Fast Networking for Disaster Recovery

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Abstract—Content-Centric Networking (CCN) is now a research hotspot aiming at building up a new network architecture compared with the traditional IP-based, host-centric one. In this paper, after leaning that CCN's content naming and content-based properties make it suitable for fast network organizing in disaster recovery, we propose methods on access point placement and routing to fast connect users in a middle-scale post-disaster scenario model. Our work includes the design of a placement algorithm using graphic union coverage and a CCN routing strategy based on Breadth-First Searching, both extracting the social attributes of user node distribution. We use real-world maps for simulation and carry out comparative analysis with existing Ad Hoc methods under the same experimental conditions. The simulation results show that CCN can bring more efficient routing and robust framework to fulfill the urgent demands of post-disaster recovery.

Index Terms—Content-Centric Networking, Fast Networking, Disaster Recovery.

1 Introduction

After more than fifty years of development and revolution, the Internet has already firmly shaped our whole cognition of computer network. Multi-layer system model and TCP/IP protocol stack together build up the traditional host-centric cyberspace. Everyone is used to the order of exchanging the confirmation information in advance and starting a conversation online, which is mature both in technical level and application level nowadays. However, going through ages of innovation in hardware, software and protocols, traditional IP network seems to fall behind our demand. A modern bandwidth-intensive situation already bursts into our sight [1], just passing by the shambling *Moore's Law*.

As early as in 2000, Cheriton *et al.* first proposed the concept of name-based routing. After that, the Information-Centric Networking Research Group (ICNRP) was set up and got its sponsorship from Internet Research Task Force (IRTF). Then in September 2014, the 1st ACM Conference on Information-Centric Networking (ICN-2014) was convened. Up to present, the idea of introducing uniquely named data as a new keystone of network architecture has been receiving more and more attention broadly.

As one of earliest ICN research projects, Content-Centric Networking (CCN) was established in 2007 by Palo Alto Research Center (PARC). CCN develops to get rid of original communication modes based on IP addresses. It sorts and deals with everything in transmission & processing in two types of packets, i.e. the *Interest Packet* and the *Data Packet*. When a user wants some contents saved in remote servers, all he/she needs to do is to send an *Interest Packet* and wait for response, access points that can hear it store the *Interest Packet* in their *Pending Interest Table (PIT)* and forward to all available interfaces recorded in *Forwarding Information Base (FIB)*. The right server answers it by returning a *Data Packet* carried the wanted content from its *Content Store (CS)*. In addition, the *Interest Aggregation* property takes advantage of named contents which also helps save bandwidths in a more reasonable and efficient way among CCN clients.

Disaster recovery, as one phase of disaster management (or emergency management), its immediate goal is to bring the effected area back to normal as quickly as possible. Based on distributed base station equipment, communication social network infrastructure is extremely susceptible to the effects of various disasters and get paralyzed. Sometimes a partial breakdown may cause disconnection of masses of clients. At this time, a fast-organized temporary emergency network resilient to disruptions and failures like CCN can provide timely help.

The motivations why we choose CCN to achieve fast network organization in disaster recovery scenario are as follows. First, compared with traditional *Ethernet*, CCN owns simpler network structure and less demand for equipment which means any device provided with *PIT*, *FIB* and *CS* is able to connect to CCN. Second, without complicated address resolution and IP addressing, routing procedure of CCN also could be simplified. Moreover, the property of *Interest Aggregation* could substantially reduce the forwarding times or hops of routing. As a result, in disaster recovery we prefer a network design like CCN, which is easy to organize and compatible with various types of devices, as well as convenience in connection/routing.

Our work focuses on the scenario of a middle-scale open area with most of the original network connections being shut down by unpredictable disasters. All users within range may no longer connect to each other or the outside, which means they are in urgent need of searching for rescue or sending out safety check. Users in such circumstance are anxious to seek any rescue as soon as possible. Thus, we hope a fast organized, efficient emergency network applying CCN rules can help.

In this paper, we propose algorithmic solutions on the access point placement problem and routing strategy, then make comparative analysis on performance with existing Ad Hoc methods in packet delivery simulation experiment.

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The main contributions are as follows.

- Present a mathematical model based on a disaster affected scenario with all user nodes waiting to joint;
- Design a algorithm using idea of graphic union covering to solve the CCN access point placement problems and evaluate the performance of solution by *minimum access point number* and *new covered area*;
- Apply *Breadth-First Search (BFS)* in graph theory to routing strategy and carry out packet delivery simulation using real-world maps;
- Compare with Ad Hoc methods under the same experimental condition and setup, use *average transmission hops* as a metric to evaluate the performance of fast organized networking.

This paper is divided into six sections to manifest all aspects of our work. Section 1 introduces and sorts out the whole work flow. Section 2 presents background and related researches on CCN and other network architecture in disaster management. Section 3 sets up the mathematical model from the disaster scenario and elaborates the details of raised problem. Section 4 proposes the designed algorithms of placing access points and routing in the model. Section 5 gives results of simulation and comparative analysis between Ab Hoc methods in fast organized network performance. Section 6 summarizes the previous work and draws conclusions, then some future work plan.

2 Background and Related Work

With the development of technology and society, we are already aware of that when facing with emergencies or disasters, *before*, *during* and *after* are equally important. As an inseparable part of modern human life, communication social network or the Internet plays a role next only to basic necessities. In a word, network infrastructure not only provides convenience in daily life, but helps a lot in multiple phases of incoming disasters. In post-disaster recovery, to restore communication social network link in urgent time, traditional *Ethernet* architecture may face challenges from devices rush repairing to transmission line reseting. Many researches have been done on adapting new technical approaches like Ad Hoc, Wireless Sensor Network (WSN) and Delay/Disruption-Tolerant Networking (DTN) into a dedicated disaster system.

In contrast to the traditional host-centric, IP-based Internet architecture, CCN treats contents as both the contents themselves and generalized unique identification which earns considerable advantages on availability, security and location-dependence. Especially with the hierarchical naming scheme and request aggregation properties, CCN can fulfill the deployment of medium/small scale wireless network in disaster scenario with high robustness and mobility. Although still not wide deploying, we suggest hypothesis in a post-disaster scenario and use experimental validation to show that there is possibility for CCN to fast organize a sustainable temporary network structure until complete restoration of normal communication.

Before ICN going into our fields of vision, to achieve scalable and efficient content distribution through existed communication facilities, technologies like peer-to-peer (P2P) and Content Distribution Network (CDN) already walk ahead. However, the idea of building up a network completely on contents (or information, names) has never got its debut until ICN projects appear. Besides CCN, there are many others like Data-Oriented Network Architecture (DONA) [2], Network of Information (NetInf) [3], Named Data Network (NDN) utilizing differentiated differing with respect to assumptions, objectives, architectural properties and approach details. Especially the NDN project, extended from CCN, now owns the largest testbed supported by 29 universities, research institutions and technology companies from different countries around the world (8 as Next Phase Principal Investigator (PI) Sites and 21 as Next Phase Collaborators, up to now) [4].

As the leading research group, Van Jacobson *et al.* from PARC thoroughly elaborate the basic properties of the CCN architecture. From model definition and routing rules [5], real-time streaming applications inspired by Voice over IP (VoIP) [6] to CCN security & authentication [7] and Custodian-Based information sharing system design [8], providing rich enough technical details follow-up studies.

CCN researchers pay much attention to turning theory into practice. Yuan *et al.* design a new scalable *PIT* to help deliver packet more efficient [9]. Liu *et al.* study the impact of item and chunk popularity in managing CCN caching [10]. Tao *et al.* design a content-centric sparse multicast beamforming for cloud Radio Access Network (RAN) [11]. Su *et al.* think about building a content-centric framework as the next generation vehicular network [12]. Internet of Vehicles also shares many fitting points with CCN, related work analyzed the possibility of fulfilling vehicle-to-vehicle communication requirement [13]. Lee *et al.* propose a new approach for name prefix matching using bloom filter pre-searching [14]. Liu *et al.* design a hop-by-hop adaptive video streaming [15]. Security and privacy used to cause various problems in Internet, which also bring new challenges to CCN [16] [17].

As a new network framework, there are also lots of researches about transferring the traditional hotspots and applications into the new field such as audio & video conference application [18], flow traffic control and mobile network [19]. Wang *et al.* study the modeling and methodology for mobility aware caching for wireless CCN [20]. Tang *et al.* focus on the role of cloud computing in content-centric mobile networking [21]. Liu *et al.* design a user-behavior driven video caching for CCN [22]. Wang *et al.* use a real-life Internet topology and video access logs to evaluate the performance of various cache allocation methods in CCN [23].

Disaster management includes monitoring and prevention, response and relief, restoration and recovery. Catastrophic natural disasters such as Hurricane Katrina (*2005, United States*) [24], Wenchuan Earthquake (*2008, China*) [25], Great Tohoku Earthquake and Tsunami (*2011, Japan*) [26] happened in recent years provide abundant first-hand research materials to help making certain what is pressing to do on improvement of existing communication social network and how to reduce losses. Many studies combine the existing network technologies to help coping with the disaster situation better. Form Ad Hoc network architecture design and evacuation service with cloud computing

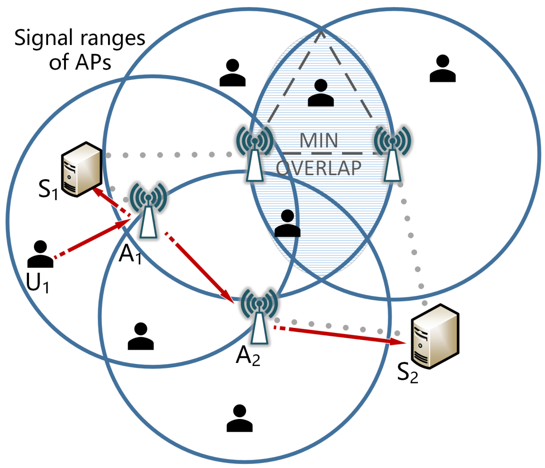


Fig. 1. The CCN Based network structure in disaster recovery scenario

in emergency management [27], crowd sourcing disaster management using social media like *Twitter* [28] to big data stream analytics for natural disaster in cloud computing [29]. Chen *et al.* try to achieve natural disaster monitoring with Wireless Sensor Network (WSN) [30]. Erdelj *et al.* focus on Unmanned Aerial Vehicles (UAV) to assist in all aspects of disaster management [31] [32].

3 Formulation and Problem Description

We consider a two-dimension fixed $x \times x$ square range as a post disaster scenario. There exist three types of nodes, each one using its name as unique identifier. User nodes U_n and server nodes S_n have fixed locations within scope. Access point nodes A_n own fixed signal coverages, and only the U_n staying in the radius of a nearest access point node are able to send out packets. A_n can be set anywhere, even overlapping some U_n as a trade-off choice. S_n can be visited through A_n nearby, which means other remote A_n may have to rely on forwarding work by neighbors. Here our *first target* is how to reduce the number of A_n and make efficient usage of each one while ensuring that each U_n has at least one A_n nearby to keep connected. We use an example to further explain the details.

As shown in Fig. 1, there are nine blue U_n relying on four yellow A_n to contact with two green S_n. Yellow circles stand for signal range of A_n, and gray dotted lines are direct relations between S_n and A_n. The *MIN OVERLAP* area represents the shortest distance between A_n to ensure interconnection. For instance, if U_1 wants to visit S_1, it only takes two hops via A_1. Then if it wants to send a *Interest Packet* to S_2, the full path is $U_1 \rightarrow A_1 \rightarrow A_2 \rightarrow S_2$. Every A_n has to guarantee that a neighbor one can do a favor when it does not find any other interfaces to forward in *PIT*.

In order to use less A_n to cover more U_n, we prefer as dispersed as possible for placement work. Besides the number of needed access points, we also pay attention to workload allocation of each A_n, which means each A_n may share a similar workload on managing U_n. Therefore we keep two metrics, the new covered area and new covered U_n number when deciding the location to place the next A_n.

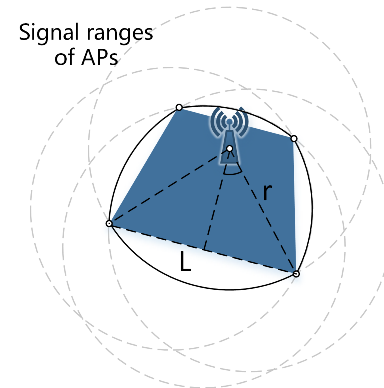


Fig. 2. The quasi-polygon made up of circular segments from signal range circles of APs

At first, each A_n has to make sure that at least one neighbor A_n stays in its coverage radius, i.e. new covered area is the differential between areas enclosed by all circles of placed A_n before and after placement.

$$
\begin{aligned}
SN_{\odot_n} = S_{\odot_n} - &\underbrace{\left(SO_{\odot_{1n}} + SO_{\odot_{2n}} ... SO_{\odot_{(n-1)n}}\right)}_{\mathrm{C}^1_{n-1}} \\
&+ \underbrace{\left(SO_{\odot_{12n}} + SO_{\odot_{13n}} ... SO_{\odot_{(n-2)(n-1)n}}\right)}_{\mathrm{C}^2_{n-1}} \\
&\vdots \\
&+(-1)^{n-1} \underbrace{\left(SO_{\odot_{12\cdots(n-2)n}} ... SO_{\odot_{23\cdots(n-1)n}}\right)}_{\mathrm{C}^{n-2}_{n-1}} \\
&+(-1)^n SO_{\odot_{123\cdots(n-2)(n-1)n}}
\end{aligned} \quad (1)
$$

New covered area ($SN_{\odot_n}$) can be calculated from Equation (1), in which $S_\odot$ and $SO_\odot$ respectively stands for circle area and overlap area of multiple circles. Our problem turns into a variant of the classical *combined area of overlapping circles* problem. There exist many mature computing methods in both mathematics and engineering with different precisions like polygon cutting, *Simpson's rule*, *Voronoi diagram* and *Monte Carlo algorithm*. Since what we prefer is a method focusing on circles of equal radii and new covered area individually, inspired by the idea and rules of graphic union coverage, an improved equal circle coverage method is designed to give solution.

Secondly, we will compute all the addends and sum them up. The overlapped parts are actually specific quasi-polygons surrounded by circular segments other than irregular patterns.

As shown in Fig. 2, each quasi-polygon we deal with can be divided into two parts, several circular segments (S_{cir_seg}) and a arbitrary convex polygon (S_{pol}). Circular segments are all minor parts of circles, whose area can be computed from the lengths of corresponding chords in Fig. 2 and Equation (2).

$$S_{cir\_seg} = \sum_{i=1}^{n} \left[r^2 \cdot arcsin(\frac{L_i}{2r}) - \frac{rL_i}{2} \right] \quad (2)$$

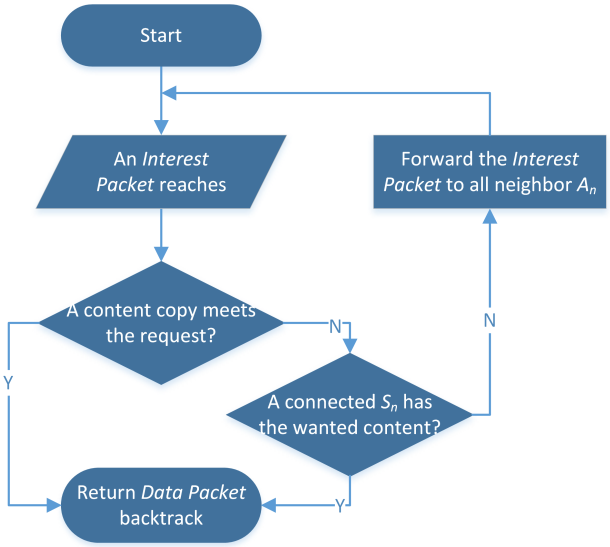


Fig. 3. CCN based routing & forwarding strategy

The arbitrary convex polygon also can be easily calculated by *Shoelace Formula* as (3). Here $(x_i, y_i), i = 1, 2, \cdots, n$ are vertices of the polygon.

$$S_{pol} = \frac{1}{2}\left|(x_1y_2 + x_2y_3 \cdots x_ny_1) - (y_1x_2 + y_2x_3 \cdots y_nx_1)\right| \tag{3}$$

After determining the locations of all A_n, the next step is to establish connections among three kinds of nodes. Each U_n needs to find the upper A_n within scope and save their names in its *Forwarding Information Base (FIB)*. Correspondingly, A_n record the names of U_n under management in their *Pending Interest Table (PIT)*. In the same way, A_n also exchange names with S_n.

As the *second target*, we design a routing strategy to distribute two types of packets in our fast organized Content-Centric Networking instance. *Interest Packet*s have the names of wanted contents, once any A_n or S_n can satisfy the requests, *Data Packet*s will be sent back in the reverse path. We use a flow chart to describe the routing strategy adopted by A_n.

At the beginning, U_n generates an *Interest Packet* with the name of wanted content and sends out to all U_n that can hear it (similar to broadcast). As shown in Fig. 3, when the *Interest Packet* reaches PIT of a A_n, firstly it needs to check if there exists a copy cached in *CS*. Once no copy matches, secondly A_n will send the packet upstream to all connected S_n and search for the wanted content by name. Either of the two cases is fulfilled, a *Data Packet* will be returned to U_n in reverse path. Otherwise, A_n has to forward it to neighbors to start a new branch judgment procedure. In this way, *Interest Packet* can get to the right place as soon as possible. Without worrying about address resolution work done by Domain Name System (DNS) server, actually we can apply the idea of *Breadth-First Search (BFS)* from graph theory into algorithm design.

4 Algorithm Design

In this section, we will set about solving the problems raised earlier in fast network organizing, access point placement and package delivery. Two algorithms are designed in building up the Content-Centric Network in disaster recovery scenario.

4.1 Algorithm Design on Access Point Placement

Algorithm 1 Access Point Placement Method

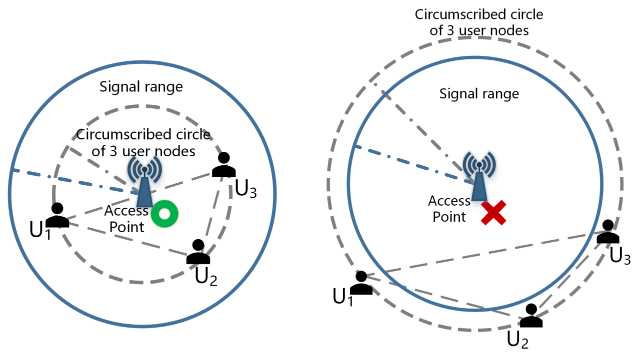
1: U_n ←**U**ser nodes within range
2: Q_U ←**Q**ueue of **U**ser nodes
3: A_n ←**A**ccess point nodes
4: r_A ←cover **r**adius of **A**ccess points
5: C_{this} ←**C**enter of current circle
6: C_{last} ←**C**enter of **last** circle
7: bubble sort all U_n by dist to square center and push into Q_U
8: **while** $Q_U == \emptyset$ **do**
9: **if** triangle circumradius of first three $U_n <= r_A$ **then**
10: C_{this} = triangle circumcenter
11: **else if** half of dist between first two $U_n <= r_A$ **then**
12: C_{this} = midpoint
13: **else**
14: C_{this} = first U_n
15: **end if**
16: **if** $dist(C_{this}, C_{last}) > r_A$ **then**
17: truncate the dist to r_A
18: **end if**
19: set an A_n at C_{this}
20: bubble sort all U_n in Q_U by dist to C_{this}
21: pop out all U_n that dist to $C_{this} <= r_A$
22: $C_{last} = C_{this}$
23: **end while**

As shown in Algorithm 1, Q_U stands for a queue saving all names of uncovered U_n, r_R is the signal coverage radius, C_{this} and C_{last} are locations of A_n just placed and last one. Algorithm 1 provides a method for placing the minimum required number of A_n to cover all U_n while each A_n should at least stay in signal radius of another A_n. Inspired by a proven geometry theorem saying *All regular simple polygons, all isosceles trapezoids, all triangles and all rectangles are cyclic* [33], which means three is the maximum number of nodes that must exist a circumscribed circle passing through all vertices. In a word, we are going to place a A_n at three cases in sequence.

- *Case 1:* Place at the circumcenter of the triangle composed of the first three U_n in Q_U (*line 9-10* in Algorithm 1);
- *Case 2:* Place at the midpoint of the first 2 U_n in Q_U (*line 11-12*);
- *Case 3:* Place at the first U_n in Q_U (*line 13-14*).

Once the previous case mismatches the condition, next one will be considered, we use a figure to describe *Case 1*, it is the same with the other two.

As shown in Fig. 4, since we can soon draw the sole circumscribed circle of an arbitrary triangle, the second-to-last step before we determine the location of a new A_n is



(a) AP can be placed when signal range is larger than circumscribed circle (b) AP can not be placed when signal range is smaller than circumscribed circle

Fig. 4. A comparison of two situations in *Case 1*

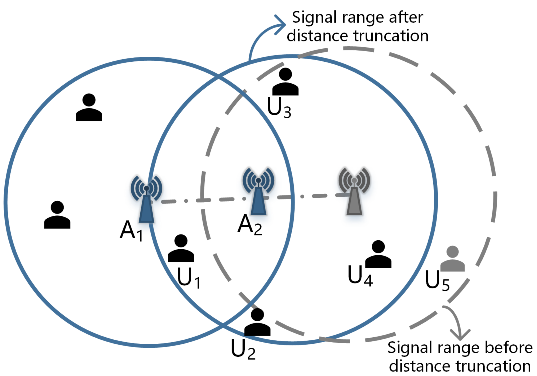


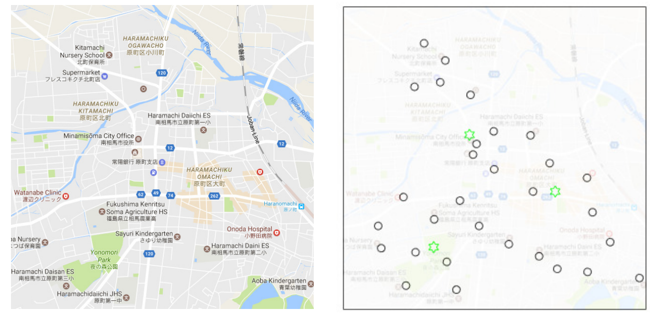
Fig. 5. An example of distance truncation

to judge the length comparison between two circle radii. In fact, when distribution of U_n in a fixed range is dense enough, *Case 1* can be easily satisfied, so does *Case 2*. And setting a A_n at the location of a U_n (*Case 3*) is never a good choice, we only treat it as a supplement to maintain algorithm integrity.

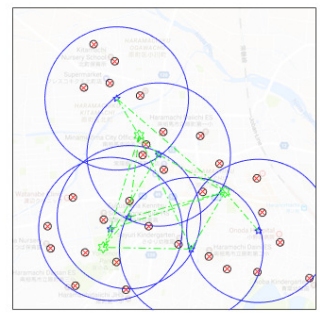
Lastly, to satisfy the specific requirement of network organizing and routing, we need each A_n capable of seeking help from neighbors when there is no connection to the right S_n. As a result, we truncate the distance between current A_n (C_{this}) and last one (C_{last}) by finally placing it at the arc of last circle.

In Fig. 5, A_1 is the last access point placed before, next we are going to choose location for A_2. The *if* statement in *line 9-15* of Algorithm 1 first considers the gray one, then after a distance truncation finally moves left. In the situation, connection status of U_n is changed partly: U_2 involves in, U_5 steps out, U_3 and U_4 stay the same and U_1 now has two A_n to request. In experiment simulation, according to different U_n densities in setup, U_n*-out* are more than U_n*-in* to a various extent. Nevertheless, we still have to pay more on covering relatively isolated U_n.

Fig. 6 is a real world example of Algorithm 1. We regard all landmarks in Fig. 6(a) as U_n or S_n (*black circles* & *green hexagrams* in Fig. 6(b). After placement procedure, all covered U_n are marked with red in center, *blue stars* & *big circles* are A_n and their signal coverage ranges. Lastly we draw green dotted lines between S_n and A_n to show



(a) Real world map (b) User node distribution



(c) CCN based network structure

Fig. 6. A typical procedure of CCN fast networking

connected relations.

4.2 Algorithm Design on Routing Strategy

Our algorithm design on routing strategy adopts a classical method originally used to search tree or graph data structures. *BFS* starts at tree root and continues until any nodes or leaves been found, with both time and space complexities being expressed as $O(|V|+|E|)$. In order to match the route discovery procedure of *Interest Packet*, *BFS* gives priority to neighbor nodes/vertices in the same level, which means we are able to traverse all A_n within the same hops from the original U_n to check if a content copy be found before forwarding one more hop to the next level. As a result, *BFS* can help achieve CCN routing and reduce forwarding times.

Algorithm 2 adopts a non-recursive implementation of *BFS*. Q_R is an *First In First Out (FIFO)* queue to achieve *BFS* rule, $THIS$ stands for the A_n just popped out of Q_R, P_I and P_D are the two types of packets in CCN. Here U_n play the role of tree root in a single *Interest Packet* trip, all A_n can receive the P_I directly will be pushed into queue Q_R first (*line 9* in Algorithm 2). The loop structure continues until P_I finds the same content by its name. While traversing the current hop level which means all U_n with the same depth in tree map, we have to make sure that each A_n may only be pushed into Q_R once, in this way rings can be avoided and routing efficiency will be improved obviously. Section 5 will use simulation datasets of different U_n distributions to find out the influence factors from experiment results.

5 Simulation and Analysis

In this section, we carry out experimental simulations using datasets of real world scenarios to validate the effectiveness and efficiency of designed algorithms.

Algorithm 2 BFS based Routing Strategy

U_n ←**U**ser **n**odes
A_n ←**A**ccess point **n**odes
S_n ←**S**erver **n**odes
Q_A ←a **Q**ueue of **A**ccess point names
$THIS$ ←the current A_n
P_I ←**I**nterest **P**acket
P_D ←**D**ata **P**acket
U_n generates a P_I contained the name of wanted content
push all A_n can receive P_I directly into Q_A
while Q_A is not empty **do**
  $THIS = Q_A.pop()$
  if $find(THIS.datacopy, P_I.name) == 1$ **then**
    $THIS$ generates a P_D contained the wanted content
  else if $find[(S_n\ that\ connected\ to\ THIS).data, P_I.name] == 1$ **then**
    the found S_n generates a P_D contained the wanted content
  else
    push all neighbor A_n of $THIS$ into Q_A
  end if
end while

Wireless Ad Hoc networking is widely applied in research of disaster recovery, here we use it as a contrast to verify the performance of our designed algorithms. To facilitate comparing between two networking methods, we build the Ad Hoc structure under the same scenarios with same U_n distribution and choose flooding protocol routing strategy.

In this Ad Hoc structure, each U_n also serves as a relay, while undertaking part of access point's job. Ad Hoc owns a much simpler routing strategy, whenever a U_n receives packets from neighbors, all it has to do is passing on to next. As a result, the connectivity of Ad Hoc may include uncertain factors, since some U_n at corners with only one $degree$ and others in the middle can serve as a transportation hub. Workloads on U_n differ from each other as well means irreplaceability is not same, that is, breakdown of a transportation hub may cause scale impact to a great extent while a 1-$degree$ one only represents itself. We will never want the above case to appear in post disaster scenarios. At this point, the role of access points should not be replaced simply, we need A_n to support as many U_n as possible. Although the networking modes of Ad Hoc and CCN exist a wide discrepancy, especially in whether lack of access points, it is meaningful for the comparisons in packet delivery simulation.

We are going to bring into real world scenarios simulation work. The city we choose is Minamisoma [34], located in Fukushima Prefecture, northern Honshu, Japan. A young city officially established in 2006, Minamisoma suffered greatly from Great Tohoku Earthquake and Tsunami in 2011, even partially inundated by seawater. Only about 25 kilometres (16 miles) north of *Fukushima I Nuclear Power Plant*, the site of the nuclear accident that followed the earthquake, much of the city lies within the mandated evacuation zone near the plant, thus most of the residents were forced to leave then until a year later. To solve the problem of *how to fast rebuild the communication social network in real world places nearly ruined after disaster* would make more sense. And we hope to help Minamisoma and people there to return to normal life.

TABLE 1
Data sheets of three districts in Minamisoma City

District	Type	Size (m)	User Number
Haramachi	Urban	1000×1000	180
Ohara	Rural	1200×800	100
Mimigai	Valley	900×1000	110

As shown in Table 1, we extract three sample areas respectively from three districts in Minamisoma City and set different numbers of U_n within each range according to both map markers and terrains. For example, in urban area like the $Haramachi$, U_n nodes can be uniformly distributed along streets and roads. Relatively, non-plain area like $Mimigai$ may have to avoid mountains and turn to narrow bottomed part of valley. $Ohara$ also faces mountain and river which vastly limits the actual usable area for placement, the shortage of traffic artery is reflected in distribution density. The coverage radius of all access points is 150m.

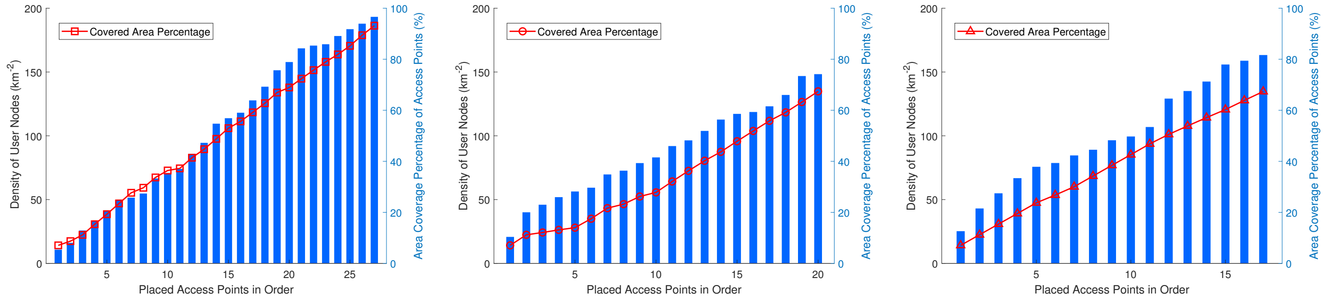
5.1 Simulation of Access Point Placement

We use *density of user nodes* and *area coverage percentage* as metrics to test the performance of CCN access point placement method. Next compute the new covered area while removing overlapped parts and count the number of covered user nodes when placing the next access point. Then calculate the ratio of covered user nodes number to covered area to get the density values. We use the form of percentage to express the change of covered area more visual and easy for comparisons among three sample areas. The simulation environments are *Code::Blocks 16.01 (C++)* and *MATLAB R2016a*.

After statistics and calculation during placement, we get the simulation results in Fig. 7. The x axis ranges of three subfigures are number of access points finally placed on, that is, respectively 27, 20 and 17 access points are needed to cover all user nodes within scope. Blue bars represent densities of user nodes when placing each access point, red broken lines stand for area coverage percentage of access points.

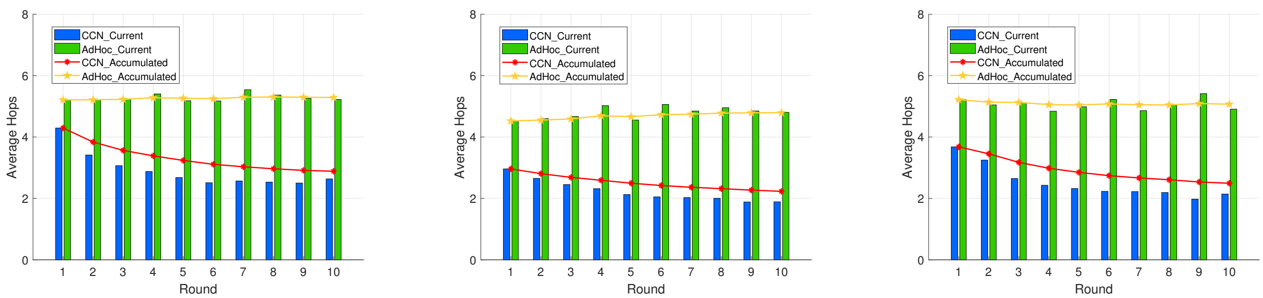
Firstly the density of user nodes, which numerically stands for number of nodes in one km^{-2}. Blue bars in Fig. 7(a) start at very low level and increase rapidly to nearly 200 km^{-2}, about a user node averagely owning 5000 m^2 (a small stadium) within total covered area. Then in Rural ($Ohara$) and Valley ($Mimigai$) areas, the density of nodes are up and down at 150 km^{-2}, which means user nodes averagely are farther apart from each other that may bring effects with different extents to routing and packet delivery.

Secondly the area percentage of area coverage. $Haramachi$ in Fig. 7(a) smoothly climbs from less than 10% to surpassing 95%, resulting in that the whole area is nearly full covered by 27 access points. As shown in figure, except for individual corners, terrain barriers are almost nonexistent. Moreover, variation on the whole, $Haramachi$



(a) $Haramachi$, urban area of Minamisoma City (b) $Ohara$, rural area of Minamisoma City (c) $Mimigai$, valley area of Minamisoma City

Fig. 7. Density of user nodes and area coverage percentage of CCN



(a) $Haramachi$, urban area of Minamisoma City (b) $Ohara$, rural area of Minamisoma City (c) $Mimigai$, valley area of Minamisoma City

Fig. 8. Average transmission hops of CCN & Ad Hoc

presents a pattern with higher slope different from the other two, which can be explained as nodes in urban area have better expansibility in four directions.

In summary, the introducing of new covered area does provide more details in proving that our work on placement method makes efficient usage of each access point and also may help analyzing the routing strategy in next subsection.

5.2 Simulation of Packet Delivery

We use *average transmission hops* as a metric to test the performance of routing strategies under Ad Hoc and CCN. Conduct 10 rounds of experiments that a single round includes each U_n sending out a request for 1 of 100 telephone numbers stored in 1 of 8 S_n (all operations based on random selection). Repeat the 10-round package delivery 10 times to reduce random impact. The simulation environment is *MATLAB R2016a*.

Fig. 8 shows the average hops of CCN and Ad Hoc in three datasets. We carry out experiments in 10 rounds which means each user node has chance to send 10 requests. Bars stand for the average hops needed for a whole packet trip in current round, broken lines conclude the rounds completed so far (for example, point on broken line at round three computes the average hops of the first three rounds).

Under urban area $Haramachi$, Fig. 8(a) can tell that variation of average hops of CCN is a downward trend. Although numerical value of each round itself (blue bars) fluctuates sometime, accumulated results (red broken line) are relatively smooth. Benefited from *Interest Aggregation*, numbers of average hops meet our expectation, that is, though at first (round one in Fig. 8(a)) the gap between CCN and Ad Hoc is less than one hop. As returned *Data Packet*s leave copies at each passed access point, next time, once any *Interest Packet* asks for the same content, it has no need to visit the final server again, content copies can satisfy the request quite enough.

In comparison to CCN, Ad Hoc (green bars and yellow broken line) packages averagely need two more hops to get to the target server while CCN access points storing a certain amount of content copies. Ad Hoc eliminates reliance on access points or other relay equipment, as a result, there exists no substantial changes in different rounds.

$Haramachi$ represents the area with all user nodes evenly and densely distributed, which can be an ideal environment for routing simulation. We also consider other types like rural ($Ohara$) and valley ($Mimigai$) to help expanding the feasibility of fast network organizing.

In Fig. 8(b), when number of user nodes reduces almost half (as shown in Table 1, $Haramachi$ 180 to $Ohara$ 100) while area stays nearly the same ($Haramachi$ 1000×1000=1×10^6 to $Ohara$ 1200×800=0.96×10^6). However, the halved density does not bring expected results from numbers written in Table 1. Both CCN and Ad Hoc use a little less hops to complete the task while the gap is less than one hop.

The total number of user nodes in a relatively fixed range can influence the routing status to a great extent since more nodes do bring more complexity on routing choice. In the designed CCN fast organizing architecture we always need more access points to take charge of more nodes, which also

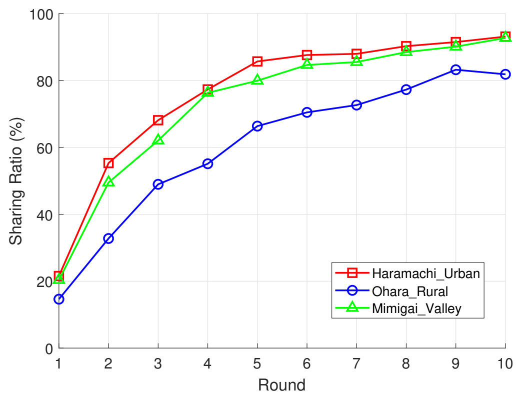


Fig. 9. Sharing ratio of content copies in CCN

brings more options in forwarding *Interest Packet*s. Considering of the fixed signal coverage range, number of circles in $Haramachi$ ought to increase further. Nevertheless, more nodes involved in routing are also able to provide shorter paths, especially when the strategy we adopt involves idea of broadcast and no channel occupancy (which is common in traditional IP network). *Interest Packet* always finds the shortest path without rings and does not worry about the impact on following decision making.

Moreover, in fact density of user nodes is not completely reflected by rate of node number and range area. In comparison with urban area $Haramachi$, we infer that the actual density of rural area $Ohara$ is not affected too much after 80 nodes being removed. The terrain of the surrounding mountains limits the available space of $Ohara$. For instance, when nodes at two remote edges of rural area want to deliver packages to each other, they may face even harder trips than urban area. In a result, multiple factors jointly do not let average hop values drop too low.

$Mimigai$ is a sample area located at a valley between mountains. A traffic artery runs across the center and top left corner is a long narrow branch along the river. Average hops in Fig. 8(c) are closer to $Haramachi$ in Fig. 8(a). Although node distributions in $Haramachi$ and $Mimigai$ differ greatly, so do user node numbers, some dense part of valley area along traffic arteries may be dragged down by top left branch, since nodes there have to deliver more times than others no matter sending out or in.

To sum up, in the current simulation scenario, Ad Hoc method needs more hops averagely in packet delivery than CCN. Also the effects from different terrains and node distributions are smaller.

To test performance of the designed CCN routing strategy, *sharing ratio* may show more details. The same with Fig. 8, we repeat 10 rounds for 10 times. In Fig. 9, three colored broken lines represent sharing ratios of content copies which means proportion of *Data Packet*s sent by passed by access points rather than original servers.

Red line shows the sharing ratio performance in $Haramachi$. At the 1st round, only 20% of *Data Packet*s come from *Content Store (CS)* in access points, the other 80% all start their trips at servers after *Interest Packet*s arriving. As round number increases, the growth rate presents a logarithmic trend. In round 10, more than 90% contents transmitting in network no longer rely on remote servers, which means workload on servers is almost replaced by *Content Store (CS)* in access points.As the densest distributed sample area, $Haramachi$ needs more hops to get to destination than the other 2. In result, there exist more chances for other passing by *Interest Packet*s to share content.

Variations of sharing ratio in three sample areas show different characteristics. $Ohara$ loses ground in both values and speed, even significantly lower than $Mimigai$ with nearly the same user node number (as shown in Table 1, $Ohara$ 100 to $Mimigai$ 110). Since in our designed fast organized CCN, user nodes depend on upper access points to send out request and bring back content from servers or copies, nodes close to each other in location are able to have better opportunities for finding the right copies. The node aggregation in Fig. 6(b) limits the scope of content name searching, just like what may happen in daily life, in most cases we (user nodes) share information (packets) with people that are familiar or talking often.

Lastly the comparison between $Haramachi$ (red line) and $Mimigai$ (green line), totally different types & sizes of sample areas own similar sharing ratio variations. User nodes of valley area $Mimigai$ are more densely distributed than description in Table 1. Nodes in lower right part can perform good sharing ratio and elevate the average values.

To sum up, in the current simulation scenario sharing ratio of fast organized content-centric network shows that content copies accumulate rapidly and can be greatly influenced by specific user node distribution. We need to take into account actual situation rather than only paying attention to scope or node density.

6 Conclusion

In this paper, we come up with the idea of using Content-Centric Networking to fast organize a middle-scale disaster recovery network helping users within scope to get connected with each other and remote servers. To solve the access point placement problem and carry out packet delivery experiment for fast organized network, we extract the social attributes from user & access point node distribution and respectively put forward two algorithms using ideas of graphic union coverage and Breadth-First Searching. After simulation and analysis under three real world datasets, we prove that our design can provide a fast organized CCN that makes efficient usage of limited number of access points while costing less average hops than Ad Hoc method under the same experimental conditions.

Future work includes taking into account packet delivery ratio and copy lifetime since our design still needs optimization on robustness and flexibility. We are going to consider more details for simulation setup and import circular feedback to constantly improve existing design.

Acknowledgments

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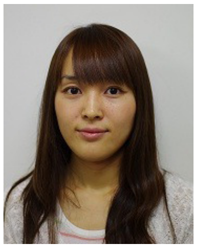

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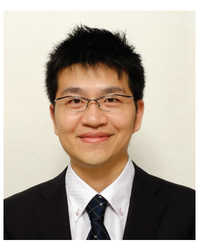

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