Peer-to-Peer Networking and Applications (2019) 12:912–923
https://doi.org/10.1007/s12083-018-0689-2

FINDER: A D2D based critical communications framework for disaster management in 5G

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Received: 8 March 2018 / Accepted: 3 October 2018 / Published online: 20 October 2018

Abstract

Public Safety Network communications technologies are at crossroads with next-generation networks to render better solutions and applications that can manage disaster efficiently. The fifth generation (5G) network is poised to have a guaranteed network connection, even in the case of partial dysfunction of cellular infrastructure due to disaster. In this paper, we have designed a framework named FINDER (Finding Isolated Nodes using D2D for Emergency Response) to locate-and-reconnect the isolated Mobile Nodes (MNs) in the disaster zone, so that the damage to assets and loss of life can be minimized. If the cellular link is non-existent over a disaster, the MNs under the impaired Base Station (BS) switch to the Device-to-Device (D2D) communications mode, and a critical D2D network is formed. The MNs in the disaster zone can reach an active network through a neighboring BS or a Wi-Fi access point. A multi-hop D2D communications based on hybrid Ant Colony Optimization is adopted to increase the energy efficiency of individual nodes and the overall network lifetime. Further, dynamic clustering curtails the numbers of active participating nodes, and data aggregation shrinks the number of packets in the network. Assistance from the Software-Defined Networking (SDN) controller at the BS benefits to have an intelligent and reliable connectivity to the MNs in the disaster zone. Our proposal FINDER is implemented using MATLAB, and the simulation results show that our framework extends the network lifetime with improved message delivery probability.

Keywords Device-to-Device communications · Disaster management · Network lifetime · Energy efficiency · Critical communications

1 Introduction

Natural disasters or physical attacks could ravage the communication infrastructure and can cause connectivity loss in both commercial and public safety networks. A reliable communication system is inevitable not only to transfer data but also necessary to take appropriate preventive measures and actions to save lives. Features in existing Public Safety Network (PSN) standards [1] like Project 25 (P25) and Terrestrial Trunked Radio (TETRA) are not supported in the commercial network due to factors like the economy of scale and volume of the network traffic. Meanwhile, the commercial networks have to enhance the system to ensure high reliability, robustness and other specific needs of the emergency services like instant and reliable mobile communication during disaster. Many countries are planning to deploy a dedicated PSN that is capable of providing a reliable and robust service. However, due to higher deployment cost, a dedicated network for public safety alone is not advisable. Instead, an alliance between PSN and the commercial network is a viable solution, with the possibility of improved resiliency, higher capacity and enhanced network coverage. The goal is to render the best practical solutions to both PSN and commercial network during infrastructure failure, without any additional resources.

Recognizing the relevance of PSN and an opportunity to establish common technical standards for commercial network and PSN, the Third Generation Partnership Project (3GPP) has started research on technologies required for the public safety communications. 3GPP has defined the requirements for direct mode communication in LTE using

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D2D communications in release 13 [2]. European 5G research project METIS also had developed Device-to-Device (D2D) communications technology for national security and public safety [3]. The idea is to follow an opportunistic approach by adopting all available communication techniques and devices, which could cooperate. Also due to the avalanche of mobile devices and wireless traffic volume, reuse of spectrum in next-generation networks is alarming and compelling. The 5G network will be an integration of several promising technologies such as Software-Defined Networking (SDN), D2D communications, Network Function Virtualization (NFV), and massive MIMO. D2D communications paradigm is envisioned as an allied 5G technology that has the potential to solve the capacity bottleneck problem of legacy cellular systems. D2D enables direct communication between proximal mobile devices, providing several benefits such as data offloading, extended network coverage, higher energy efficiency, and infrastructure-less connectivity [4]. An efficient and scalable framework for D2D communications is essential to reap the maximal benefits. Thus, D2D communications become an indispensable candidate technology for the next-generation wireless networks.

The D2D communications in cellular networks foster new mobile services by enabling direct communication link between Mobile Nodes (MNs) in proximity, without traversing through the Base Station (BS) and core network [5]. D2D communications are non-transparent to the cellular network and can occur both in the licensed spectrum (inband) and in unlicensed spectrum (outband), as per the requirement. D2D communications into the cellular network can improve various network parameters like the spectrum utilization, energy efficiency, cellular coverage, and network throughput [6]. D2D communications could also significantly reduce power consumption and end-to-end latency. Although inband D2D can dilute the load of the BS by traffic offloading, interference to the cellular network due to D2D communications in the shared spectrum is a challenging issue [6]. On the other hand, outband D2D exploits the unlicensed spectrum and eliminates the interference issue due to the coexistence of cellular and D2D links. Comprehensively, D2D communications are more suitable for the critical communications through its infrastructure-less communication ability. Efficient inter-weaving of D2D communications with the cellular network enables better dissemination of critical communication service to a more significant number of mobile users. The D2D communications can be deployed for distinct scenarios like full network coverage, partial network coverage, and out-of-network coverage.

In this paper, we consider a disaster scenario where the cellular link is not available under a faulty BS due to the after effect of a disaster. Our prime objective is to locate-and-reconnect the isolated nodes in the disaster zone by replacing the dead cellular link with the D2D link, to form a critical D2D network. Also, the lifetime of this critical D2D communications network is enhanced by employing energy efficient routing algorithm. The proposed framework FINDER (Finding Isolated Nodes using D2D for Emergency Response) is equipped with the hybrid Ant Colony Optimization (ACO) based routing algorithm, which takes the inspiration from the real ant behavior in nature to overcome the absence of a central controller.

The rest of the paper is structured as follows: In Section 2, a survey on the public safety network is done. Then, the FINDER framework for critical communications is proposed in Section 3. In Section 4, the performance evaluation of the proposed framework and routing method is validated through MATLAB simulation. Finally, we conclude in Section 5.

2 Related works

Effective disaster management and emergency response is depend on the efficient data communications between the first responders and the victims in the disaster zone. Failure of communication networks due to disaster makes the first responder's task very difficult. Research communities from government and academia have attempted to propose several network architectures, to deliver solutions that are resilient to disasters. Due to high significance, social networking sites like Twitter and Facebook also have developed applications for disaster management [7]. We have broadly divided the PSN research works into two different groups: D2D based approach and non-D2D based approach.

D2D based approach: D2D communications is an efficient alternative to cellular communications in disaster owing to the features like infrastructure-less sustenance, energy efficiency, and spectral efficiency. In [8] Nishiyama et al. developed a model namely Relay by Smartphone, of D2D relaying smartphone that allows sending emergency messages from detached areas and sharing of information between people assembled in evacuation centers. However, the work did not consider the problem of rapid increase in the number of users and the security issues. In [9] a novel D2D based messaging solution to overcome the problem of UE power limitation faced by the cellular radio access technologies in disaster scenarios was proposed. The proposed D2D messaging mechanism was compared with the default Random Access Channel (RACH) based messaging mechanism. However, the proposed RACH based power consumption was not unambiguously modeled for different radio access technologies such as Global System for Mobile

Communications (GSM), Universal Mobile Telecommunications Systems (UMTS) and Long-Term Evolution (LTE), and so additional research is desirable to assess the power consumption. Ahmad et al. [10] have proposed a D2D-based cooperative communication mechanism named Survival on Sharing (SoS), as an alternative to the existing critical communications technologies. SoS needs two additional entities implemented at the eNB, a disaster management cache (DMC) and disaster management server (DMS). The dependency of SoS on eNB makes it infeasible for all disaster scenarios. The authors in [11] applied a Poisson Point Process (PPP) to model a homogeneous cellular network and studied the impact of using multi-hop D2D relays in the disaster area to extend the coverage of cellular networks by evaluating the network-level service success probability. However, by focusing on the coverage for disaster recovery, it was assumed that the traffic handling capability of D2D relays and base stations was unlimited.

Non-D2D based approach: Public safety communications have been through an unprecedented evolution, starting with the use of 'receive only' mobile radio in 1928 by the Detroit Police Department in the United States, until the release of Voice over Long Term Evolution (VoLTE) standards [12]. In [13], Nippon Telegraph and Telephone (NTT) Japan presented the resource unit concept named Movable and Deployable Resource Unit (MDRU). The idea of MDRU is to deploy a recovery network by transporting a complete resource unit to the disaster site. However, the cost of creating an MDRU is very high, and the MDRU deployment may not be practical considering that the spectrum and energy resource in a disaster area is significantly limited, while the demand of network connectivity, capacity and power habitually increase with time during and after a disaster. Vergne et al. in [14] proposed a disaster recovery mechanism to evade coverage holes due to disaster by randomly adding new BSs in the disaster area. However, the addition of new BSs is not always practical and is very costly. Altay et al. [15] proposed a standalone eNode-B architecture, which deploys its own integrated virtual Evolved Packet Core (EPC) to guarantee service without backhaul connection. The proposed standalone eNode-Bs are also designed to establish backhaul connection with each other to extend the coverage without the requirement of a central EPC. The notion of eNode-B not only offers enhanced interoperability but also increase the functionality in terms of transmitting data specifically in emergencies and disaster scenarios. However, the work did not address the power consumption issue during the disaster events. In [16], the effect of the relay mobility was addressed, where the authors considered the coverage and capacity extensions by mobile relays and the influence of mobility on the probability of route formation and the expected availability duration. However, this work limits their scope to point-to-point communication with a single cell in the idealized circular coverage area.

While most solutions for PSN [1] that exploits D2D paradigm are focused on extending the coverage, spectrum management, resource allocation, random access and device discovery; our proposed framework offers a novel way to locate-and-reconnect the isolated nodes and improve the energy efficiency of the network using opportunistic path gain and clustering. The implementation results show the extended FINDER network existence over the traditional solutions. More network lifetime means a higher chance of communication and survival, which is crucial for PSN.

3 FINDER system model

A natural or human-made disaster may devastate the network infrastructure, leading to partial or full disconnection of the cellular link by the MNs. We are considering a disaster scenario as shown in Fig. 1. where not all the BSs are faulty, instead, if a BS is entirely down, the nearby BSs or other HetNets are functioning fully or partially. The MNs in the dead spot, i.e., the place where the cellular connection is not available, need to send critical data to the appropriate destination including PSN control center, to save lives and assets. We developed a framework named FINDER to decrease the effect of a disaster on the cellular network and showed how the D2D communications technology could alleviate the harm by extending the coverage originated from a nearby healthy BS towards the damaged BS.

We have considered a random BS phase-out disaster propagation scenario, which affects the cellular network. The implicit assumption of the random BS phase-out process is due to the inherited random nature of the effect of disasters, which allows capturing the average behavior of the network during and after the disaster. This random phase-out scheme allows tractable analysis and formulation of the network performance [11]. For simplicity and without loss of generality, we assume that the BSs are deployed according to a homogeneous PPP with a certain base-station density λ (BS per unit area). The plausibility of PPP was verified by comparing with real deployments in [17, 18]. Moreover, modeling a cellular network using PPP facilitates the tractability, without resorting to complex system-level simulations. Also, we assume that the MNs are randomly distributed in the failure region (according to another PPP with a different density). Based on real-world data, the importance of node distribution in emergency communications is discussed in [19, 20]. The PPP model for the distribution of MNs and BSs for D2D communications is well studied in [21].

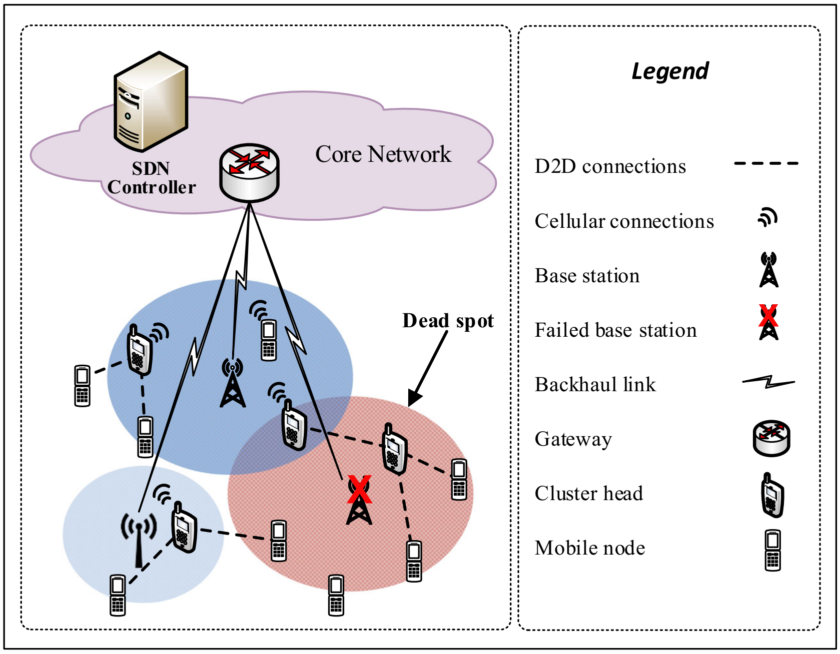


Fig. 1 System model of FINDER

Since the cellular link is not available in the dead spot, the better option for easy and fast communication is to have a multi-hop D2D communication [22, 23]. Using the multi-hop D2D relay, the MNs under the dead spot could transfer the data to the control center through a pBS (proxy Base Station (pBS): Mobile Node connected to an active BS in the neighboring cell). An outband autonomous D2D communications [6] is considered here by exploiting the available unlicensed spectrum to alleviate the unavailability of cellular link. However, to have the unlicensed spectrum, an extra interface is required in the MNs to adapt other wireless technologies, preferably Wi-Fi Direct.

Network lifetime is crucial but challenging from the perspective of a disaster scenario. The energy consumption by the MNs can be restricted using data aggregation and energy efficient routing [24, 25] which in turn prolong the overall network lifetime. Our proposed framework FINDER has an efficient routing mechanism, which adopts a minimum cost function in the routing table, to discover the optimal path from source to destination. Thus, our primary interest is to locate and render network connectivity to the isolated MNs and to increase the network's lifetime, so that the data can be transmitted for a longer time from the disaster region to control center so that more lives and assets are saved.

In this section, we describe FINDER, a framework with a routing scheme to locate-and-reconnect isolated mobile nodes in the disaster area by enabling D2D relay mode instead of a cellular connection. Using D2D relay [26], data is transferred from isolated nodes to the active network nearest to the disaster zone. No additional hardware is required, and the whole system is created automatically in an ad hoc manner. Network lifetime is increased using cluster-based data aggregation approach [27], where the whole region under the dead spot is divided into different clusters. Each cluster has a potential Cluster Head (CH) selected by the members of the cluster. We assume that all nodes have the MN-to-MN relay feature [10], without the assistance from the BS. The MNs in each cluster sends the data to the CH and the CH aggregate the data and send it to the nearest active BS via multi-hop D2D communications, using neighboring CHs as a relay.

The disaster zone acquires the network connectivity by extending the coverage of nearby healthy BS. The extension of the network connection is managed by leveraging SDN controller assistance from the core network that has a network view at the global level [28, 29]. At the time of disaster, the central SDN controller directs the nearby BSs of the disaster zone, to extend the cellular network coverage via multi-hop D2D communications. The components and a working model of the FINDER are discussed below.

The components of FINDER are integrated with the operating system of MNs as depicted in Fig. 2. At lowest-layer, an opportunistic forwarding algorithm is used to increase the energy efficiency by reducing the number of re-transmissions. The idea is that in case of packet loss at the receiver node, instead of re-transmission from the source node, the source node delegates the re-transmission to an intermediate node, which has a better link with the receiver node and has received the packet in the first transmission. This module lies in between the network layer and the data link layer. This method helps to alleviate re-transmission from the source and thereby increases the network efficiency and lifetime.

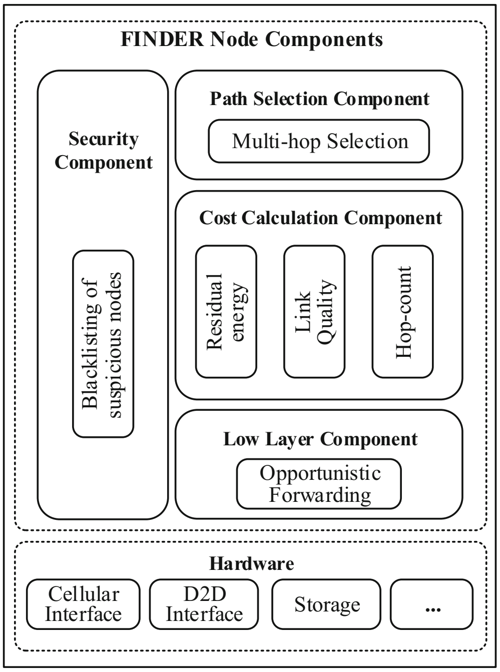


Fig. 2 Components of a mobile node in FINDER

The cost calculation component fetches input such as residual energy, link quality, and hop-count from the low-layer component and assigns a cost value to each node in the network. Various cost metrics like energy metric, link-quality metric, and distance metrics are taken into account for making better routing decisions. The path selection component helps to select the optimal route from source to destination based on the resultants offered by the cost calculation component. We use multi-hop based route selection, where CHs in between the source and destination acts as the relay. Finally, we use blacklisting of nodes as the security module, which could detach suspicious nodes that show misbehavior at any stages of routing. All modules can invoke the security module at any time to avoid any breach of trust. The flowchart of critical D2D network formation and termination is shown in Fig. 3. FINDER follows four distinct phases for energy efficient optimal routing to prolong the network lifetime.

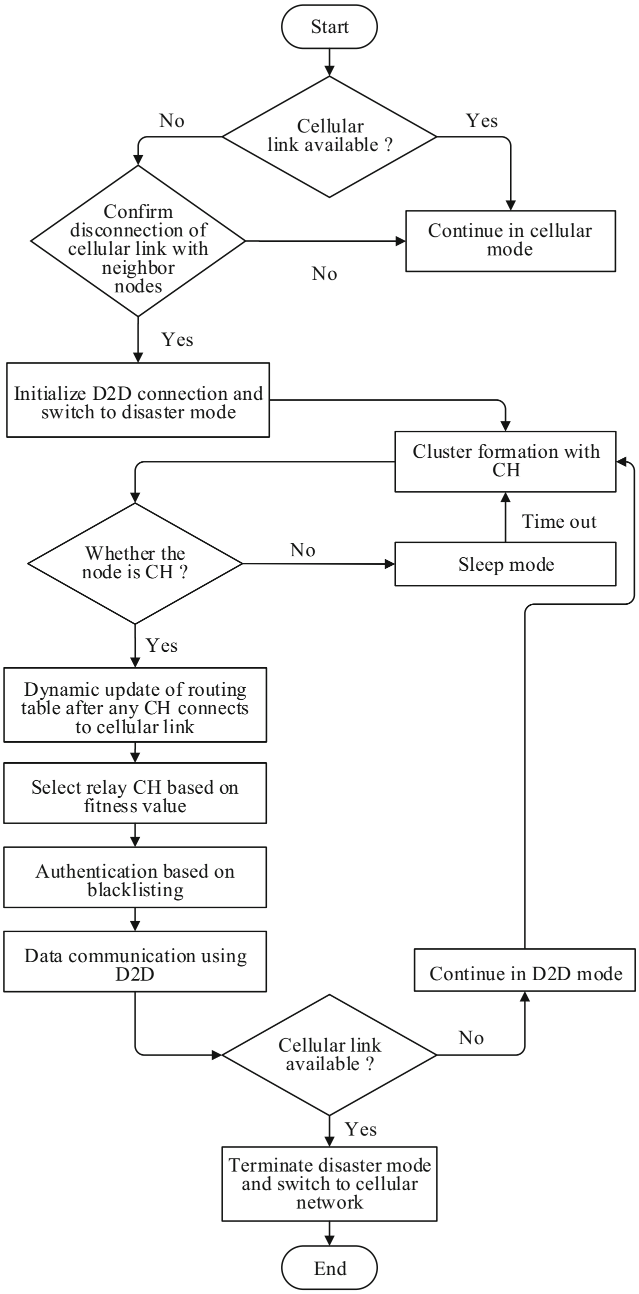


Fig. 3 Flowchart of critical D2D network formation and termination

3.1 Mode switching and neighbor discovery

We assume that the MNs or smartphones in the disaster zone can decide appropriate transmission mode [30] based on information like cellular link state, energy level, and location. Whenever the cellular link is unavailable for a specified time interval, the MNs enquires the status of the cellular link by sending a broadcast message to the neighboring MNs. If the adjacent devices confirm the disconnection of the cellular link, the MNs are automatically switched to D2D disaster mode. Then the MNs broadcasts direct beacon frames to neighboring MNs, such that the MNs in proximity could join to form a D2D network. When any of the devices identify the cellular network, it broadcast the link status to other devices. After confirming the status, the D2D mode is terminated and all the MNs are connected back to the cellular network.

3.2 Clustering with buffering

During a disaster, it is necessary to save energy and maximize the network lifetime. To save energy, a clustering

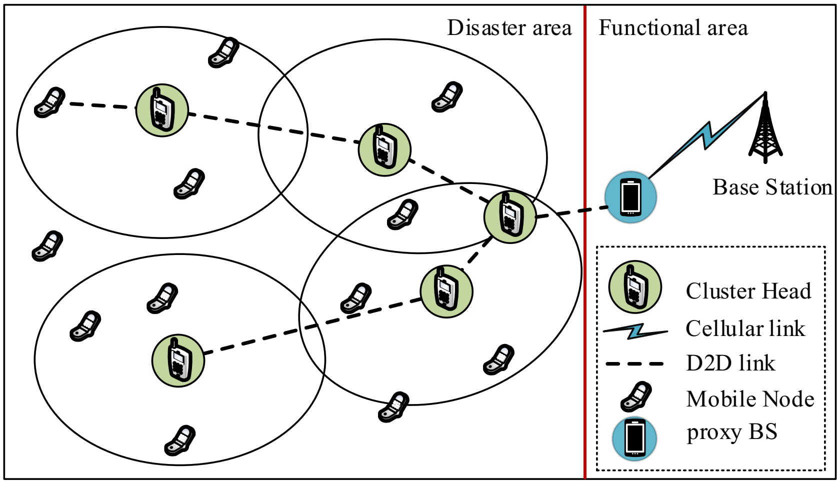


Fig. 4 Cluster formation and communication using D2D in the disaster zone

mechanism [31] is used to associate the co-located mobile devices to form a cluster with a potential Cluster Head node. The cluster head selection is dependent upon several factors like device's residual battery energy, computational power, SNIR, and bandwidth availability. Once the CH is selected, it sends a welcome message to all other nodes in the cluster, to join the cluster under its control. Other nodes confirm the cluster formation by sending an acknowledgement message. The CH coordinates the cluster members for transmission of control and data packets. As shown in Fig. 4, all the mobile nodes in a cluster are supposed to send the data only to the CH. The CH forwards the data to the destination using neighboring CHs as relay nodes. Thus, the number of participating nodes is minimized, and the network load is contracted. Finally, a group of clusters interconnected with cluster heads is formed in the disaster area.

To expedite the rescue operation in the disaster zone, FINDER follows a double buffer scheme at the CH level. The CH is build up with two buffers, an Emergency Information Buffer (EIB) and a Data Buffer (DB). The EIB stores critical data such as present location and medical information, whereas the DB stores the data of cluster members that need to be sent to the network. After the successful formation of clusters, the first thing the CH has to do is to get the emergency data from the cluster members and is stored in the EIB. When there is a sign of good network connection, the CHs forwards the contents of EIB first, and then the Data Buffer. Thus, the critical data is transferred instantly. When a cluster member wants to send some data, instead of waiting for a connection signal, it just sends the data to the CH and goes to sleep mode. The CH stores the data in the DB and forwards the data only when a good network connection is detected. Buffering scheme is justified by the decreasing cost of memory and increasing memory space in the latest smart phones.

3.3 Determine the destination dynamically

When any of the MNs in disaster zone is connected to a live network through any technologies like cellular or Wi-Fi, other devices could also share the connection to the external network through the pBS using the multi-hop D2D connection. The intermediate CHs are used to relay and reach the active network as shown in Fig. 5. The routing

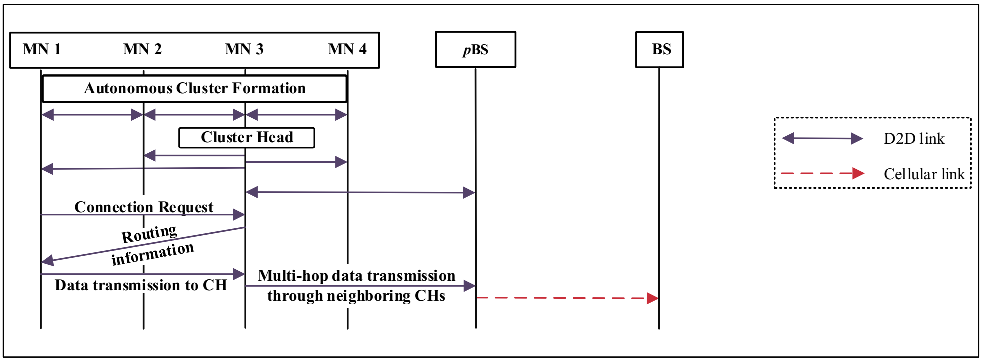


Fig. 5 Cluster formation and data transfer using CH from MN1 to BS

table is dynamically updated, such that pBS or the node having a live network is set as the destination. The SDN controller can help the MNs in the dead spot to find the optimal route to the destination. When a BS is down, the disconnected cellular link could be identified by the global SDN controller at the core network. The SDN controller would then as instruct the nearby BSs to extend the cellular network coverage [28] by permitting the edge MNs in the active BS to connect with the MNs in disaster zone through D2D communications.

Upon receiving the control instructions from the SDN controller, the respective pBS in the neighboring cell of the dead spot runs Algorithm 1 and broadcast the advertisement packets (ADV) which get flooded over the dead spot area to introduce the pBS to the MNs in a disaster zone. The ADV packet contains information such as mobileNode_ID, residual_energy, and max_no_of_hops. When a CH in a cluster receives this packet, it stores a copy and broadcast it to other CHs depend upon the max_no_of_hops or other constrains if specified. A sequence number (ADVseqNum) is maintained for the ADV to avoid redundant transmission. Thus, the destination is discovered by the CHs and other MNs in the disaster zone. If more than one destination node is found, the best one is selected depending on some election parameters like the residual energy, computation power, number of hops to reach and the link quality.

Algorithm 1 The advertisement broadcast algorithm

```
Begin
    TX (SRC=pBS, DST=Broadcast, ADVpacket)
    if ADVinterval is reached then
        Increment (ADVseqNum)
    end if
End
```

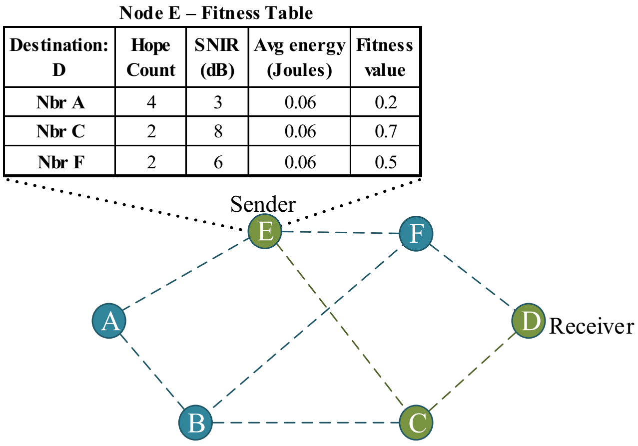
Once the destination (pBS) is fixed, the CHs could then find the optimal route to the destination, based on hybrid Ant Colony Optimization method. An optimal and efficient network is built using hybrid ACO based routing with clustering.

3.4 Route selection and data dissemination

FINDER routing is proposed based on hybrid ACO, where pBS is the destination node, intermediate CHs are relay nodes, individual CH node is the source, and the D2D is the connection path. In FINDER routing, the forward packets should leave the source node to reach the destination node. Each CH should find the best path to the neighboring relay CH node and should update the routing table with the fitness metric. The acknowledgement packets travel from destination to source based on the existing fitness value along the same path of forward packets in reverse direction and updates the fitness table again. After a few iterations, the data packets will be traveling in an efficient available path. If the number of nodes is large, route finding by all nodes will result in congestion and drain of battery. Clustering helps to tackle this problem by curtailing the number of participating nodes and packets.

3.4.1 Basic ACO routing

The MNs in the dead spot are represented by a weighted undirected graph G(V, E), where V is the set of CH nodes, and E is the set of D2D links between these nodes. Any node in this graph has a set of neighbors through which multi-hop communications can occur. An example network graph representation is given in Fig. 6, where CH node E connects to D using C as the relay. In ACO, control packets are used to discover and optimize the routing path between source and destination. The ACO algorithm [32] uses two kinds of control packets called forward packets and backward packets with the assumption that the network has a valid destination. The forward packet travels from source to destination by exploring new paths and gather network information. In each travel, the forward packet selects a next-hop node from the list of neighbors from routing table at each node, to establish the next-hop link. The fitness metric represents the information captured from the current path being explored. The fitness value is increased whenever a control packet repeatedly travels through a particular path and the value is dismissed if a path is idle for a particular time period. Thus, the fitness value includes both previous information and the instantaneous information instilled by the forward control packets and the backward control packets respectively. Consequently, the accumulated fitness value helps to learn the routes more accurately and the routing efficiency is increased.



Node E – Fitness Table

Destination: D	Hope Count	SNIR (dB)	Avg energy (Joules)	Fitness value
Nbr A	4	3	0.06	0.2
Nbr C	2	8	0.06	0.7
Nbr F	2	6	0.06	0.5

Fig. 6 Routing table in Node E, and graphical route representation

The neighbor candidate list in the routing table contains the mobileNode_IDs, which are in the communication range of the current node. The probability of control packet moving from current node x to neighboring node y in the traditional ACO [33] is given by

$$\mathbb{P}^k_{xy}(t) = \frac{\left[\varphi_{xy}(t)\right]^\alpha * \left[\varepsilon_{xy}(t)\right]^\beta}{\sum \left[\varphi_{xy}(t)\right]^\alpha * \left[\varepsilon_{xy}(t)\right]^\beta} \tag{1}$$

where $\mathbb{P}^k_{xy}(t)$ is the probability of selecting the node y from node x by the forward control packet k in time t. $\varphi_{xy}(t)$ is the fitness value accumulated on the x, y path. $\varepsilon_{xy}(t)$ is the location function for the path, and α, β are the two constant exponents associated with the algorithm. ε_{xy} is defined as:

$$\varepsilon_{xy} = \frac{1}{d_{xy}} \tag{2}$$

where d_{xy} is the Euclidean distance between x and y calculated by:

$$d_{xy} = \sqrt{\left(p_x - p_y\right)^2 + \left(q_x - q_y\right)^2} \tag{3}$$

where $x = (p_x, q_x)$ and $y = (p_y, q_y)$.

When the forward control packet spots the destination node, the path between source and destination is established and generates the backward control packet. The backward control packet returns to the source node using same but reverse route of the forward packet. The backward packet updates the fitness value while traveling and initiates the forwarding of data packets. The fitness metric $\varphi_{xy}(t)$, will be updated at the end of the searching period on the path as

$$\varphi_{xy}\,(t+1) = (1-\rho) * \varphi_{xy}\,(t) + \Delta\varphi_{xy}\,(t) \tag{4}$$

where ρ the fitness reduction factor, $\Delta\varphi_{xy}$ is the fitness increment factor on the route which is given by

$$\Delta\varphi_{xy} = \sum_{k=1}^{n} \Delta\varphi^k_{xy} \tag{5}$$

$$\Delta\varphi^k_{xy} = \frac{A}{L^k} \tag{6}$$

L^k is the length of the path initiated by the control packet k and A is a constant. This algorithm repeats for a certain number of iterations by a certain number of control packets. However, for the particular case of D2D routing in PSN scenario, the routing algorithm has to be aware of residual energy, number of hops and link quality. We propose FINDER routing method that inherits the characteristics of biological systems such as autonomy, self-organization, robustness, energy efficiency and scalability, which are all desirable properties to deal with the challenges posed by the public safety networks.

3.4.2 FINDER routing

In this section, we propose a hybrid ACO based routing algorithm that increases the efficiency of the network by reducing the energy consumption of the MNs. Algorithm 2, the energy-aware FINDER routing algorithm, enables the MNs to learn the next hop probability towards the destination based on the residual energy. The probability of choosing y node from x node is modified as:

$$\mathbb{P}^k_{xy}(t) = \frac{\left[\varphi_{xy}(t)\right]^\alpha * \left[\mu_{xy}(t)\right]^\beta}{\sum \left[\varphi_{xy}(t)\right]^\alpha * \left[\mu_{xy}(t)\right]^\beta} \tag{7}$$

where $\mathbb{P}^k_{xy}(t)$ is the next hop probability, $\varphi_{xy}(t)$ is the fitness value and $\mu_{xy}(t)$ is defined as follows:

$$\mu_{xy}(t) = \frac{1}{Ie - Ce_y(t)} \tag{8}$$

where Ie is the initial energy and $Ce_y(t)$ is the current energy of node y at time t.

To increase the efficiency, it is better to select a path, which is having maximum link quality and min hop-count. So, the link quality and hop-count are considered when choosing the neighbor node, from the list of candidate nodes to the destination. A node having good link quality and minimum hop-count has the higher probability to select as the neighbor node. The Eq. 4 is modified as

$$\varphi_{xy}\,(t+1) = (1-\rho) * \varphi_{xy}\,(t) + \frac{\Delta\varphi_{xy}(t)}{hop^k_{count}} \tag{9}$$

where hop^k_{count} is the number of nodes that k has visited in the network from the source to reach the destination.

$$\Delta\varphi_{xy} = c * (hop_{max} - hop^k_{count}) * R^k_{avg} * SNIR^k_{avg} \tag{10}$$

where hop_{max} is the maximum allowed hops for control packets in the network, hop^k_{count} is the number of hops traveled by k from source to destination, R^k_{avg} is the average residual energy of the nodes, c is a constant and $SNIR^k_{avg}$ is the average $SNIR$ of the nodes that the control packet k visited.

Further, for an extended network lifetime, a new probability function that considers the distance parameter also is used for selecting the next-hop. The distance parameter is used based on the fact that, nearer node to the destination node in the neighbor candidate list of current node can reach the destination with a minimum number of hops. The new probability function for the choice of the next-hop node with energy and distance parameter is:

$$\mathbb{P}^k_{xy}(t) = \frac{\left[\varphi_{xy}(t)\right]^\alpha * \left[\mu_{xy}(t)\right]^\beta * \left[\epsilon_{xy}(t)\right]^\gamma}{\sum \left[\varphi_{xy}(t)\right]^\alpha * \left[\mu_{xy}(t)\right]^\beta * \left[\epsilon_{xy}(t)\right]^\gamma} \tag{11}$$

where $\mathbb{P}^k_{xy}(t)$ is the next node selection probability, $\varphi_{xy}(t)$ is the fitness metric, $\mu_{xy}(t)$ is the energy metric and

$\epsilon_{xy}(t)$ is the location function. α, β and γ are the control parameters.

$$\mu_{xy}(t) = \frac{R_y(t)}{\sum R_{cx}(t)} \tag{12}$$

where R_y is the residual energy of the node y and R_{cx} is the residual energy of the candidate list of x node. Equation 12 makes sure that the node with higher residual energy has the higher probability to select as the next hop.

$$\epsilon_{xy}(t) = \frac{d_{yd}}{\sum d_{cxd}} \tag{13}$$

where d_{yd} is the distance between node y and the destination d. d_{cxd} is the distance between destination d and the nodes in candidate list of node x. Equation 13 makes sure that the nearer node to destination node in neighbor candidate list has the highest selection probability. When all control packets complete the travel, each will add more value to fitness metric as per the given equation:

$$\Delta\varphi^k_{xy} = \frac{c * (hop_{max} - hop^k_{count}) * R^k_{avg} * SNIR^k_{avg}}{hop^k_{count}} \tag{14}$$

where c, hop_{max}, hop^k_{count}, R^k_{avg}, and $SNIR^k_{avg}$ are same as in Eq. 10

Algorithm 2 FINDER routing algorithm

```
Begin
Initialize the network with size m x n
Number of control_packets = N
Number of iterations = I
Distribute the nodes uniformly
Initialize default fitness value and $SNIR$ of D2D links and energy level of each node.
for (i = 1 to I)
    for (j = 1 to N)
    current_node=source_node
        while current_node! = destination_node
        Calculate $\mu_{xy}(t)$ and $\epsilon_{xy}(t)$ between current_node and its neighbors in its candidate_list using Eqs. 12 and 13.
        Calculate $\mathbb{P}^k_{xy}(t)$ probability function for nodes in candidate_list of current_node by Eq. 11
        Choose the next-hop-node based on probability function
        current_node = next-hop-node
        end while
    end for
 Update fitness value of path using Eq. 14
end for
End
```

Table 1 Simulation parameters

Parameter	Values
Network size	4500 x 3400 m^2
Number of nodes	100-600
Radio range	100 m
ρ	0.8
$\varphi_{xy}(0)$	0.01
α, β, γ	1.5
MAC layer protocol	IEEE 802.11n
Simulation time	24 hours
Data packet size	512 bytes
Initial energy of nodes	4800 mJ
Energy to transmit	0.08mJ
Energy to receive	0.05mJ

4 Implementation and results

In this section, the FINDER algorithm's performance is compared with Epidemic routing. The Epidemic is a traditional routing algorithm for intermittently connected wireless networks [34]. We compared the performance of the two algorithms with a set of MNs ranging from 100 to 600. We simulate FINDER using MATLAB. The LTE System Toolbox in MATLAB provides different inbuilt options and scenarios to model and analyze the D2D performance. Application Note is also available which focuses exclusively on direct communication as defined for public safety usage. The simulation parameters for our experiments are given in Table 1. The various performance metrics utilized for the evaluation of algorithms are message delivery probability, overhead ratio, energy consumption and the percentage of dead nodes.

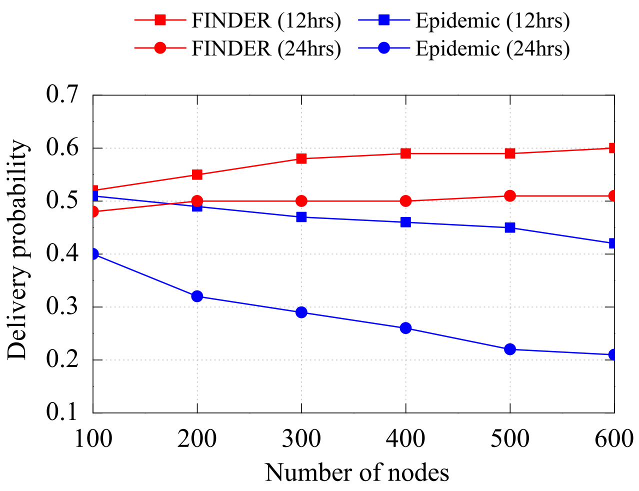


Fig. 7 Delivery probability *vs*. Number of nodes

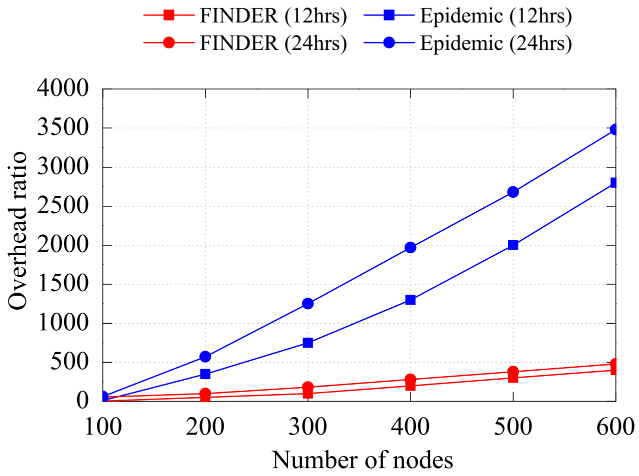


Fig. 8 Overhead ratio *vs*. Number of nodes

a) Message delivery probability: Message delivery probability is the total number of messages delivered divided by the total number of messages created in the network. From Fig. 7 we can see that FINDER performance is better than the Epidemic in most cases. Generally, when the number of nodes is increased in the network, the delivery probability is decreased. This is because a lot of messages are copied and forwarded to neighboring nodes causing a buffer overflow and the message may be dropped before they are delivered to the destination nodes.
b) Overhead ratio: The overhead ratio is defined as the number of copies created per delivered messages. If more messages are copied, then there will be more transmissions consuming more bandwidth. Lower the ratio better the performance, as less bandwidth is used for message delivery. As shown in Fig. 8, FINDER outperforms the Epidemic in overhead ratio, as it makes less number of copies per delivered messages and uses less bandwidth. In Epidemic, whenever a node meets a neighbor node, if the neighbor does not have the copy of the message, the messages are copied and forwarded to the neighbor. Consequently, the number of copied messages increases in Epidemic and the overhead increases with an increase in the number of nodes. FINDER is better than Epidemic because of better routing strategy against simple copy and forward.

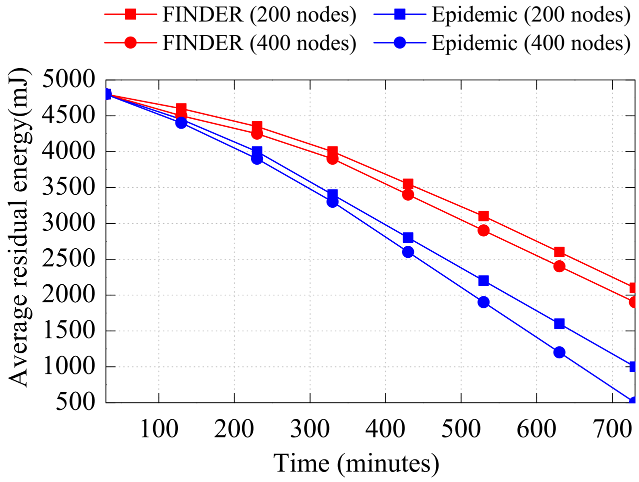


Fig. 9 Average residual energy *vs*. Time

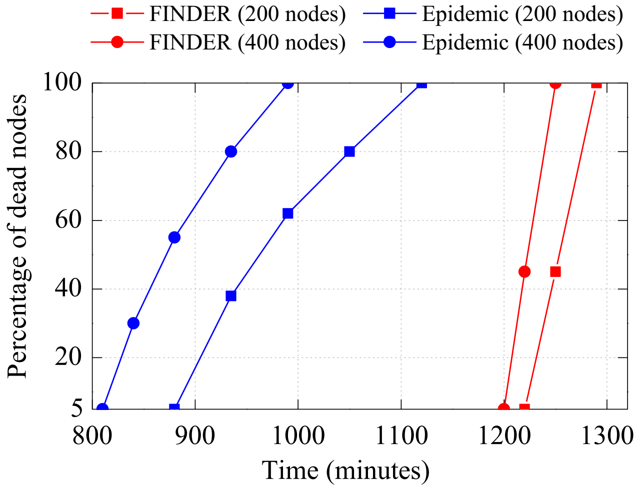


Fig. 10 Percentage of dead nodes *vs*. Time

c) Residual energy: Fig. 9. shows the average remaining energy of nodes during the simulation time. Results show that the rate of energy consumption is higher when the number of nodes is increased in the network. In the case of Epidemic, the rate of energy consumption is high due to the broadcast of messages. FINDER performs better than Epidemic mainly due to the intelligent selection of next-hop node instead of broadcasting to all nodes.
d) Network lifetime: Fig. 10 shows the percentage of dead nodes after the simulation time. FINDER achieves better performance by employing dynamic clustering of the mobile nodes and non-usage of periodic beacons. In addition, the sleep mode of mobile nodes avoids energy loss in the inactive state. Reduction in energy consumption and load balancing among nodes further increases the network lifetime. We can analyze that the network size has the least influence on FINDER.

Table 2 Effect on traffic load

Scenario	Delivery probability	Overhead ratio
FINDER(12hrs)	0.60	400
FINDER(24hrs)	0.51	480
Epidemic(12hrs)	0.42	2800
Epidemic(24hrs)	0.21	3480

Table 3 Effect on simulation time

Scenario	Average residual energy	Time alive
FINDER(200 nodes)	2100	1290
FINDER(400 nodes)	1900	1250
Epidemic(200 nodes)	1000	1120
Epidemic(400 nodes)	500	990

We have experimented different scenarios with changes in time and number of nodes, and compared the performance of our algorithm with the Epidemic. Results show that FINDER has better performance than Epidemic in most of the scenarios. More importantly, the effect of a change in the number of nodes has the least effect on FINDER performance. This shows the adaptability of the FINDER routing algorithm to efficiently balance the energy consumption. The extended network lifetime is achieved using dynamic clustering, intelligent selection of hops, optimal path based on hybrid-ACO and implementation of sleep mode. The metrics values at the end of the simulation are summarized in Tables 2 and 3. Except for overhead ratio, the maximum metric value is better. The simulation results show that the energy saving by individual nodes helps to extend the network lifetime of FINDER by 18% than other methods.

5 Conclusion

In this paper, we proposed FINDER, a novel D2D communications framework especially for potential disaster communications and management in the 5G network. The aim is to locate-and-reconnect the isolated mobile nodes in the disaster zone by creating a critical D2D network having higher lifetime with available resources. The out-of-coverage mobile nodes in the disaster zone can experience the network using FINDER. The implementation results show that using our framework FINDER the energy consumption of the routing process is reduced and the network lifetime is increased by 18%. In future, the proposed framework can be extended to enable wireless energy harvesting from radio frequency such that the energy efficiency and the network lifetime can be improved further.

Acknowledgements Anil Thomas and Gunasekaran Raja would like to thank NGNLab, Department of Computer Technology, Anna University, Chennai, for the support.

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