’s weights. The evaluation metric is regret against the best fixed-weight oracle used in Section 5.

6.5 Interference-aware adaptive power control

Underlay D2D reuses cellular resources, so a well-elected CH can still harm a neighboring cluster or a surviving cellular UE. Raziah et al. demonstrated that LEACH clustering plus adaptive power control lowers outage and raises throughput relative to fixed power [19]. The natural extension is to add a sixth gene—or a separate inner loop—that sets the CH transmit power from the measured intra- and inter-cluster interference. The evaluation metrics are SINR outage, cellular-UE protection margin, and the extra energy of the power-control loop.

6.6 RF energy harvesting and SWIPT at the CH

Section 5 shows that even MILEACH loses tens of nodes under corner coverage because batteries are finite. Disaster-oriented designs that couple clustering with wireless power transfer [5] and UAV-assisted simultaneous wireless information and power transfer (SWIPT) [22] can be layered on MILEACH by giving harvested-energy rate a sixth (or replacement) term in Eq. (6). CHs would then be nodes that are both geometrically convenient and RF-rich (for example, those still illuminated by a surviving site or a UAV beacon). The evaluation metric is the extension of the first-dead and half-dead times of Fig. 6(a) when a realistic nonlinear harvester is added.

6.7 Multi-hop CH backbone, CFACHS-style sub-clusters, and digital-twin rehearsal

A single CH-to-gNodeB hop is optimistic when the site is at a corner (Case III). CFACHS already splits clusters into a main and a sub-cluster and routes over a multi-hop CH backbone [7]. MILEACH should elect a backup CH (the second-best chromosome) and allow CH-to-CH forwarding inside a planar backbone. A digital twin of the cell—fed by the same neighborhood tables used for

discovery—can rehearse the backbone offline and push a recommended CH set before responders enter the area. The evaluation metrics are end-to-end latency of a 200-byte emergency short-data burst and the packet-delivery ratio of the farthest UE.

6.8 Rel-18 sidelink positioning for victim localization

Rel-18 sidelink positioning reference signals (SL-PRS) and the sidelink positioning protocol enable ranging without GNSS [9], [10]. MILEACH CHs are natural location anchors: they already collect neighbor lists and have the highest residual energy. Adding SL-PRS to the beacon turns each cluster into a local positioning cell that can report relative coordinates of silent or low-battery UEs to the rescue command. This is the most direct life-saving extension of the protocol and aligns with the IMT-2030 usage scenario of ubiquitous connectivity plus integrated sensing [2]. The evaluation metrics are ranging RMSE inside a cluster and the time to produce a first location fix after a gNodeB outage.

6.9 Recommended implementation order

A realistic laboratory roadmap is: (1) density-adaptive patches and a backup CH, which require only MATLAB changes; (2) adaptive power control and learning-based weights, still at system-simulation level; (3) a sidelink-relay abstraction compatible with TS 38.351; (4) UAV sink and SL-PRS, which need a joint communication–sensing simulator. Steps (1)–(2) can be completed without new hardware; steps (3)–(4) are the 5G-Advanced / 6G publications that should follow this manuscript.

7. CONCLUSION

This paper presented MILEACH, a mobility-aware enhancement of circular I-LEACH clustering that uses a genetic algorithm to elect cluster heads from battery state, intra-cluster distance, mobility, and coverage. The protocol is decentralized and therefore remains usable when a 5G gNodeB is congested, pushed to the cell edge, or reduced to a single surviving corner site. MATLAB experiments over 2000 rounds show that MILEACH outperforms I-LEACH and the 2024 GA-LEACH benchmark in both static and mobile fields. In the mobile campaign the dead-node count after 2000 rounds is 8 / 26 / 18 / 50 across the four geometries, against 24 / 100 / 100 / 146 for I-LEACH and 14 / 32 / 50 / 62 for GA-LEACH. Energy preservation versus I-LEACH grows from 4% of the initial pool under center coverage to 32% and 36% under edge and corner coverage. The protocol can therefore be used not only after a disaster but also as a congestion valve during peak hours, by exploiting proximity and D2D / sidelink reuse.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Declaration of Competing Interest

The author declares that there is no known competing financial interest or personal relationship that could have appeared to influence the work reported in this paper.

Data Availability

The MATLAB simulation parameters are listed in Table 2. Simulation scripts and figure sources can be provided by the corresponding author upon reasonable request.

REFERENCES

- [1] Ericsson, “Ericsson Mobility Report,” Nov. 2025. [Online]. Available: <https://www.ericsson.com/en/reports-and-papers/mobility-report>
- [2] ITU-R, “Framework and overall objectives of the future development of IMT for 2030 and beyond,” Recommendation ITU-R M.2160-0, Nov. 2023. [Online]. Available: <https://www.itu.int/rec/R-REC-M.2160>
- [3] S. Aslam, F. Alam, S. F. Hasan, and M. A. Rashid, “A machine learning approach to enhance the performance of D2D-enabled clustered networks,” *IEEE Access*, vol. 9, pp. 16114–16132, 2021, doi: 10.1109/ACCESS.2021.3053045.
- [4] A. A. Ateya, A. Muthanna, A. Vybormova, and A. Koucheryavy, “Multi-level cluster based device-to-device (D2D) communication protocol for the base station failure situation,” in *Internet of Things, Smart Spaces, and Next Generation Networks and Systems*. Cham, Switzerland: Springer, 2017, pp. 795–805, doi: 10.1007/978-3-319-67380-6_71.
- [5] K. Ali, H. X. Nguyen, Q.-T. Vien, P. Shah, and Z. Chu, “Disaster management using D2D communication with power transfer and clustering techniques,” *IEEE Access*, vol. 6, pp. 14643–14654, 2018, doi: 10.1109/ACCESS.2018.2793532.
- [6] M. F. Khan, K.-L. A. Yau, R. M. Noor, and M. A. Imran, “Survey and taxonomy of clustering algorithms in 5G,” *J. Netw. Comput. Appl.*, vol. 154, Art. no. 102539, 2020, doi: 10.1016/j.jnca.2020.102539.
- [7] A. Elshrkasi, K. Dimyati, K. A. B. Ahmad, and M. F. B. M. Said, “Enhancement of cellular networks via an improved clustering technique with D2D communication for mission-critical applications,” *J. Netw. Comput. Appl.*, vol. 206, Art. no. 103482, Oct. 2022, doi: 10.1016/j.jnca.2022.103482.
- [8] 3GPP, “NR; Sidelink Relay Adaptation Protocol (SRAP),” TS 38.351, Version 18.1.0, Release 18, 2024.

- [9] H.-S. Cha, G. Lee, A. Ghosh, M. Baker, S. Kelley, and J. Hofmann, "5G NR positioning enhancements in 3GPP Release-18," IEEE Commun. Stand. Mag., vol. 9, no. 1, pp. 48–56, Mar. 2025, doi: 10.1109/MCOMSTD.0001.2400006.
- [10] T.-K. Le, S. Wagner, and F. Kaltenberger, "5G sidelink positioning in 3GPP Release 18 and Release 19," in Proc. IEEE Conf. Standards Commun. Netw. (CSCN), 2023, doi: 10.1109/CSCN60443.2023.10453143.
- [11] W. B. Heinzelman, A. P. Chandrakasan, and H. Balakrishnan, "An application-specific protocol architecture for wireless microsensor networks," IEEE Trans. Wireless Commun., vol. 1, no. 4, pp. 660–670, Oct. 2002, doi: 10.1109/TWC.2002.804190.
- [12] F. A. Mohammed, N. Mekky, H. H. Suleiman, and N. A. Hikal, "Sectored LEACH (S-LEACH): An enhanced LEACH for wireless sensor network," IET Wireless Sensor Syst., vol. 12, no. 2, pp. 56–66, 2022, doi: 10.1049/wss2.12036.
- [13] I. Raziah, Y. Yunida, R. Muharar, Y. Away, and N. Nasaruddin, "Implementation of LEACH protocol for cluster head selection in D2D cooperative communication systems," in Proc. Int. Conf. Comput. Syst., Inf. Technol., Elect. Eng. (COSITE), 2021, doi: 10.1109/COSITE52651.2021.9649556.
- [14] A. R. Tarawneh, B. Malahmeh, and A. Al-Odienat, "Improved LEACH protocol for increasing network lifetime based on circular patches clustering," Universal J. Appl. Sci., vol. 7, no. 1, pp. 8–17, 2020, doi: 10.13189/ujas.2020.070102.
- [15] V. Midasala, S. N. Bhavanam, and P. Siddaiah, "Performance analysis of LEACH protocol for D2D communication in LTE-Advanced network," in Proc. IEEE Int. Conf., 2016.
- [16] P. Sivakumar and M. Radhika, "Performance analysis of LEACH-GA in wireless sensor network," Procedia Comput. Sci., vol. 125, pp. 711–716, 2018, doi: 10.1016/j.procs.2017.12.091.
- [17] P. S. Mehra, M. N. Doja, and B. Alam, "Stability enhancement in LEACH (SE-LEACH) for homogeneous WSN," EAI Endorsed Trans. Scalable Inf. Syst., vol. 6, no. 20, 2019, doi: 10.4108/eai.13-7-2018.156592.
- [18] S. Haghzad Klidbary and M. Javadian, "Improvement of low energy adaptive clustering hierarchical protocol based on genetic algorithm to increase network lifetime of wireless sensor network," Int. J. Eng., Trans. C: Aspects, vol. 37, no. 9, pp. 1800–1811, 2024, doi: 10.5829/ije.2024.37.09c.10.
- [19] I. Raziah, Y. Yunida, Y. Away, R. Muharar, and N. Nasaruddin, "A new adaptive power control based on LEACH clustering protocol for interference management in cooperative D2D systems," IEEE Access, vol. 10, pp. 113513–113522, 2022, doi: 10.1109/ACCESS.2022.3217219.
- [20] S. Aslam, F. Alam, S. F. Hasan, and M. Rashid, "Performance analysis of clustering algorithms for content-sharing based D2D enabled 5G networks," in Proc. 29th Int. Telecommun. Netw. Appl. Conf. (ITNAC), Auckland, New Zealand, 2019, doi: 10.1109/ITNAC46935.2019.9078015.
- [21] A. Panchal, L. Singh, and R. K. Singh, "RCH-LEACH: Residual energy based cluster head selection in LEACH for wireless sensor networks," in Proc. Int. Conf. Elect. Electron. Eng. (ICE3), Gorakhpur, India, 2020, doi: 10.1109/ICE351665.2020.1572618825.
- [22] K. C. Gouda and R. Thakur, "Energy-efficient clustering and path planning for UAV-assisted D2D cellular networks," Ad Hoc Netw., vol. 170, Art. no. 103757, Apr. 2025, doi: 10.1016/j.adhoc.2025.103757.
- [23] A. Masaracchia, L. D. Nguyen, T. Q. Duong, and M.-N. Nguyen, "An energy-efficient clustering and routing framework for disaster relief network," IEEE Access, vol. 7, pp. 56520–56532, 2019, doi: 10.1109/ACCESS.2019.2913909.
- [24] M. A. Hossain, S. K. Ray, and J. Lota, "SmartDR: A device-to-device communication for post-disaster recovery," J. Netw. Comput. Appl., vol. 171, Art. no. 102813, 2020, doi: 10.1016/j.jnca.2020.102813.
- [25] X. Lu, P. Wang, D. Niyato, D. I. Kim, and Z. Han, "Wireless networks with RF energy harvesting: A contemporary survey," IEEE Commun. Surveys Tuts., vol. 17, no. 2, pp. 757–789, 2015, doi: 10.1109/COMST.2014.2368999.
- [26] 3GPP, "Proximity based Services (ProSe) in the 5G System (5GS)," TS 23.304, Release 18, 2024.
- [27] 3GPP, "NR; Sidelink Positioning Protocol (SLPP)," TS 38.355, Release 18, 2024.
- [28] First Responder Network Authority, "3GPP moves Release 18 freeze date to March 2024," FirstNet blog, 2024. [Online]. Available: <https://www.firstnet.gov/newsroom/blog/3gpp-moves-release-18-freeze-date-march-2024>
- [29] A. Hassan, R. Ahmad, W. Ahmed, M. Magarini, and M. M. Alam, "UAV and SWIPT assisted disaster aware clustering and association," IEEE Access, vol. 8, pp. 204791–204803, 2020, doi: 10.1109/ACCESS.2020.3035959.
- [30] S. Aslam, F. Alam, S. F. Hasan, and M. Rashid, "A novel weighted clustering algorithm supported by a distributed architecture for D2D enabled content-centric networks," Sensors, vol. 20, no. 19, Art. no. 5509, 2020, doi: 10.3390/s20195509.

— End of manuscript —

Submission checklist (for the author)

- Insert the official affiliation, ORCID, and corresponding e-mail on the title page.
- Confirm the target journal (IEEE Access, IET Communications, Ad Hoc Networks, JNCA, or a public-safety special issue) and convert citations to that journal's style if it is not IEEE.
- Regenerate Figs. 6–10 from MATLAB at 300 dpi / vector (EPS or PDF) if the editor requests higher graphic quality; the embedded figures are those of the original study.
- Do not add numerical claims for Section 6 unless a new simulation campaign is run.
- If co-authors contributed to the original experiments, restore their names and a CRediT statement before submission.