Geo-based Content Sharing for Disaster Relief Applications

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Abstract Floating Content (FC) is an infrastructure-less communication paradigm based on opportunistic replication of a piece of content in a geographically constrained location and for a limited amount of time. The fact that it does not rely on any infrastructure makes it appealing for all those settings where infrastructure is not available or malfunctioning. In this paper we analyze its feasibility in the aftermath of a disaster, as a communication service in support of applications for rescue coordination and situational awareness. We analyze the possible scenarios of disaster, with a special focus on the local context (Iceland in our case), and on a subset of disasters which are of economic and social interests. We characterize the available communication network, its structure, and we individuate some criticalities which could play a key role in case of disaster. Specifically, we consider two services, related to two disaster scenarios. A first one is a form of situation awareness, without the support of fixed communication infrastructure. A second service is a form of infrastructure-less social driving application. The exchange of information between vehicles in the vicinity of a region interested by a disaster, enabled by such app, could help mitigate the impact of disasters and hazardous conditions on vehicle traffic. For both services, we describe a possible implementation using Floating Content. Finally, for these scenarios, we identify some research issues which stand in the way of a realistic, practical implementation based on FC.

1 Introduction

Disasters can seriously disrupt a communication network, making its services unavailable. However, communication is paramount for disaster relief. Internet of Things (IoT) devices such as smartphones or devices embedded into vehicles can be used to create an ad hoc network that allows to exchange critical disaster relief

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information between IoT devices and using a data mule approach eventually even seamlessly the Internet.

This paper describes the communication problems that can occur in Iceland: due to its sparse inhabitation, cellular network coverage is not always given and natural hazards occur frequently due to weather condition and due to volcanism – these hazards can be detrimental for the communication infrastructure. To address these problems, we suggest a mobile application that applies the concept of Floating Content (FC) to achieve ad hoc delay and disruption tolerant networking (DTN). In the context of disaster relief, FC is used to disseminate information in the aftermath of a disaster to enable situation awareness for search and rescue teams and mitigating the effects of hazardous condition of traffic by enabling communication between and in-between search and rescue teams and people fleeing from the disaster area.

The structure of this paper is as follows. Following this introduction, Section 2 provides previous and related work. In Section 3, disasters recurring in Iceland are surveyed together with their effect on communication infrastructure. The necessary diffusion of critical information in the aftermath of a disaster is described in Section 4. To address this diffusion problem, Floating Content is suggested as a solution (Section 5). Problems to be solved for such a Floating Content solution are discussed in Section 6. A summary and an outlook conclude this paper in Section 7.

2 Previous work

Floating Content (FC) [1] is an opportunistic ad hoc networking approach based on the idea of delay and disruption tolerant networking (DTN). FC achieves infrastructureless distributed content sharing over a certain geographic area called Anchor Zone (AZ). The objective of FC is to ensure the availability of some content items within the AZ by replicating them opportunistically to users which come in contact within the AZ, so that the content items "floats" within the AZ (see Fig. 1). Initial work covered performance of the FC service with respect to theoretical conditions under which a content item floats with high probability [1], application-level performance modeling [2] and simulations [3]. The first real experimental study using a smartphone FC app based on Bluetooth communication in a university campus setting is described in [4] where the first author of this paper was involved.

Concerning communication in the contexts of disasters, Bagrow et al. [5] analyse mobile phone data with respect to communication patterns taking place during/immediately after a disaster. These analyses suggest that a lot of information concerning such an extraordinary event is propagated. However since the cellular network was in place, communication took mainly place along the existing social networks of the eye witnesses spanning long spatial distances. This is in contrast to the more local communication cascades of floating content.

The "112 Iceland" app [6] is an emergency mobile app for Iceland to make via cellular network an emergency call accompanied with an SMS containing GPS coordinates. In addition, it allows to send periodically the current GPS location so that if

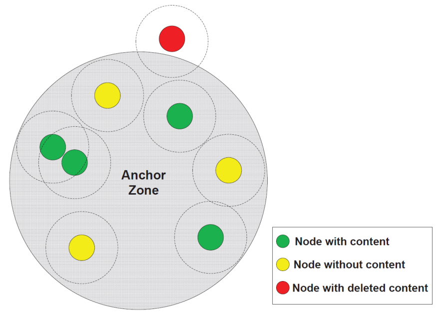

Fig. 1 Content floating in an anchor zone

an emergency call is not possible anymore, at least the last logged position is known to emergency services. This app requires a working cellular network coverage.

3 The Icelandic Context

This section surveys natural hazards that are recurring in Iceland and typical disaster scenarios and their impact on communication infrastructure. The source of most of this information is personal communication with experts from Icelandic telecommunications companies.

3.1 Natural hazards and disasters in Iceland

Iceland is located in the North Atlantic Ocean on the Mid-Atlantic Ridge. This results in a subarctic climate and high geological activity with many volcanoes. The following natural disasters are recurring in Iceland:

- **Volcanic eruptions, in particular ash fall**. In particular the interaction of lava and glacial ice cover leads to ash creation: Electrically-charged ash can cause interference to radio waves (experience is, however, that microwave communication was not affected in recent incidents in Iceland). Air-cooling systems of communication equipment is vulnerable to over-heating if these units fail or need to be switched off (due to ash fall). Ash is conductive and may cause short circuits.
- **Glacial outburst floods/jökulhlaups**. Geothermal heating or volcanic subglacial eruptions lead to generation of meltwater resulting in a large and abrupt release of water. For example, the peak discharge of the flood caused by Eyjafjallajökull eruption 2010 was 3 000 m^3/s (for comparison: the Niagara falls have an average flow rate of 2 400 m^3/s); the 1996 Grímsvötn eruption resulted in a 50 000 m^3/s peak discharge; the historic Katla eruption 1755 had an estimated peak discharge of 200 000 to 400 000 m^3/s. These floods destroy roads and communication in-

frastructure. Potentially, such a flood can also destroy hydropower infrastructure. People such as tourists visiting glaciers are also in danger and need to be warned, for example by SMS cell broadcast, but cellular coverage is in fact not everywhere given in the potential areas.

- **Earthquakes**. The high geological activity leads also to frequent earthquakes. However, strong earthquakes that destroy communication cables or fibres and other communication structures or cause landslides (potentially destroying infrastructure) are rare, because earthquakes in Iceland are rarely stronger than magnitudes 6.3–6.6.
- **Storms, blizzards, icing**. Storms and/or weight of accumulated icing let frequently overhead power transmission and communication structures (including antenna structures) collapse. Furthermore, close to the coast, the icing may contain salt (due to seawater), thus making high voltage line insulators conductive, thus triggering circuit breakers. Power outages affect communication infrastructure. In addition, many remote places (such as farms) are only connected by radio communication: again, antennas are subject to icing which can lead to communication disruptions. Extreme and rapidly changing weather weather conditions also affect transport including high road traffic due to tourism even in deserted areas where lack of information puts tourists into danger.

3.2 Communication infrastructure

Iceland is the most sparsely populated country in Europe. At the same time, the recent growth of tourism in the island brought large variations of population density in the island over the year [7]. This has crucial implications on the communication infrastructure:

- Sparsely or non-inhabited areas (in particular the highlands, but also many other even less remote areas simply due to path loss caused by topology characteristics) are not covered (or not reliably) by cellular network. This is evidenced by Fig. 2, which shows the aggregate coverage from all operators in Iceland, as derived from the OpenSignal crowdsensing initiative [8]. The map shows that several area around the coast are poorly covered by the cellular network, and that coverage in inland areas (many of which are of great touristic interest), when present, is very spotty. Even Terrestrial Trunked Radio (TETRA) used by emergency service lacks coverage in some of these areas [9].
  However, these areas are nevertheless populated, in particular by tourists.
- The communication backbone is provided by a fibre ring going around Iceland. The ring topology provides some redundancy, for example if a local flood destroys the ring in the south of Iceland, a detour via the North is still possible. However, some areas outside the ring have no redundant connection (or only low-bandwidth radio backup).
- While there is some redundancy in the communication links, the communication nodes can be a single point of failure. For example, central server infrastructure

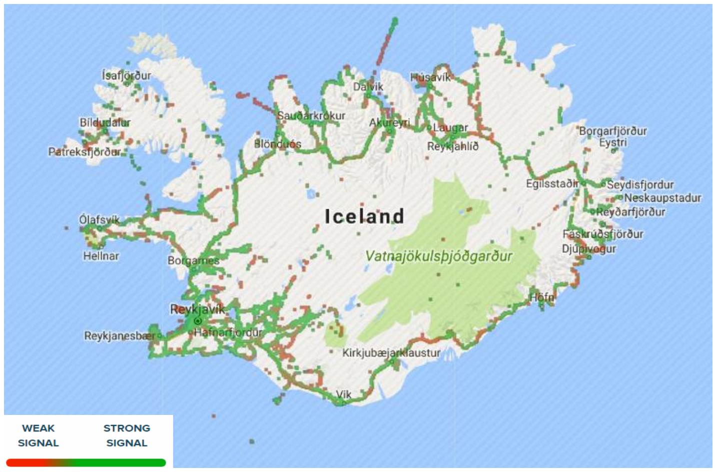

Fig. 2 Aggregate coverage map of Iceland, built from crowdsensed data [8].

for whole country is typically located only in the capital Reykjavík. Even though these nodes are redundantly located at different locations in Reykjavík, a partitioning of the network (e.g. as a result of a disaster) would mean that these central services would not be available for any partition not containing Reykjavík.

3.3 Reference disaster scenario

In the remainder of the document, we consider the following reference disaster scenario: a large sub-glacial volcano erupting (e.g. Katla), melting glacial ice and creating a flow of a huge amounts of water. We assume an area downhill the volcano to be a popular touristic spot (e.g. Thórsmörk), and hence hosting camping sites, various hiking trails, and a few roads connecting it to the rest of the country. The volcano is monitored with sensors which are able to predict the incoming danger, and that cellular coverage in the area to be absent/insufficient, so that not all tourists can be warned through an SMS cell broadcast as it would for example be done by the civil protection in the case of danger.

4 Diffusion of information in the aftermath of a disaster

Coverage holes make any measure to mitigate consequences of a disaster hard to apply. Disasters might exacerbate the coverage issue, further reducing availability of communication infrastructure. Indeed, at the occurrence of a disaster, various kinds of infrastructure might be not available (or only partially available), such as roads, power grids, and communication networks (cellular access network, fixed internet, phone network).

For instance, in the reference scenario, the water flow might have erased the power lines and/or the cellular base stations, making it even harder for people in the region to be aware of the incoming hazard and of its features. In what follows, we focus on specific issues which are relevant in case of the aforementioned disasters, and which arise from lack of communication infrastructure.

We can expect two main mobility patterns: people fleeing from a disaster and search and rescue teams coming from the opposite direction. While this may lead to extra chaos, it is also an opportunity for information exchange.

4.1 Situation awareness, for search and rescue coordination in the aftermath of a disaster

In such a context, one of the main aspects affecting the effectiveness of rescue operations is availability of information on the status of the affected region, on the status of operations, on the local conditions in which the rescue teams have to operate, and so on. Indeed, the lack of infrastructure following a disaster makes it hard to collect data about the pre-disaster status of the affected area, and to implement a common, shared vision of the status of the affected area, and of the ongoing search and rescue actions (situation awareness).

Coordination of rescue and search is a key problem. Diversity of rescue teams, presence of random, untrained rescuers make coordination very challenging with delays in interventions and waste of resources. For instance, in our reference scenario, people already invested by the water flow typically have precious information for the rescuers (e.g number of people affected, their medical condition, strength of the water flow in their proximity, etc) but they cannot make it available because of lack of communication and because of physical isolation from rescuers.

Coordination of action indeed can only be achieved by sharing a common information base, and achieving this without infrastructure and without prior coordination between all actors is particularly challenging. Sharing effectively information may speed up intervention, optimize it and build correct priorities for actions. In search and rescue operations, coordination may be facilitated if everyone shares same platform, or in any case a common vision of the current status of damages, of people to be rescued, of people who could be under, for example, rubble, and of availability of rescuers, of their skills, etc.

4.2 Mitigation of effects of hazardous conditions on traffic

In non-urban settings, under adverse and rapidly changing weather conditions, or following natural disasters affecting viability (e.g. floods wiping off roads, earthquakes destroying bridges), road conditions are affected in a way which is hard to predict. Travelling in the areas affected by such conditions might be unsafe, given the difficulty of rescue operations in those contexts.

As an example, unbridged rivers in the Icelandic highlands are regularly crossed by tourists in off-road cars. It depends on current and past weather conditions and type of off-road car whether they can be crossed or not. (The same applies for mountain hiking routes where hikers have to wade through rivers.) Errors of evaluation here are frequent, and they are at the origin of accidents, which take place in hostile regions, often with no cellular coverage. Indeed, communications availability could enable road users to take timely and informed decisions (based on experience and observations from others), and to ask for help. In the reference scenario, warning vehicles of the dangers related to travelling along routes which are going to be (or are already) affected by the flow might save lives. In those cases, often some vehicles (e.g. those getting out of the zone affected by the danger) posses information on the hazard, which could be valuable for other vehicles and people in the region.

5 Service Implementation through Floating Content

Being a communication paradigm which does not require (but can benefit from) support from infrastructure, Floating Content (FC) is a good candidate for data sharing in the two scenarios described in the previous Section 4. It can benefits from the mobility patterns of traffic in opposite directions (people fleeing from an area and rescuers entering that area).

In the **situation awareness** scenario, we assume that mobile phones of the people on site (and hence of both the people affected and of the rescuers) run an app which supports FC. One possible implementation of the situation awareness service via FC, could be as follows: The app starts with fluctuating in the region affected a map of the region itself. Each participant then enriches the map with geographically contextualized information, and floats the resulting, enriched map. Whenever a user receives different versions of the same enriched map (with different tags and information), the user consolidates the information, possibly eliminating duplicated data and outdated information.

For instance, during a flood, the first rescuers (or the people getting isolated by the flood itself, in a car or on a hill) could start floating the info on who needs help, and where they are located. But as rescue operations progress, this information is updated by other rescuers, and the enriched map is updated before being replicated.

This helps creating a shared vision of the disaster area and of the status of rescue operations, without necessarily having a pre-established coordination between the different rescue teams. If the density of the users fluctuating the information is not sufficient, fixed battery powered extra nodes running the FC application could also be employed. They could be disseminated in the area in a random fashion, with the only constraint of keeping a minimum density of devices.

Such enriched maps should allow to be updated in near-real time, and it could be used to ”mark” locations and space in the form of digital graffiti, in a context where there are no more walls for physical graffiti. Augmented reality apps could be a good way to use the info spread through the platform.

In the vehicular scenario, the FC application could reside on the phones of the vehicle passengers, or be integrated as embedded devices in the vehicle itself. In this case, the seeder could be any vehicle which detects a hazardous event (such as a flood or an impassable river in general, or bad local weather conditions) or an issue on the road (such as washed away road sections, or snowdrifts), which the lack of communication infrastructure makes it difficult to announce in the region interested by the hazard. In this case the information would be replicated by vehicles flowing in both directions on the road. The extension of the floating region would depend on both the area interested by the hazard, and the area within which the road users should be aware of the issue.

6 Some research issues

In order to make the implementation of the services described above feasible, several research issues need to be addressed. Among those that we identified so far, are:

6.1 FC Implementation over Wi-Fi Direct

In the aforementioned scenarios, a large transmission range would be essential for FC performance. Hence, using short-range Bluetooth as in [4] is not a viable option. Instead, implementing FC over Wi-Fi (possibly, on Wi-Fi Direct [10]) has to be explored. Existing results for ad hoc networking over Wi-Fi Direct are based on building a complex network architecture [11] based on playing with double role of nodes (Access Point and Wi-Fi direct peer). The main research challenge here is how to create such network structure in an automatic, unsupervised fashion, without a central coordination function, and how to maintain it in case of churn.

6.2 Fast, efficient dissemination of FC App

The main weakness of the FC approach is its relying on the availability of an app residing on each device, for enabling content to be replicated. Of all the mobile devices present on a disaster scenario, only those equipped with such an app can take part in the exchange of floating information. As we have stated, coordination is one of the main challenges in the immediate post-disaster. Hence, managing to increase the adoption of FC application using other channels than communication itself might prove ineffective and too slow with respect to the reaction times required by the emergency. We propose to tackle this issue by devising an approach to effectively spread and inject the app to the largest possible amount of devices within a region. We envision that an architecture which combines Floating Content and captive portal techniques [12] could be a viable option to make the FC disaster app itself a floating content.

6.3 *Modeling and evaluation of Offline Waze over vehicular FC out of urban centers*

One of the main engineering issues in FC is determining the size and shape of the region within which replication should take place. Limiting geographically the content replication is essential in order to maximize the efficiency with which bandwidth is used by FC. Existing results [4] do not apply on a linear geometry, such as that of a highway or country road.

Waze [13] is a community-based traffic app that takes user provided traffic data (such as road hazards) into account. However, it is an online solution relying on a cellular network connection. A modeling and evaluation of a offline FC variant looks worthwhile.

7 Summary and Outlook

We have provided a survey on the typical natural disasters occurring in Iceland and how they affect communication. In this Icelandic context, we identified a typical disaster scenario which is affected by lack of cellular network coverage and characterised by a mobility pattern of fleeing people and search and rescue teams coming from the opposite direction. In case of a disaster, situation awareness based on information exchange is important to co-ordinate search and rescue operations. Hazardous condition on traffic of both fleeing and helping people can be mitigated by information exchange on traffic conditions.

Floating Content (FC) is a good candidate to enable the required communication despite the lack of cellular network infrastructure, because data is exchanged and stored in an ad hoc peer-to-peer manner when mobile devices meet. An FC disaster app allows to build up and update a map of important information needed for search and rescue. For transport, the FC disaster app allows to spread information on obstacles such as rivers or road hazards. To lay the ground for implementing such an FC disaster app, we identified a couple of issues that need to be solved.

In order to tackle these issues, we plan of looking for partnership with local institutions, associations and operators, both in Switzerland and in Iceland, which deal with rescue operations in case of hazards. The goal is, on one side, of revising the service requirements we have characterized, checking all the possible operational constraints (e.g. battery lifetime, size of the area where information should be available). On the other side, we aim at a characterizing people and vehicle mobility patterns in the time immediately after a hazard, by collecting data about past hazards.

Acknowledgements

This publication is based upon work from COST Action CA15127 ("Resilient communication services protecting end-user applications from disaster-based failures – RECODIS") supported by COST (European Cooperation in Science and Technology).

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