Ad Hoc Networks 40 (2016) 46–60

Contents lists available at ScienceDirect

Ad Hoc Networks

journal homepage: www.elsevier.com/locate/adhoc

On-site configuration of disaster recovery access networks made easy

Quang Tran Minh[a,*], Yoshitaka Shibata[b], Cristian Borcea[c], Shigeki Yamada[d]

[a] *Ho Chi Minh City University of Technology, Ho Chi Minh, Viet Nam*
[b] *Iwate Prefectural University, Takizawa, Japan*
[c] *New Jersey Institute of Technology, Newark, NJ, USA*
[d] *National Institute of Informatics, Tokyo, Japan*

ARTICLE INFO

Article history:
Received 5 December 2014
Revised 4 December 2015
Accepted 25 December 2015
Available online 7 January 2016

Keywords:
Wireless multihop communication abstraction
Access network
Disaster recovery
Tree-based network
On-site configuration

ABSTRACT

Catastrophic disasters can destroy large regions and, in the process, leave many victims isolated from the rest of the world. Recovering the communication infrastructure is typically slow and expensive, which is not suitable for emergency response. Multihop wireless access networks have the potential to quickly provide Internet connectivity to victims, but so far no simple and practical solution has been proposed to help people configure these networks easily. We are pursuing the approach of utilizing wireless virtualization techniques to establish wireless access networks on-the-fly using on-site mobile devices. While our previous work has demonstrated proof-of-concept solutions, it lacked fundamental communication abstractions, a rigorous design, and a thorough analysis on the effectiveness of these solutions. The main new contributions of this article are: (1) the *wireless multihop communication abstraction* (WMCA) as a fundamental communication concept for a practical *tree-based disaster recovery access network* (TDRAN), (2) the complete design and implementation details of TDRAN, and (3) a comprehensive analysis of the effectiveness of the proposed approach based on field experiments, both in indoor and outdoor settings, at different sites in Japan. The results demonstrate the effectiveness of the proposed solution for on-site configuration of wireless access networks, as it can easily extend to 20 hops by 15 m-distance and 16 hops by 30 m-distance networks, which result in 300 m and 480 m (respectively) in radius or about 1 km in diameter. This work also confirms that our approach is ready for realization as a real disaster recovery solution.

1. Introduction

The world has recently seen catastrophic natural disasters which caused loss of hundreds of thousands of lives and destroyed millions of houses as well as the communication infrastructure in the affected regions [1]. Failure in communication and information exchange leads to further heart-breaking crises to human beings [2]. Recent tragic disasters, such as the Great East-Japan Earthquake in March 2011 [3] and the Haiyan typhoon in November 2013 (in The Philippines), show the limitations of current communication technologies in the event of disasters.

Safety information including the number of wounded people, their locations and real-time health status are

* Corresponding author. Tel.: +84 969852729.
E-mail addresses: quangtran@cse.hcmut.edu.vn, goldenqht@gmail.com (Q.T. Minh), shibata@iwate-pu.ac.jp (Y. Shibata), borcea@njit.edu (C. Borcea), shigeki@nii.ac.jp (S. Yamada).

http://dx.doi.org/10.1016/j.adhoc.2015.12.008
1570-8705/

essential for rescue and crisis mitigation. It is necessary for people to access the Internet to share their safety status with rescuers as soon as possible. Our experience from analyzing disaster recovery efforts suggests that the first 24-h represent the "golden time" for emergency relief. However, recovery of disaster-damaged communication infrastructure is complicated and prolonged which is not suitable for emergency response. Strategic approaches should be proposed considering the following essential requirements:

(R1) **Quickly re-establish Internet connectivity**: Immediately after a disaster occurs, users need Internet access to data such as information about the disaster, evacuation notifications, their families status, etc., using common Internet-based applications (e.g., email, web browsing, Skype). Quickly providing Internet connectivity is a hard but essential requirement which must be satisfied by the proposed approach.

(R2) **Leverage commodity mobile devices**: Commodity mobile devices (laptops, tablets, smart phones) carried by disaster victims should be leveraged in the process of re-establishing Internet connectivity when part of the network infrastructure is down. This feature becomes very useful, for example, in and around evacuation centers where people gather after a disaster.

(R3) **Configure and extend the network in an easy way**: The network must be configured easily, requiring no technical skills from the disaster victims. Ordinary users should access the Internet as easily as if they are connected to conventional WiFi access points (APs). Furthermore, once joining the network, users should automatically contribute to the extension of the network coverage as per (R2).

In order to satisfy these requirements, a wireless multihop communication approach to reach the still-alive Internet gateways (IGWs) or Internet connected WiFi APs is the best solution. This work aims at **quickly extending Internet connectivity** from surviving IGWs/APs to victims by leveraging their mobile devices to form multihop wireless access networks.

Existing multihop ad hoc network approaches face difficulties in real-world deployment, especially in emergency response situations since they require dedicated hardware (e.g., additional mesh routers or network interface cards—NICs), complicated routing protocols, and IP address allocation and network configuration mechanisms to be installed on each mobile node (MN) in advance. In addition, it is still too complicated for ordinary users to change their devices into ad hoc mode and configure ad hoc networks.

We are pursuing the idea of quickly setting up wireless multihop access networks for disaster recovery utilizing wireless virtualization techniques [4–7]. Concretely, a novel approach to on-the-fly establishment of multihop wireless access networks to extend Internet connectivity from surviving APs to disaster victims using their own mobile devices has been proposed in [6]. The network is set up on-demand using wireless virtualization to create virtual access points (VAPs) on mobile devices which greedily form a tree-based topology to bridge far apart victims with a surviving AP. Ordinary users can easily connect to the Internet through the established network as if they are connected through conventional APs; the users also contribute to increase the network coverage, which is essential in emergency relief situations. A proof-of-concept prototype for this approach has been built and demonstrated in practice. However, this approach still lacks a high-level fundamental communication abstraction that can simplify network establishment and configuration, a more rigorous design, and a thorough analysis of its effectiveness in different real-life settings.

This paper overcomes these drawbacks and presents the following main new contributions:

(i) The **wireless multihop communication abstraction** (WMCA) is devised as a fundamental communication concept for the design of a practical **tree-based disaster recovery access network** (TDRAN). This concept helps to hide the inherent complexity of multihop communication establishment as each node is simply aware of only its associated AP (or VAP) using one of its virtual WiFi interface (WIF), and serves as a VAP using another WIF.

(ii) A full system design and implementation of the TDRAN scheme, which details the new features in this work, as compared to those in [4–6]. We also propose the **software-based WiFi access node** (SAN) concept, which involves the **software-based implementation of network functions** that run on mobile devices without the need for additional hardware. In addition, we propose a mechanism for auto-reconfiguration of link failures to improve the usefulness of the proposed network establishment and configuration approach. This mechanism has been implemented to display the connectivity status table (CST) at each node.

(iii) A thorough feasibility and performance analysis based on medium-scale field experiments, including indoor and outdoor setups. The experiments were conducted at two different locations seriously affected by the Great East-Japan Earthquake, namely Iwate and Miyagi prefectures, Japan. The analysis of the results provides a comprehensive understanding of the effectiveness and feasibility of the proposed approach. These new experimental results reveal that the proposed network is capable of extending to 20 hops by 15 m-distance and 16 hops by 30 m-distance networks, which result in 300 m and 480 m (respectively) in radius or about 1 km in diameter (much larger than that of 7 hops obtained by previous experiments in Iwate prefecture [6]). This coverage is large enough for disaster recovery and evacuation centers.

It is worth noticing that the simple yet practical mechanisms for auto IP addresses configuration and IP address conflict avoidance, as well as routing and DNS resolution in the tree-based networks [5,6] are carefully integrated in the design of TDRAN proposed in this paper.

The rest of the article is organized as follows: Section 2 reviews the related work revealing the necessity of this research. Section 3 presents the problem definition and introduces the WMCA concept.