# Chapter 8
# Application of Game Theory for Network Recovery After Large-Scale Disasters

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## ABSTRACT

*In recent years, large-scale disasters took place frequently and always caused severe damages to the network infrastructures. Due to these damages, available network resources are usually not sufficient to meet the data transmission requirements of users after disasters. Moreover, users tend to behave selfishly by consuming as much network resources as possible. Incentive mechanisms are therefore essential for the users to voluntarily cooperate with each other and improve the system performance. In commercial networks, this can be efficiently achieved through pricing. Namely, by selecting an appropriate pricing policy, it is able to incentivize users to choose the service that best matches their data transmission demands. In this chapter, assuming that a time-dependent pricing scheme is imposed on network users, a Stackelberg leader-follower game is then formulated to study the joint utility optimization problem of the users in a disaster region subject to maximum delay and storage constrains. The equilibrium for the Stackelberg leader-follower game is also investigated.*

## INTRODUCTION

As shown in *Figure 1*, Large-scale disasters such as earthquakes, tsunamis, hurricane-force winds, and floodwaters, always cause severe damage to devices or components that make up the network infrastructure. For instance, the Great Tohoku, Japan Earthquake and Tsunami in 2011 destroyed thousands of homes and network infrastructures including 1,900,000 telecommunication circuits and 29.000 cellular base station towers (Oskin, 2015). Disaster recovery, especially the Internet service recovery has been a critical issue and attracted significant attention from both academia and industry.

After disasters, available network resources become extremely limited, while traffic demand on the other hand may increase since most users make voice calls to confirm the safety of their relatives or friends. NTT docomo, the predominant mobile phone operator in Japan, reported up to 50-60-fold increases in voice calls being made after the Great Tohoku, Japan Earthquake and Tsunami in 2011 (MIC White paper, 2013). The limited network resource and surge in traffic demand lead to severe network congestion.

Vehicle-based Delay Tolerant Networks (DTN) have consequently emerged to address the network congestion problem after disasters. The Vehicle-based DTNs rely on messengers, which could be helicopters, unmanned aerial vehicles (UAVs), busses, or trains with data storage, to carry message bundles to or out of disaster-affected regions. Burgess, Gallagher, Jensen & Levine (2006) proposed an DTN routing protocol which is termed MaxProp. The authors considered the problem of determining which packets should be deleted when the storage of messenger is not enough. Harras & Almeroth (2006) proposed several inter-regional messenger scheduling algorithms in DTN and evaluated the efficiency of these scheduling algorithms through simulations. Uddin, Nicol, Abdelzaher & Kravets, (2009) pointed out that DTN depends on the underlying mobility model of messengers, then thy proposed a mobility model for post-disaster scenarios, and extended the capabilities of a DTN simulator (ONE) to adapt to the mobility of messengers. Fajardo, Yasumoto, Shibata, Sun & Ito (2012) presented a DTN-based solution to aggregate disaster-related information from a disaster region. A filter was then constructed to drop duplicate message generated from users. Simulation results confirmed that this solution achieve a small delay in message delivery. Takahashi, Nishiyama & Kato (2013) studied the fairness issue in DTN. The authors evaluated the performance of existing routing algorithms in DTN through extensive simulations and show that none of the existing routing algorithms can achieve the fair message delivery.

In vehicle-based DTNs, the storage as well as the time duration that messengers exist in disaster-affected regions could be limited. However, users always act without considering the system performance even during disasters. For example, network users may transmit nonurgent or even unnecessary data,

*Figure 1. Damage to network infrastructures due to large-scale disasters*
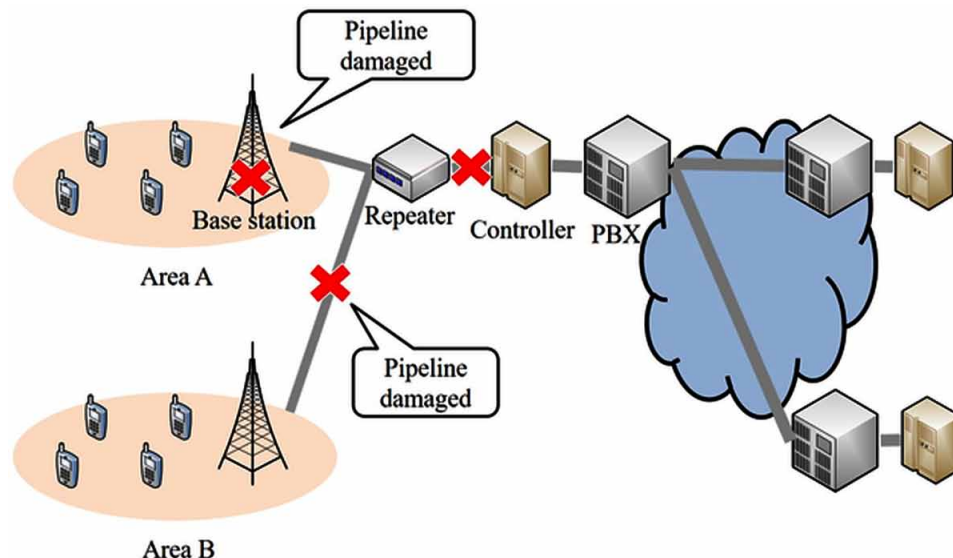
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