Drone-Assisted Fog-Cloud IoT Content Service Platform for Rural Communities

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***Abstract*— Although social media and contents are being generated and shared with an unprecedented scale and speed, rural and underdeveloped areas throughout the world have only limited access due to the lack of high-speed Internet. Connecting rural communities to the digital world and providing them with right contents will provide the much-needed bridge between urban and rural areas. In this paper, we propose a communication and information framework that utilizes simple Internet of Things (IoT) in a rural community to assist delay-tolerant content distribution. Specifically, a hybrid fog-cloud content distribution network is constructed by deploying low-end simple fog nodes and utilizing the movement of community vehicles. Moreover, drones are used to distribute content on demand as a compliment of the delay tolerant network for better delivery rate and lower delay time. A novel drone scheduling algorithm is proposed to plan drones' tours optimally. Extensive simulation experiments have been performed to evaluate the performance of the proposed framework.**

Keywords—cloud computing, fog computing, Internet of Things, Drone, Delay Tolerant Network, content distribution

I. Introduction

According to the Cisco's Visual Networking Index, video traffic will account for 82% of all IP traffic [1]. Social media such as YouTube, Facebook, Instagram, Flicker have connected people all over the world, enabling information exchange, life experience sharing, and entertainment. Decreasing prices of smart phones with digital cameras have made them affordable to low-income rural communities. People in underdeveloped rural communities have started to use their mobile phones to take pictures and video. As a result, there is an increasing need in these communities to access social media tools and sites to share the user-generated content. People in these community have more demands of accessing Internet content for education, entertainment, and social networking [2]. Base on existing studies [2], [3], there are various benefits to share user generate content and social media across different rural areas.

However, rural and underdeveloped communities are not well served by telecommunications services today. According to the Federal Communications Commission, approximately 14 million rural Americans and 1.2 million Americans living on Tribal lands still do not have high-speed broadband [4]; Rural residents also go online less frequently than their urban and suburban counterparts; Lots of Native communities do not even have a landline telephone service [1]. A lack of broadband bandwidth and connectivity is a major issue in establishing connected rural communities. Unavailability and unaffordability keep rural and underdeveloped communities from accessing broadband services, leaving them poorly connected among themselves and to the rest of the world.

Expanding high-speed internet services to rural and underdeveloped areas has been one of the key issues across the U.S. However, because of the insufficient population to support those services, deploying such services doesn't provide a payback to the telecommunication industries. Although some communities may have one or more cellular networks providing some networking coverage, the coverage may be limited. Also, users in the region may not afford the fee to subscribe for the service. Even for subscribers, they want to reduce their data usage to save money. While efforts continue to drive the deployment of various infrastructure to support broadband access, there is still a lack of high-speed broadband access in many areas of the country.

To facilitate content distribution in rural communities with limited broadband and intermittent internet connections, in this paper, we propose a multi-layer hybrid fog-cloud IoT data dissemination framework. It utilizes existing community public vehicles, drones, and simple wireless storage resources to form a delay-tolerant content distribution network. Specifically, we use cloud to process content download and upload requests and organize data distribution accordingly. We strategically deploy a number of geographically distributed low-end storage-based fog nodes to form a decentralized data broker network to enable effective data distribution, using delay-tolerant networking. To improve data delivery rate and reduce latency, an optimized drone scheduling mechanism is proposed. Using extensive simulations, we show that the proposed framework, called the Drone-Assisted Fog-Cloud (DAFC) content distribution platform, is efficient in terms of data-dissemination success ratio and content convergence time.

The rest of the paper is organized as follows. Section II surveys related work on designing and developing ontologies. Section III provides an overview of our proposed DAFC system. Section IV describes the detailed methodologies of the content distribution framework. Section V presents the simulation experiments performed on the proposed DAFC framework. Finally, in Section VI, we conclude the paper with future work directions.

II. RELATED WORK

As the volume of web video and multimedia content propagated over the Internet keeps growing and is expected to continue to grow in the future, more and more content providers have started to use Content Delivery Networks (CDN) [5] for large-scale content delivery to improve service quality. CDNs replicate large content to geographically distributed locations that are closer to final users at different areas. CDNs improve QoS by reducing content delivery cost and increasing robustness of delivery. In order to reduce latency of content accessing and minimize network bandwidth consumption, it is important to determine the optimal location for each replica. Theoretical approaches model the content replica placement problem as the center placement problem. Example approaches include the minimum k-center problem [6] and k-hierarchically well-separated trees (k-HST) [7]. Heuristics-based approaches such as greedy replica placement [8] and topology-informed placement strategy [9] were proposed to get local optimality. Fog nodes in our system are alike content replicas in CDN, but they are not connected to the network through Internet access.

Fog computing [10] is an emerging technology that is closely associated with cloud computing and Internet of Things. It can help cloud to provide high quality engaged localized services. Fog nodes are connected to form a fog network. Managing a heterogeneous fog network in scenarios of the IoT is challenging. There are research attempts to use emerging techniques, such as software-defined networking (SDN) [11] and network function virtualization (NFV) [12] to support effective fog networking. For example, Ku et al. propose SDN-based mobile cloud architectures for vehicular ad hoc network [13]. This architecture achieves good packet delivery ratio with acceptable overhead. It is based on an on-demand caching and a communication scheme between the fog nodes and the Internet nodes. In their work, Wu et al. proposed an NFV-based communication scheme between the fog nodes and the future Internet [14]. They designed a control function virtualization approach to implement smart control for routing and caching. In our system, fog nodes are not directly connected with each other, although through some delay-tolerant virtue links, information can be transmitted between fog nodes.

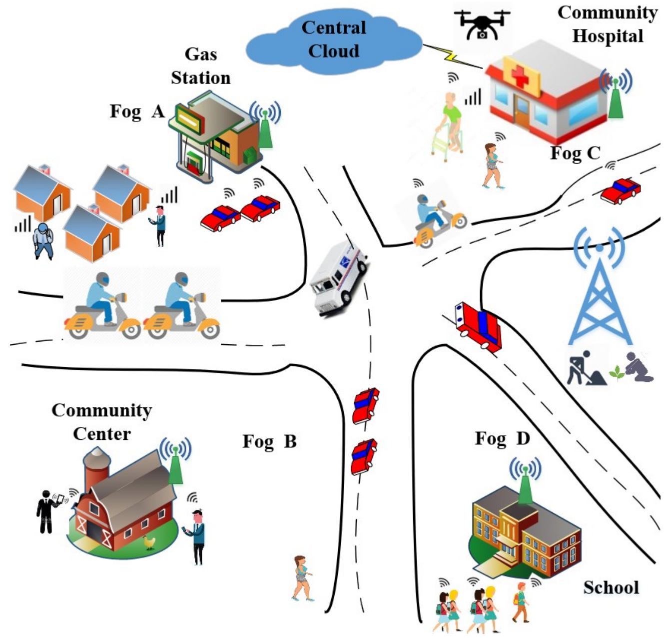


Fig. 1. Fog-enabled rural community network

Delay-tolerant network (DTN) [15] is a computer network architecture that strives to connect networks that may lack continuous network connectivity in most of the time. DTNs have been used to serve in extreme terrestrial environments, or planned networks in space. For example, in [16], Giannini et al. exploit mobility of a city's bus to route sensor-generated data to the sink node in a smart city paradigm. Similarly, in [17] Doering et al. also utilize the transport system of a city to propagate information generated by the citizens and delivered to nodes in the city. While in another work [18], the human's walking mobility is integrated into a DTN routing mechanism. Bouk et al. [19] have applied DTN routing techniques for transmitting data generated by underwater sensors.

Different routing mechanisms have been proposed for efficient routing in DTNs. In First Contact routing [20], a DTN node forwards a message only to the first node in its radio range. While in Epidemic Routing [21], a node forwards the message to all contacts it first meet. The Spray and Wait Routing [22] has two phases, namely Spray and Wait. During the Spray phase nodes forward packets to certain number of contacts. During the Wait phase, nodes stand by for direct delivery to the final destination. PROPHET routing [23] use probability to estimate the optimal route to the destination based on node encountering. Part of our proposed hybrid routing mechanism can use these DTN routing mechanism to transmit short messages, which will not bring large overheads to DTN nodes.

III. DAFC SYSTEM OVERVIEW

We propose a fog-cloud IoT computing paradigm to enable sustained content distribution networking. Fog nodes in our DAFC system extend the Cloud content distribution service to the "ground," where applications or contents located on far away

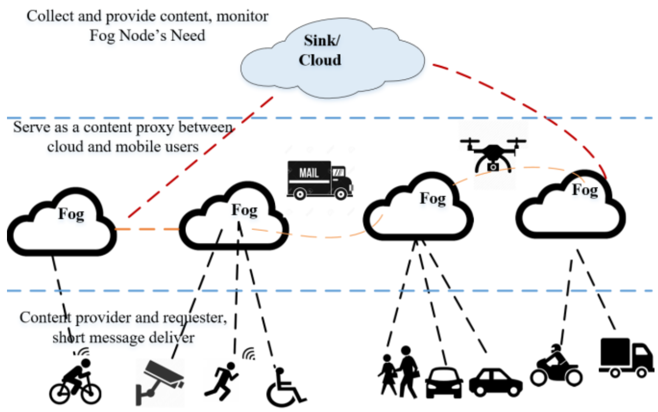


Fig. 2. Layered Hierarchical DTN

from the Cloud servers and disconnected from the Internet now can use the cloud's content services. These fog servers have simple process, storage, and network transmission capabilities. Mobile users access fog servers with just one-hop wireless connection, and therefore large-sized content can become available even in an area with a poor Internet coverage.

Data dissemination between Cloud and Fog nodes can be expensive, especially for a rural community which lacks fast and reliable Internet access. Most large-sized files are video-based, such as videos, games or teleplay. These contents are not always necessary to be strictly up to date: hours or even days of delay is tolerable. Therefore, we propose to use inexpensive devices, existing community resources, and delay-tolerant network technologies to enable data dissemination for the high volume and nonurgent data between fog nodes and cloud. This would help the community to preserve the bandwidth for more critical data.

As shown in Fig.1, in a rural community, fog nodes are strategically deployed at locations with more traffic, such as gas stations, convenient stores, community centers, etc. Most of these fog nodes are simple devices with only short-range communication capability (such as Wi-Fi) and large storage. We assume there is one or more sink sites in the community, which has internet connections, i.e., connect to the Cloud. Fog nodes act as a drop box for local mobile nodes to drop and collect large content data. Content and content requests may have different urgency level and expiration time.

We utilize the mobility of citizen, community public vehicles, and drones to form a multi-layer delay-tolerant network to disseminate different types of information. To disseminate content between fog nodes and cloud, community service vehicles such as garbage trucks, USPS service delivery trucks, will routinely pass through these nodes and get information exchanged. Drones will also be deployed to collect and disseminate content based on the real-time data need. We propose a novel optimized drone navigation planning algorithm to schedule drones for content delivery between fog nodes and cloud. Citizens (including pedestrians, private vehicles etc.) do not have the incentive to deliver large content data, but they can forward short messages which will not consume much of their battery or bandwidth. These short messages will help cloud get a global idea of the fog content distribution, although these fog nodes are not connected to the cloud.

IV. Hybrid Multi-Layer Content Distribution

Fig. 2 presents the proposed Cloud-Fog IoT networking architecture. As shown in the figure, the architecture has three layers, including the edge layer, the fog layer, and the cloud layer. Cloud controls the global content distribution; it provides content to users and collect contents provided by users. Fog nodes serve as proxies between the cloud and mobile users. They act as mailboxes for mobile users to "send" and "receive" content. Edge layer includes nodes/devices with different roles: (a) mobile service requesters (MSR), they provide and request contents; (b) mobile gateway nodes (MGN), including pedestrian and vehicles that forward short messages for other mobile gateway nodes and fog nodes; (c) routine content delivers (RCD), including public vehicles such as post trucks, garbage truck that routinely collect content from fog nodes to the community sink nodes which are connected to the Cloud (or deliver content from Cloud to fog nodes); (d) on demand content delivers (OCD) that are drones deployed by the cloud to collect or deliver content when necessary. One entity in the DAFC system may play multiple roles. For example, an MSR can be an MGN at the same time.

There are five kinds of communication links between different layers, namely, device to fog, device to cloud, device to device, fog to fog, and fog to cloud. Some of these links use short-range wireless connections (device to fog, device to device), some use Internet connections (device to cloud), some others utilize the movement of objects such as (human, vehicle) and short-range wireless connections (device to fog, fog to fog). The purpose of this communication platform is to enable data propagation using all the available links, including the delay-tolerant network (DTN)-enabled links.

A. *Routine Content Distribution*

The basic idea of this content distribution mechanism is to utilize the movement of a community's public ground transportation (RCD) to deliver large content files. RCD may have fixed travel time (e.g., once per day or once per week), route, and stops. This can be exploited for scheduled content distribution. Using this community mobility and transfer, the network operates in a large geographic area with no extra cost. The community only needs to mount some simple devices with short transmission range to these vehicles in order to transport content. Content distribution is just a by-product of RCDs. RCDs don't need to change their route and schedule for this add-on services. Therefore, it is a sustainable service.

B. *Time-Varying Fog Request Map Construction*

Although RCDs will deliver content periodically between fog and cloud, it is still possible that some of the content (or content requests) with shorter Time to Live (TTL) may get expired; also, fog nodes' storage may reach their full capacity before RCD's arrival. When these situations happen, to improve content delivery rate and reduce latency, drones are used in the system to transport content on demand. However, as fog nodes in our system do not connect to the cloud, it is challenging for the cloud to decide when and where the drones should be deployed to collect or deliver content.

In order to address the aforementioned issue, we utilize the movement of MGNs, i.e., the community citizens (pedestrians, private vehicles), to create a DTN to report fog nodes' status to the cloud. When a fog node is reaching its storage capacity or it has certain number of contents or requests that are going to expire, it will send out "rescue" messages. The rescue message includes the ID of the fog node and the timestamp of the message. As these messages are lightweight, storing and forwarding these messages will not consume much battery power and bandwidth. Therefore, MGNs would be able propagate these messages through the DTN network. Existing DTN routing algorithms such as Epidemic [21] or PROPHET [23] can be applied to MGN routing. The destination of the rescue message is the sink node or any mobile nodes that have an Internet access.

Based on the rescue messages collected from the MGN DTN network, the cloud can create a time-varying fog request map in which each node represents a fog node that needs to be served by the cloud within a certain time period.

C. On-demand Content Distribution by Drones

With the time-varying fog request map ready, the cloud can plan route for drones to collect and deliver contents on demand. The overall drone route planning problem can be formulated as finding an optimal (or near optimal) set of paths that allows a team of drones to visit a given number of fog nodes in the shortest amount of time or path. This problem is similar to the well-known Multiple Traveling Salesmen Problem (mTSP), a more generalized version of the Traveling Salesman Problem (TSP) [24]. mTSP can be presented as follows: given n cities, one deport where m salesmen are located, and a cost metric, the goal of mTSP is to find m closed tours (paths start and end at the deport), such that each city is visited only once and by only one salesman and thus, the total cost of visiting all cities is minimal.

We add additional constraints to this mTSP problem: a drone's flight distance after each charge is limited. Moreover, data communication will also significantly consume a drone's energy. Therefore, the number of fog nodes from which a drone can gather or give content data during a flight is limited. It depends on the fog node's location, the size of the content to be collected, and the reception range of the drone. The number of drones that need to be deployed, m, is not known in advance. As mTSP is an NP-hard problem, we propose a heuristic approach to solve this problem. Below we present the detailed approach:

1) Clustring fog nodes.

The first step is to cluster fog nodes based on their distance from each other. Based on the nature of this problem, we apply the Density-Based Spatial Clustering of Applications with Noise (DBSCAN) [25] to cluster the fog nodes. DBSCAN is a density-based clustered algorithm. We use DBSCAN to group fogs that are close to each other based on the Euclidean distance ε (eps) and a minimum number (minN) of fogs. It also marks as outliers the fog nodes that are in low-density regions. It starts with an arbitrary fog node and finds all the fogs in epsilon ε distance. Then it tries to find the fog nodes in the ε (eps) neighborhood and identifies the core fog nodes with more than minN neighbors. After that, we can find the connected components of core fog nodes on the neighbor graph, ignoring all non-core fog nodes. We can assign each non-core fog node to a nearby cluster if the cluster is an ε (eps) neighbor, otherwise assign it to noise. In this way, fog nodes are grouped to clusters.

2) Optimizing the mTSP-based drone planning with Ant Colony Optimization algorithm

After fog clusters have been located, we will compute the best route to service all fog nodes. This can be modeled as the mTSP problem. One or more drones start from a depot (the sink node) and should visit all fog nodes only once and come back to depot. All drones start from depot $\alpha \in \mathbb{R}^2$ and finish in the same depot α. For cluster C which as n fog nodes $\{x_i\}$ and m drones. Distance of two fog nodes i and j is $d_{i,j}$ calculated by squared Euclidean distance $d_{i,j} = \|x_i - x_j\|_2^2$. In a tour, each fog node is visited once, and is defined by the sequence $(\sigma_1, \cdots, \sigma_n)$. Our goal is to minimize the tour defined below:

$$\min_{\substack{\sigma \\ \{\alpha_{k_j}\}}} \left\{ \sum_{i=1}^{n-1} d_{\sigma_i,\sigma_{i+1}} + d_{\sigma_1,\alpha} + d_{\sigma_n,\alpha} + \sum_{j=1}^{m-1} \alpha_{k_j} \left[-d_{\sigma_{k_j},\sigma_{k_j+1}} + d_{\sigma_{k_j},\alpha} + d_{\sigma_{k_j+1},\alpha} \right] \right\}$$

$$s.t.\quad \forall j, \sum_{k_j} \alpha_{k_j} = 1, \qquad \alpha_{k_j} \in \{0,1\}, \quad 1 \le k_j \le n-1$$

$d_{\sigma_1,\alpha}$ and $d_{\sigma_n,\alpha}$ are the distance of the first and last fog node, respectively, with the depot α on the route. By removing edge between σ_{k_j} and σ_{k_j+1}, the route would be separated for drone *j* and *j+1*. So, $d_{\sigma_{k_j},\alpha} + d_{\sigma_{k_j+1},\alpha}$ indicates that drone *j* flies back to depot and drone *j+1* starts flying from depot to σ_{k_j+1}. α_{k_j} equals one if the edge related to the fogs σ_{k_j} and σ_{k_j+1} is removed; otherwise, it is zero.

Many heuristic and meta-heuristic approaches have been proposed to find an efficient solution to solve this NP-hard problem. We modify the ant colony optimization (ACO) [26] to solve this problem. ACO was inspired by the behavior of ants in a colony to help each other finding the shortest path from their colony to the food. It finds the right solution in small scale problems but fails for complicated problems such as the mTSP problem. So, many modifications (e.g., [27]) have been made in ACO to solve its problems and improve its performance.

We adopt the idea of a modified ACO, NMACO [27]. The steps of this approach can be summarized as follows:

Step 1: Build n solution for mTSP.

Step 2: Improve the current best solution and the best solution by insert, swap, and 2-opt rules.

Step 3: Update the global pheromone information.

Ant k moves from node i to j with probability P_{ij}^k:

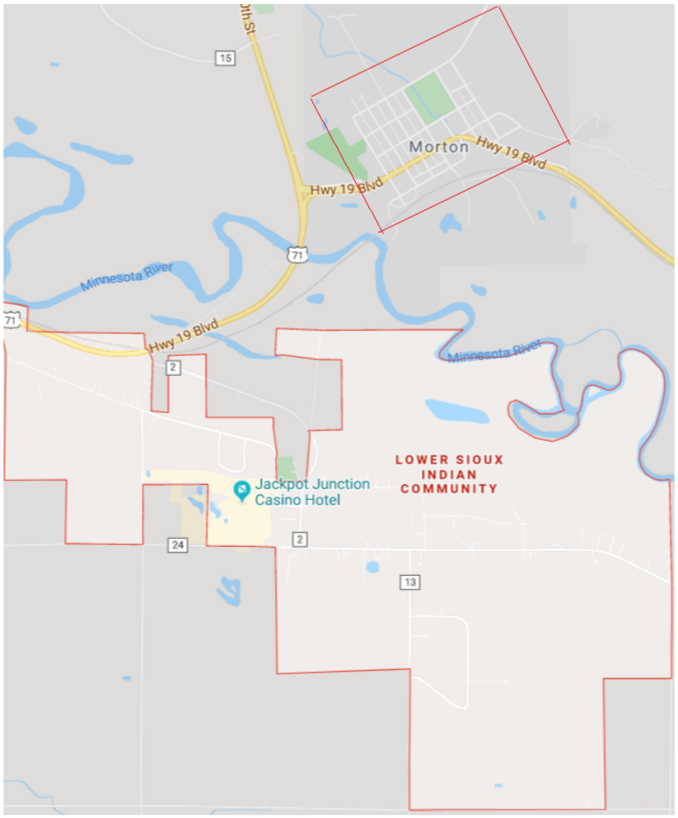


Fig. 3. Map of the simulation area- Lower Sioux Indian Community

$$P_{ij}^{k} = \begin{cases} \dfrac{\tau_{ij}^{\gamma}\eta_{ij}^{\beta}K_{ij}^{\lambda}}{\sum_{j\in N_i^k}\tau_{ij}^{\gamma}\eta_{ij}^{\beta}K_{ij}^{\lambda}} & if \quad j \in O_i^k \\ 0 & if \quad j \notin O_i^k \end{cases}$$

where $\gamma, \beta, \lambda \geq 0$ are set to control the influence of each parameter; τ_{ij} is the value of pheromone on the arc joining i to j; η_{ij} is the inverse distance between i *and* j; K_{ij} is defined as saving of having both nodes i and j in one tour. $K_{ij} = \acute{\gamma} d_{i,\alpha} + \acute{\beta} d_{\alpha,j} - \acute{\lambda} d_{i,j}$ where it shows distance $d_{i,\alpha}$ for flying back from node i to the depot α will be added to the distance $d_{\alpha,j}$ for flying next drone from α to node j and removing the direct distance between to node i and j. Each ant release pheromone $\Delta\tau_{ij}$ on its path while moving. Each arc has its pheromone amount, and it is calculated by this formula:

$$\tau_{ij}(t) \leftarrow (1-\rho)\tau_{ij}(t) + \Delta\tau_{ij} \qquad 0 \leq \rho \leq 1$$

where ρ is the pheromone evaporation coefficient. Ant k in node i has a to-do list N_i^k in memory, which shows the set of unvisited nodes. However, the next node j would be selected among candidate list O_i^k which has about 30% number of the total number of nodes.

V. Evluation

We have used the Opportunistic Network Environment (ONE), a Java based simulator, [28] to evaluate the performance of the Drone-Assisted Fog-Cloud (DAFC) content distribution platform. The ONE is an open source probabilistic DTN networking simulator. It provides tools for us to create the an environment and mobility scenarios that are close to reality.

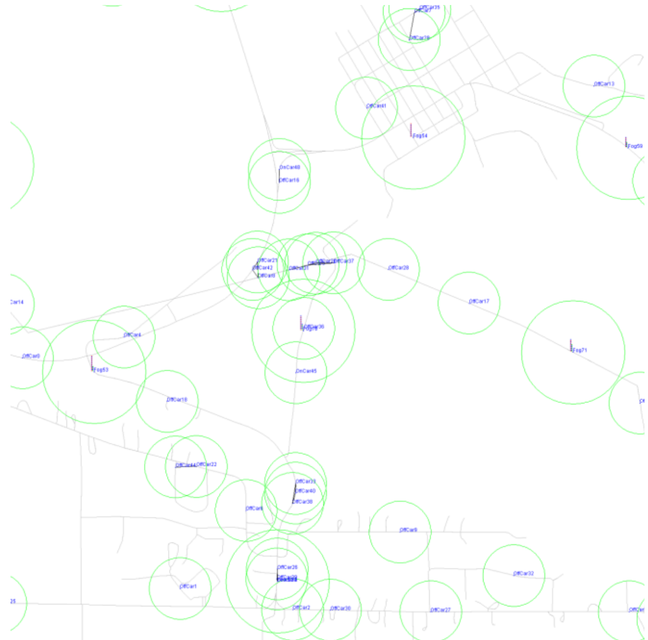


Fig. 4. . Screenshot of part of the simulation interface

A. Environment Setup

We choose the Lower Sioux Indian Community (also known as the Mdewakanton Tribal Reservation) as our simulation area. It is a federally recognized Indian tribe located in south central Minnesota in Redwood County. The Community Center is located on the southern bluffs of the Minnesota River Valley. Approximately 145 families live on 1743 acres of a tribal land. A total tribal population of 982 resides throughout a 10-mile service area and beyond. We also include Morton, a city in Renville County in our simulation, as it is the administrative headquarters of the Lower Sioux Indian Reservation. Fig. 3 shows the map of the simulation area.

In the simulation, we deploy a set of fog nodes (28 by default) spread out in the community in sites with more traffic (e.g., gas stations, convenient stores, community clinic), each with storage capacity of 500GB, and using 5GHz Wi-Fi 802.11n module with speed of 600Mbps and range of 250 meters. They are not connected to the Internet. We simulate different types of mobile IoT nodes: pedestrians (with smart phones) moving with speeds of 2-3 mph and pause times of 0-180 seconds, public vehicles (garbage trucks, post trucks) moving at speeds of 11-20 mph, pausing for 0-500 seconds. Citizen's vehicles moving at speeds of 10–30 mph, pausing for 0-200 seconds. These IoT node use 5GHz 802.11a Wi-Fi module with speed of 50mbps and range of 120 meter.

The community has 4 garbage trucks, and they are scheduled to collect garbage and content data required by our DAFC system every week following fixed route. The community also has one post truck that goes out to the community every day to deliver mails and collect content and requests for our DAFC system. We assign edge IoT devices 500MB of free RAM for buffering messages in these devices. Citizens may travel on foot or in cars. 10% of citizen nodes have an Internet access.

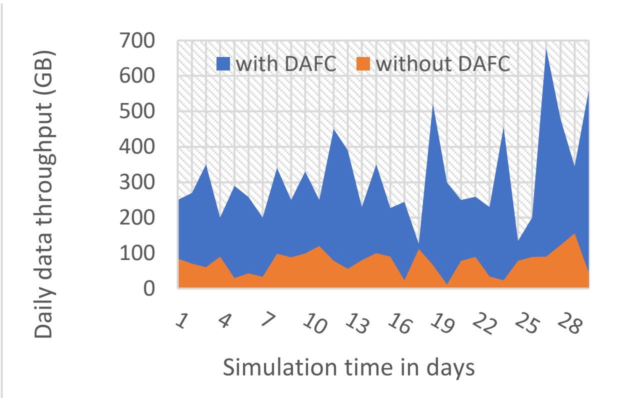


Fig. 5. Community daily data throughput

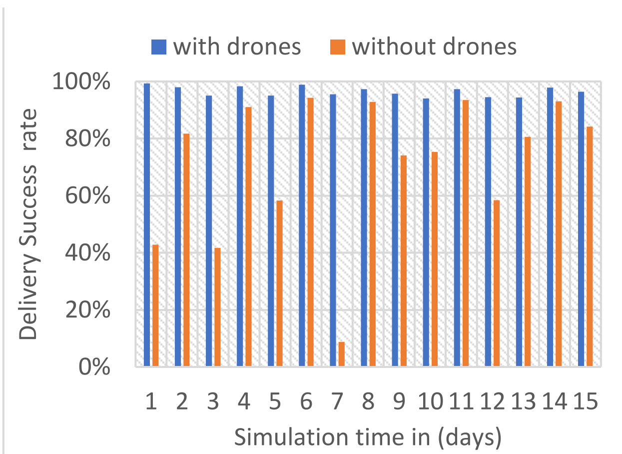


Fig. 6. Content delivery success rate (with drones vs. without drones)

The community have 5 drones that can be dispatched when needed. They use 5GHz Wi-Fi 802.11n module with speed of 600Mbps and range of 250 meters. Their flight speed is 20 mph. During their flight, they do not connect to cars or buildings, but only connect to fog nodes when they are approaching the fog nodes. One sink node with an Internet access is located at the center of the community (Lower Sioux Government Center). The simulation lasts for 15 days. We assume that everyday each person living in the community has 50% possibility to generate 1MB-2GB content data or content request that need to be delivered. People will store the content data (or requests) to a nearby fog node.

Fig. 4 shows a small part of the simulated area, in which the green circle represents each node's transmission range. The purple bar on top of every node represents a node's message queue. (PRoPHET) [23] routing algorithm is applied for MGN nodes. Moving nodes adopt the shortest path-based movement model, SPMBM [28], in which nodes use Dijkstra's shortest path algorithm to calculate shortest paths from the current location to the destination location.

B. *Experimental results*

In the first set of experiments, we verify that the proposed DAFC platform improves the community's content distribution.

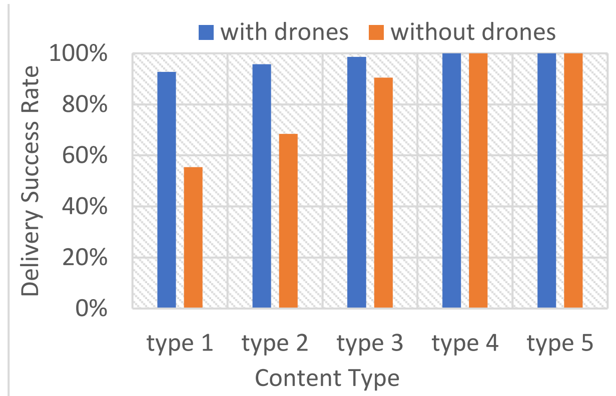


Fig. 7. Average content delivery success rate of different types of contents (with drones vs. without drones)

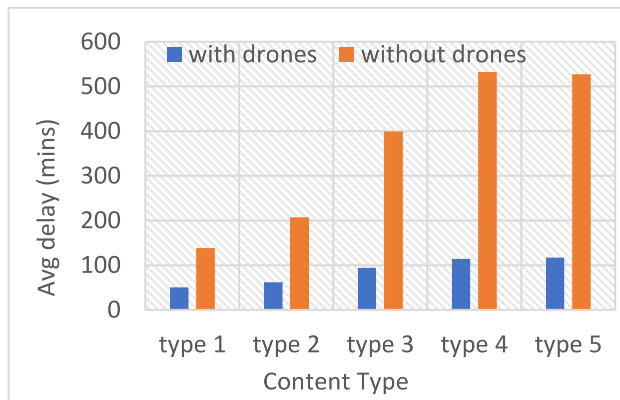


Fig. 8. Average delay time of different types of contents (with drones vs. without drones)

We assume 20% of community families have Internet access, and 30% of residents have cell phone data plan (1GB-12GB). Fig. 5 compares the daily data throughput of using the DAFC platform and without using the platform in the community in a 30-day period of simulation time. It is clear that the DAFC platform significantly improves the community's data throughput. The fog node and the DTN network can effectively deliver a large amount of content for the community.

We studied how drones help the community's content delivery. Drones are deployed based on the rescue messages collected by the sink nodes. In these experiments, we have multimedia contents with 5 different TTL settings: 6 hours, 12 hours, 1 day, 3 days, and 7 days. Fig. 6 shows the contentment delivery rates with and without using drones. In this experiment, each different content category (with different TTL) accounts for 20% of the total number of contents. It is clear that using drones does improve the delivery rate by "rescuing" fog nodes that need immediate assistance.

Fig. 7 and Fig 8 illustrates the platform's performance in terms of delivery rate and delay time for different types of content (specifically, content with 5 different TTL settings: Type 1: 6 hours, Type 2: 12 hours, Type 3: 1-day, Type 4: 3 days, and Type 5: 7 days). We can see from Fig. 7 that deploying

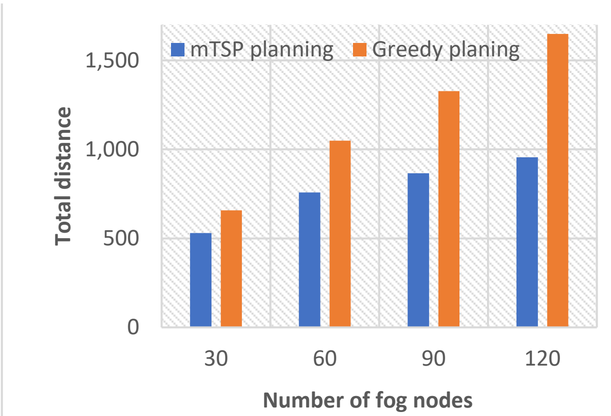
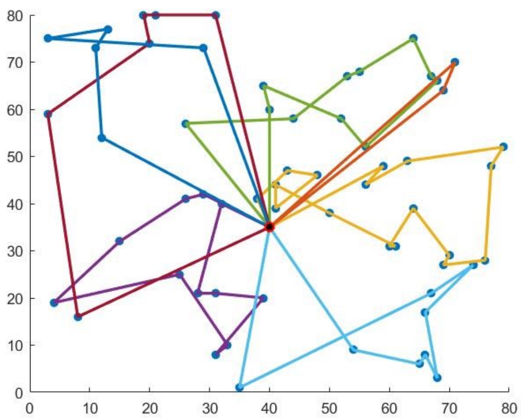
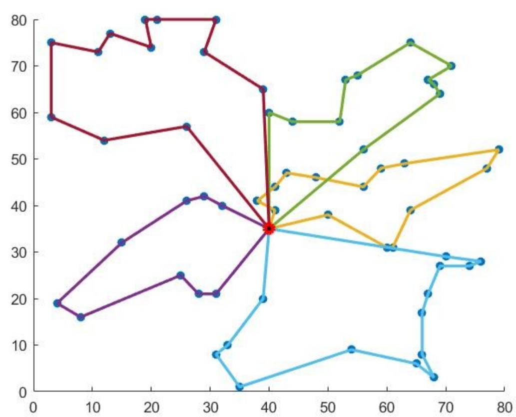


Fig. 9. Comparison of total flight distance (mTSP planning vs. greedy planning)



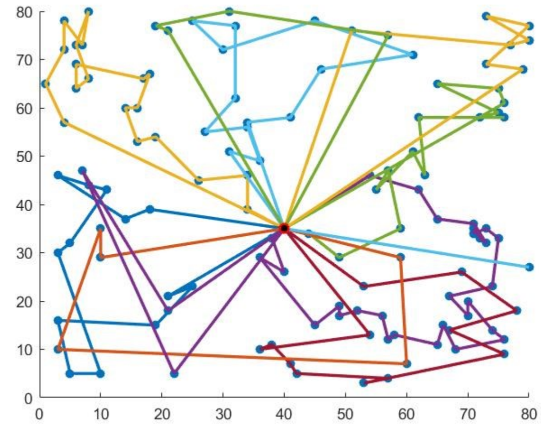
(a) First iteration



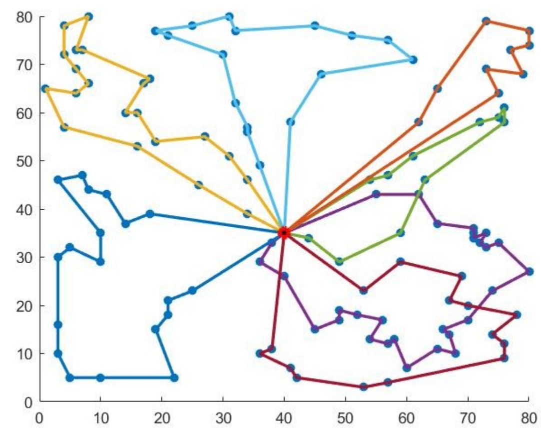
(b) Last iteration

Fig. 10. Drone path planning using mTSP Ant Colony Optimization (60 fog nodes)

drones can improve delivery rate, especially for more urgent messages (i.e., content message with smaller TTL expiring time, in this experiment, content with TTL 6 hours and 12 hours, respectively). Fig. 8 illustrates the average delay time for different types of content. The delay time counts the time



(a) First iteration



(b) Last iteration

Fig. 11. Drone path planning using mTSP Ant Colony Optimization (120 fog nodes)

difference between sending a content request from a fog node and receiving the content back, or the time difference from a content loaded at the fog node to the content uploaded to the sink node. Again, in this experiment each different content category (with different TTL) accounts for 20% of the total number of contents.

The last set of experiments verify the effectiveness of our mTSP-based drone planning mechanism. In these simulations, we projected the fog nodes on a field of size 80× 80 km^2. We assume that every drone is fully charged at the base station (sink node), which is the only charging station in our simulation. The maximum distance that a fully charged done can fly is 168 km. Moreover, during a contact period between a drone and a fog node, drones will stay in the communication range until all the content uploading and downloading is fully completed.

Fig. 9 compares the drone travel distance with simple greedy planning and with our optimized mTSP planning. It is clear that, when the number of fog nodes increases, our optimized algorithm greatly improves the drone travel efficiency by reducing the travel distance, and consequently travel time and battery usage. Fig. 10 demonstrates the actual flight path planned for 60 fog nodes based on our mTSP-based drone planning with Ant Colony Optimization algorithm. Through a set of iterations, we can provide near optimal paths for the drones. Similarly, Fig. 11 shows the path for 120 fog nodes.

VI. CONCLUSIONS

Rural and underdeveloped areas throughout the world share some common obstacles to their development, such as spatially dispersed population and limited access to the Internet. A well-connected community is the first step towards a well-served community and hence, connecting rural community will provide the much-needed bridge between urban and rural areas.

In this paper, we propose a framework that assists connecting rural communities through best-effort content distribution over the community. The goal of this framework is to construct an IoT content service platform using existing telecommunication infrastructure to empower millions in rural areas, connect "humans" to the mainstream, and improve resource management and rural well-being.

The proposed framework is based on a multi-level fog-cloud-edge architecture and utilizes a hybrid DTN network formed by the community public transportation system to enable best-effort content delivery. The drone planning problem was modeled as a mTSP problem and an ant colony optimization algorithm (ACO) was adopted as a heuristic algorithm to find (sub)optimal solutions for this NP-hard problem. Results of the experimental simulations have demonstrated the effectiveness of the proposed framework.

In the future, we plan to deploy the framework in the Lower Sioux Indian Tribe Community. We will study, evaluate, and improve this framework based on the real community needs.

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