6

Joint Network for Disaster Relief and Search and Rescue Network Operations

6.1. Introduction

Disasters are exceptional events that are either man-made, such as terrorist attacks, or natural, such as earthquakes, wildfires and floods. Disasters create emergency situations and cause physical and social disorder. In these emergency situations, food, water, shelter, protection and medical help are needed, and the effort needed to provide these basic services to the victims must be coordinated quickly via a reliable communication network. Disaster relief operations typically involves a series of steps including establishment of communication infrastructures, performing search and rescue operations, and providing any needed first aid

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services. Disaster networks can be classified as disaster mitigation networks and disaster relief networks. A disaster recovery network is a network that is used in the pre-disaster stage to plan effective post-disaster relief operations.

A disaster recovery network, which is a part of disaster relief operation, is considered to be a life saving network that is used to provide emergency support to the disaster victims and the crew members who are helping the victims, and to provide communication infrastructure in the affected area. Sometimes the disaster relief operation involves searching for and locating the survivors, and then rescuing them. Currently this process typically involves manual searches in the disaster area, which can be hampered by the shortage of manpower in the disaster area, and it is also time consuming. To expedite this process, there must be a mechanism that enables survivors to report their locations to the Command Center, if they can, so that crew members can be directed to those locations for the rescue operation. Our interest is in the disaster recovery network and the motivating problem can be stated as follows:

– how can the survivors provide their locations quickly to the Command Center?

– what types of technologies are required, and how much time does it take for the survivors to learn to use these technologies to report their locations?

– how can these technologies speed up the rescue operation in the disaster area?

The goal of this chapter is to survey various existing solutions to these problems and their shortcomings, and propose an architecture that solves the problem. This chapter is organized as follows. Section 6.2 of this chapter provides an overview of disaster recovery network (DRN), search and rescue network (SRN) and essential network requirements. Section 6.3 discusses various existing solutions for DRN and SRN networks. Section 6.4 describes joint DRN-SRN solution called the *portable disaster recovery network* (PDRN) and its operation. Section 6.5 provides the simulation parameters for evaluating PDRN network architecture and simulation result. Finally, the chapter concludes with future activities and remarks in section 6.6.

6.2. Overview and requirements of DRN and SRN

6.2.1. *Disaster recovery systems*

As stated earlier, disasters are catastrophic events that occur unexpectedly in a random manner. They are either man-made, like terrorist attacks, or natural calamities, like earthquakes and tsunamis. The lack of infrastructure for disaster mitigation around the world and its prediction accuracy leaves civilians vulnerable to disasters. Disaster relief is an operation carried out after a disaster has occurred. A DRN is considered to be a life-saving network. The purpose of DRN is to provide emergency support to affected people and to support the crew members helping the victims. All existing networks were completely damaged in the areas that were affected by the recent incidents of Indonesia's tsunami in 2004, Hurricane Katrina in 2005, Japan's tsunami in 2011, the Haitian earthquake in 2010, and Hurricane Sandy in 2012. This rendered the crew members helpless, and many victims were trapped inside the disaster areas for a long time. There is now an increasing awareness among the government agencies for the need to implement disaster mitigation and relief systems.

Planning for disaster relief is a complicated operation that involves the use of proven technologies to coordinate, among several agencies, victims and crew members. A disaster can occur in any part of the world and no assumption must be made about any existing communication infrastructure in the disaster region. Therefore, DRN systems must be able to work autonomously, and if there is any communication infrastructure that exists before and after the disaster, then DRN must use and co-exist with such systems; this will expedite the disaster relief operation.

Since disaster relief is a life-saving operation, a DRN must be easy to deploy and operate, and it should require a short learning time by the disaster relief crew and victims in the affected area. With these basic requirements in mind, it is easy to see that wireless networks are the best choice for disaster relief operations because many of them do not require any pre-existing infrastructure to be established and are easy to operate. Several radio access technologies are currently available that can be used in cellular networks, wireless local area networks, wireless mesh networks, geographical area networks (GAN), unmanned aerial vehicles (UAV) and wireless personal area (WPAN) networks. Unfortunately, not all these technologies are directly applicable for DRN use because they are not designed for that purpose. However, several architectural solutions and protocols have been proposed and developed that use combinations of these existing technologies for partial disaster relief operations.

6.2.2. *Search and rescue systems*

Search and rescue operations are used to track individuals after a serious mishap, such as a wildfire, building collapse, earthquake, and when people are lost while hiking or trapped in mines. Data from previous disaster incidents indicate that more than 50% of deaths occurred within a few hours after the disaster event [MAJ 09]. Therefore, disaster relief and search and rescue operations (SRO) must take place within a short time after a disaster has occurred in order to increase the chances of rescuing the victims while they are still alive.

The key difference between a DRN and an SRN is that a disaster network is deployed at a particular location where a disaster has happened, and its main goal is to establish communication with the victims and then carry out the search operation. Search and rescue networks can be used in a disaster affected area as well as in wilderness scenarios where there may be no disaster and thus no impact to geographical areas. When an SRN is used in a non-disaster-affected area, the problem becomes that of searching for and rescuing people who are lost. In this case there may be no definite location or boundary defined for the search area, or it may be a well-defined large area. In a disaster-affected area, a disaster recovery network is first established followed by a search and rescue operation. Thus, a disaster leads to the use of both a disaster recovery network and a search and rescue network. In general, the area where a search and rescue network is deployed is larger than the area where a disaster recovery network is deployed.

Systems that can locate disaster victims within a short time are essential in search and rescue systems. As in the case of the World Trade Center (WTC) disaster, the nature of a disaster can be such that it can disrupt the entire communication infrastructure. In the WTC case, the rescue crew members could only use one-way and two-way radio systems to communicate. Because everyone was using the same frequency band, it was difficult to locate the victims due to signal interference.

Tracking and identifying the locations of disaster victims are two of the operations that take place in a search and rescue operation. In the past, dogs, human signs and acoustic signals were the primary means for this purpose. These techniques worked in the cases where humans and animals could access the affected areas. Unfortunately, these solutions often involve a great deal of human assistance that is typically in short supply in many disaster areas. Recent developments in sensor technology, wireless communication, robotics, computing and audio-visual technology have led to techniques that can be used to track and identify the locations of disaster victims and rescue them quickly. Some of the available sensor-based identification schemes include barcodes, biometric schemes, RFID and cell phones. These technologies are used in search and rescue network (SRN) systems, which include the global position system (GPS), wireless networks and sensor networks. These identification and tracking schemes complement each other because no one scheme can be used in all situations. For example, GPS-based solutions are applicable for outdoor situations only because they cannot provide the exact floor location inside the building. Similarly, many RFID-based schemes are useful only in indoor office applications.

6.2.3. *Key disaster recovery network and search and rescue network requirements*

Essential requirements that need to be part of a disaster recovery system are discussed here. The over-riding assumption is that DRN and SRN are wireless networks, and the requirements discussed in this chapter are specific to wireless communication networks.

6.2.3.1. *Quick response*

A disaster is an emergency situation that requires a quick turnaround for the infrastructure required to respond to the situation. Thus, a major criterion for evaluating a DRN and SRN is how quickly it can become operational and be used to meet the needs of the disaster victims.

6.2.3.2. *Life Expectancy of the Network*

Based on previous disaster incidents, the time to restore the damaged infrastructure takes on the order of months, if not years. Therefore, the disaster recovery network must be able to provide normal service until the rescue mission is completed and possibly beyond the completion of the rescue mission until normal infrastructure is restored.

6.2.3.3. *Interoperability*

Some proposed DRN's are expected to be interconnected with either the public switched telephone network (PSTN) or the Internet. Therefore, such networks must be designed to permit them to interoperate with these networks. It is known that some popular DRN's, such as police emergency networks and fire department networks, use proprietary protocols. Thus, any DRN and SRN that is required to be interconnected with these networks must have the necessary interface to enable the protocol conversion.

6.2.3.4. *Tariff-free operation*

In GSM-based networks, users are required to "pre-pay" for service before using the network by having the necessary minutes in their accounts. This is usually the case for most countries outside the USA. Thus, if a DRN supports voice-based applications that permit users to connect to the outside world, it should allow these users to use the network free of charge. This requirement is applicable to DRN system.

6.2.3.5. *Network coverage*

When a disaster occurs, the communication infrastructure may be partitioned into a number of islands. In this case, a disaster recovery system should be such that it can be quickly used to interconnect the different islands of disaster areas. If no part of the pre-existing infrastructure is available after the disaster, then it should be possible to deploy a solution that can cover the disaster area with one network or a cluster of networks that can be interconnected to permit communication across the affected area.

6.2.3.6. *Support for heterogeneous traffic types*

The ability of a DRN to support voice, data and video applications is a major concern. Some proposed solutions are voice-only solutions while others are data and/or video-only solutions. A desirable feature of a DRN is its ability to support different traffic types. This requirement is applicable to SRN systems.

6.2.3.7. *Network capacity*

Consider a situation where some or all the victims in a disaster area have devices with which they can communicate with the outside world, but the infrastructure is damaged by the disaster. Any DRN that is subsequently set up must have sufficient capacity to handle the sessions generated by both the victims and the disaster relief crewmembers. Thus, a DRN solution should have the capacity to support this traffic scenario.

6.2.3.8. *Ease of use and equipment cost*

A user terminal or mobile node is the mobile device that is used by either the disaster victims or the crewmembers to access wireless service. Such a system should be simple to use with little or no learning time due to the emergency situation. For example, if the device to be used by the victims is a voice device, then it should be as simple to use as the normal mobile phone that the victims are used to. Therefore, ease of use is a major issue in evaluating a DRN. Also, the user terminals that could be distributed to the disaster victims should not be expensive in order to ensure that every victim that needs such device gets one.

6.2.3.9. *Outdoor and indoor scenario*

The search and rescue (SAR) system must work for both outdoor and indoor scenarios. SRO applications must work seamlessly for both indoor and outdoor environments. If the SRN has two separate solutions in which one is for indoors and the other is for outdoors, then they must work together seamlessly.

6.2.3.10. *High precision for localization and search operation*

Locating the subject or a survivor is an important operation. For this reason, the system must provide the survivors' location with reasonable accuracy without any ambiguity. Using this information, the search team will be able to respond quickly to rescue the survivors.

The following are the possible scenarios that the system must consider:

1) The system must provide high-precision location information and narrow the search area for SAR operation.

2) If the system is not able to provide high-precision location information but provides or has defined target search areas, then the solution must propose a faster search mechanism to rescue the survivors.

3) If the location information is of high precision, then the search area will be very narrow. This will lead to fast search and rescue.

6.3. Previous work

6.3.1. *Disaster recovery network solutions*

Several solutions that use a combination of *ad hoc* wireless network, mesh network, satellite and wireless sensor network have been proposed as DRN solutions. Most of these proposed solutions establish a DRN for only crew member-to-crew member communication. Very few systems consider survivor-to-crew member communication or expect the survivor to be holding a tracking device.

6.3.1.1. *Ad hoc networks*

An *ad hoc* network is a network that is constructed on the fly without any pre-existing infrastructure. A mobile *ad hoc* network uses a wireless medium for communication and user terminals act as relay stations. A wireless mesh network (WMN) is a form of *ad hoc* network that is designed to provide more than one path between nodes in the network [AKY 05]. SKYMESH is an example of a wireless mesh network where the complete infrastructure is constructed using Wi-Fi access points [SUZ 06]. SKYMESH uses commercial off-the-shelf components to construct a wireless architecture in the disaster-affected areas using balloons in the sky. The goal of SKYMESH is to provide accessibility and connectivity in the disaster affected areas with no assumption of any pre-existing network infrastructure. It creates WLAN network by using a huge helium-filled balloon which floats in the air. The payload of the balloon consists of WLAN hardware that creates wireless coverage. A group of WLANs connects to the balloon in a line-of-sight manner. One balloon can be chosen to have connectivity to satellite ground station that in turn uses stationary satellite to connect to the Internet. The focus of SKYMESH is to have rapid deployment of a network and the network is assumed to be temporary. This is a short-lived network and is not suitable for all types of terrain. Note that such a network is used to provide crew member-to-crew member communication. The search operation performed to locate the survivors is manual, and will not scale when impact of the disaster is large.

Multimedia WMN for disaster network architecture uses standard WMN protocols for DRN [KAN 07]. This architecture uses PDAs and laptops to form a WMN access mesh network that connects to a Command Center via a satellite backbone. The goal of this solution is to rapidly deploy the mesh networks among disaster-affected regions, and use the devices with Wi-Fi interface for communication. It is used to share pictures and videos using peer-to-peer technologies. This architecture uses standard MANET Optimized Link State Routing Protocol in the mesh networks and is established by crew members so that they can share the pictures with Command Center and among themselves. One or more of the laptops are equipped with satellite interfaces so that they can establish communication with satellite backbone networks. This solution is used to enable communication among the crew members only. The search operation performed to locate the survivors is manual, and will not scale when impact of the disaster is large.

6.3.1.2. *Hybrid networks*

Hybrid networks are heterogeneous networks formed using cellular networks and 802.11x WLAN networks. Unfortunately, cellular networks require huge infrastructure to operate and, therefore, are not suitable for disaster recovery operations. When one or more cellular base stations is damaged due to disaster, mechanisms must be in place to quickly divert the traffic by deploying a mobile base station and provide coverage, or by quickly deploying an *ad hoc* network that will act as a relay to cover the affected area. There is an increasing interest in recent years in hybrid networks, and 3G and 4G standardization efforts are in progress. Most of the hybrid network protocols require the user terminal to have multiple interfaces in order to freely roam between a cellular network and WLAN network.

The unified cellular and *ad hoc* network (UCAN) [LUO 07], the integrated cellular and *ad hoc* relay system (iCAR) architecture [WU 01], the cellular aided mobile *ad hoc* network (CAMA) [BHA 04], and the enhanced communication scheme combining centralized and *ad hoc* networks (ECCA) architecture [FUJ 05] are based on the hybrid network design. Each of these solutions focuses on one or more specific aspects of the solution, such as to increase throughput by doing handoff from the cellular network to the WLAN, or to have uniform load across all APs, or to provide QoS guarantees within the *ad hoc* network. Because all these systems are built around existing cellular infrastructure, their applicability to DRN operation is limited. For instance, ECCA is similar to iCAR, but its focus is on having accessibility and reachability as opposed to performance improvement. ECCA assumes that only a portion of the network will be impacted by disaster and makes such solutions less applicable to disaster operation.

6.3.1.3. *Satellite networks*

Satellite networks provide robust, global coverage, complementing disaster relief efforts. Satellite images are used to identify the effects of natural disasters and are used in aiding long-term recovery efforts. Using satellite phones, one can communicate from any part of the world. A satellite phone is like any other phone and is portable.

However, due to limited adoption by the civilians around the world (there are currently an estimated 1 million satellite phones worldwide) when compared to 2G/3G phones (there are currently about 3 billion phones), satellite phones are not going to be an effective and complete solution for disaster recovery operation. Moreover, satellite phones are expensive and not easy to use. The satellite phone finds its use only among crew members that use it to assess the damage at a disaster site before embarking on the rescue operation.

The wireless infrastructure over satellite for emergency (WISECOM) uses the satellite network as backbone and connects existing wireless networks to landline systems [BER 07]. WISECOM is composed of three components, namely WISECOM Access Terminal (WAT), WISECOM Transport and WISECOM Servers (WS). WISECOM network provides both crew member-to-crew member communication and survivor-to-survivor communication. It demands huge infrastructure to operate and manage the network.

Geosynchronous Earth Orbit (GEO) satellites are at 35,786 km above sea level at an equatorial orbit and they orbit the Earth at same rate as the Earth turns on its axis. This allows the satellite to remain in a relatively fixed position and allows communication from Earth with simplified infrastructure. The drawback of a GEO satellite is that it has a very high round trip time and is not suitable for latency driven applications. The Medium Earth Orbit (MEO) satellite operates at 8,000 km and enables applications that demand low latency [BLU 13].

6.3.1.4. *Amateur radio*

Amateur radio (or HAM radio) is one of the oldest P2P technologies that are operated by certified professionals [SIL 04]. It was shown to work during recent disaster incidents, such as Hurricane Katrina and the Indonesian tsunami. It mainly provides voice and Morse code communication and Hurricane is expensive to deploy and operate. HAM radio consists of transmitter, receiver and antenna sub-systems. A separate frequency band is allocated for HAM radio communication and HAM radio operators tune to this band and use Morse code for communication. In 1997, the Internet Radio Linking Project (IRLP) started to interconnect HAM radio and the Internet using voice over IP protocols [IRL 14]. Since HAM radio is used by certified professionals, its applicability and usage are so far restricted to crew members or first responders; also, it supports only voice and no data. There is no support for crew member-to-survivor communication. The search operation performed by crew members is manual, and will not scale if the impact of the disaster is large.

6.3.1.5. *Wireless sensor networks*

Sensor systems with wireless capabilities are becoming increasingly important as they are used to collect data for different applications. Wireless sensor networks

(WSNs) [AKY 02, MAC 08, YIC 08] are a part of disaster warning systems (DWS) that perform two operations: disaster mitigation and rescue operation after disaster. Some of the useful applications of WNS are detection of floods, earthquakes, wildfires and other environmental disasters. They are also useful in finding victims who are trapped in disaster areas, and for searching for people who are lost while mountain climbing or hiking. When used in this environment a wireless sensor network is not a total solution; it complements the previously discussed disaster recovery network architectures. Sensor network design must consider scalability, fault tolerance, topology, power consumption and transmission power. A typical sensor consists of a sensing unit, a power unit, a transceiver unit and a processing unit. Sensors are designed in such a way that twice the energy is consumed in transmitting the sensed information than receiving the information and their energy consumption is higher in communicating than computing the actual sensed information. Sensors can be deployed from helicopters and are unmanaged. Sensor network routing nodes, which are unattended for most of the time, may fail for various reasons, and routing protocols must compensate for these issues in their design. Most of the sensor routing techniques use location-based information. Many of the existing routing protocols suffer from topology changes and lack scalability.

Sensor for disaster relief operations (SENDROM) [CAY 07, SAH 07] is a management system primarily used for rescue operations after large disasters. The problem with any sensor-based approach is that it demands infrastructure to collect and transmit information. Sensors are battery operated and unmanaged and are usually not deployed uniformly. The SENDROM architecture demands that the sensors be kept in every home and office for accuracy. After a disaster has occurred, it is very likely that these sensor locations will be disturbed and may not be accessible due to obstacles getting in the way. Thus, installing sensors in homes and offices prior to a disaster requires huge deployment cost.

6.3.1.6. *Unmanned aerial vehicle*

Unmanned aerial vehicles (UAV) are a class of aircrafts that can fly without the onboard presence of pilots [WAT 12]. Unmanned aircraft systems consist of the aircraft component, sensor payloads and a ground control station. They can be controlled by onboard electronic equipments or via control equipment from the ground. When it is remotely controlled from ground it is called RPV (Remotely Piloted Vehicle) and requires reliable wireless communication for control. Dedicated control systems may be devoted to large UAVs, and can be mounted aboard vehicles or in trailers to enable close proximity to UAVs that are limited by range or communication capabilities.

UAVs are used for observation and tactical planning. This technology is now available for use in the emergency response field to assist the crew members.

UAVs are classified based on the altitude range, endurance and weight, and support a wide range of applications including military and commercial applications. The smallest categories of UAVs are often accompanied by ground-control stations consisting of laptop computers and other components that are small enough to be carried easily with the aircraft in small vehicles, aboard boats or in backpacks. UAVs that are fitted with high precision cameras can navigate around the disaster area, take pictures and allow the crew members to perform image and structural analysis. As UAV operations require onsite personnel, it will be helpful for onsite crew members to access the disaster area first before entering the disaster affected area. UAVs that are suitable for outdoor operation and can fly at reasonable altitude are used for disaster impact analysis. The important aspect of such UAVs is that the initial assessment gives a clear disaster planning direction. After the survivors are detected via image analysis, crew members can then try to make contact with the survivors and perform quick rescue operations. Nano UAVs can be used in-built and combined with robots capabilities and can be a very useful in detecting structural damages to buildings and detect survivors trapped inside debris.

In recent years, increasing research efforts and developments are improving UAV for various application and reliability. UAV is still in experimental stages at the moment. Also, a shortage of skilled onsite crew member is a bigger problem. [PRA 06] highlights that a minimum of three staff members is required to operate a UAV.

6.3.1.7. *Device to device communication*

Public safety agencies and organizations have started network evolution planning for LTE-based public safety solutions. LTE supports a wide variety of services from high bandwidth data services to real-time communication services – all in common IP-based networks. Mission critical communication in demanding conditions like natural disaster sets strict requirements, which are not necessarily supported by regular commercial mobile networks. Globally, the USA is the main driving market, where FirstNet government agency has a mandate to build nationwide public safety network using 700 MHz bands (band 14). In Europe, the driving market is the UK, where the UK Home Office has established a program with a target to build new emergency service networks that will provide mobile services for the three emergency services (police, fire and ambulance). However, such deployment models will be expensive.

3rd Generation Partnership Project (3GPP) standardization bodies are responsible for defining standards for wireless cellular networks [GGP 13]. Currently, to develop and assist public safety network systems, standardization is in progress to develop direct device-to-device communication capabilities from one mobile device to another mobile device at a distance of up to 500 m. Figure 6.1

describes various possible communication mechanisms for the user to communicate to other users with and without the support of network infrastructure. These features are currently in the specification phase and are expected to be made available in coming years. One of the key features of Release 13 is to enable proximity services and communication. This useful feature allows one mobile user to communicate directly or through other intermediate mobile device that acts as relay without needing cellular infrastructure. Such infrastructure less communication is critical for disaster relief operation wherein one survivor can communicate directly with other survivors. At this moment, standardization is still in progress and aspects related to device discovery, interference free communication, privacy and other services are still under development.

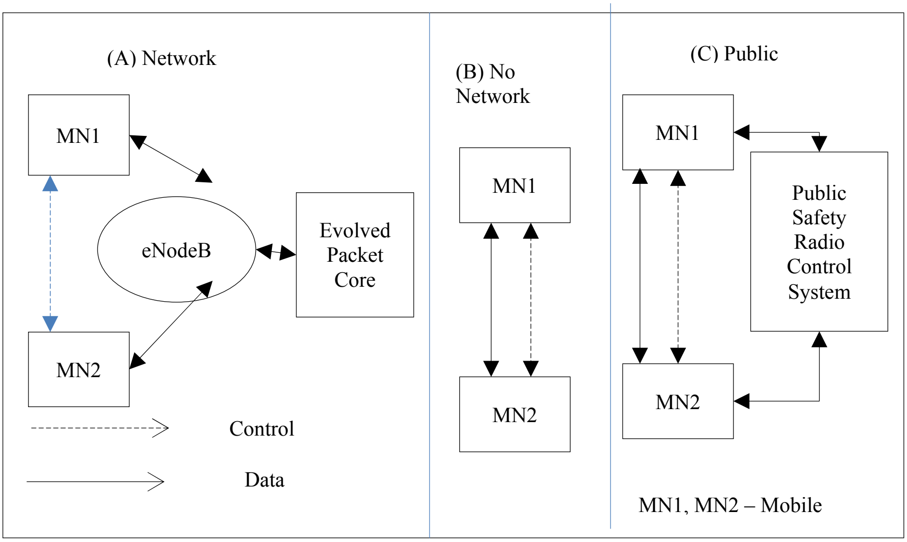

Figure 6.1. *Device-to-device communications*

6.3.2. *Previous search and rescue network solutions*

6.3.2.1. *Satellite-aided tracking systems*

The satellite-aided tracking systems that have been proposed include the use of satellite phones, geographical information systems (GIS), global positioning systems (GPS), location-based services (LBS), the cosmicheskaya sistema poiska avarynyh sudov (COSPAS, which is Russian for Space System for Search of Vessels in Distress), the search and rescue satellite-aided tracking (SARSAT), global navigation satellite systems (GNSS) and the slobalnaya navigatsionnaya sputnikovaya sistema (GLONASS, the Russian equivalent for GNSS).

COSPAS and SARSAT are satellite-based search and rescue systems that are used to detect and locate emergency beacons carried by aircraft, marines and individuals. These systems were developed by Russia and the United States, respectively. The architecture is composed of satellites, ground stations, local user terminals (LUT), mission control centers (MCC) and rescue coordination centers (RCC). The MCC and RCC are distributed geographically around Europe and US. Their main function is to coordinate with their rescue teams. The user terminals include the emergency position indicating radio beacons (EPIRB), the personal locator beacon (PLB) and the emergency locator transmitter (ELT). These are the three devices that are used by marines, individuals and aircrafts, respectively [ASC 09]. The user terminals generate beacon distress signals in emergency situations. The distress signal is received by the satellite systems, and the information is relayed to the LUT, which computes the location information. The computed location information is then forwarded to the MCC, which generates an alert message to RCC along with the received location information for rescue efforts. PLB systems are expensive and not affordable by civilians in many developing countries. Adoption of such systems is not common among civilians and requires everyone to carry these devices.

6.3.2.2. *Robot-assisted emergency and search and rescue systems*

When victims are trapped inside debris disaster areas, it is usually difficult to rescue them quickly. Mobile robots are useful gadgets that can go inside the building and detect if any victim is present and then signal the crew members for recovery. The purpose of using mobile robots is to track both the victims and to track the rescue crew who are helping the victims. The size of robots ranges from a small device to a moving crane. Robots can also be used in hazardous locations, such as chemical plants and nuclear reactors, where humans cannot reach. Due to advances in wireless technologies, robot-based solutions have been proposed for SRN operations [ASC 08, CAM 02].

A robot typically consists of electromechanical parts, processing units, sensing units and communication units. Sensors in robots fall into two categories, namely sensors used to control the movement of robots and sensors used to identify the victims or track their locations. A robot collects its location and movement from the environment and either computes the location locally or forwards it to a control station via a wireless link. Five basic requirements for robots are localization, environmental mapping, path planning, motor control and communications [KO 09].

Recently, robots, along with Nano UAVs, are getting more attention in the research community. For indoor navigation, GPSs cannot be used to track the location of the users trapped inside the building. A wireless mobile robot tracking system architecture is composed of mobile robots tied with blind nodes and reference nodes. Reference nodes are typically deployed at different locations of the building. A blind node, which is installed in a mobile robot, is allowed to move freely inside the building. ZigBee interface protocols are being used for communication between reference nodes and blind nodes. Reference nodes are static nodes and when a blind node sends a request, it responds with the location information. A blind node collects all the location information from several reference nodes and, using the received signal strength indication (RSSI) values, it computes its own location. All the signals received from various reference nodes are computed at a blind node using a centralized algorithm. The calculated location value is sent to the control station for processing and in this way the amount of information that needs to be communicated is small.

A drawback of the system is that it assumes that reference nodes are distributed uniformly prior to the disaster. Also, it uses RSSI values as a wireless signature to determine its location, which may not be accurate due to interference from other sources.

Even though the robot-based SAR operations are getting more attention and importance, the human–robot interaction is complicated and requires skilled personnel to operate the systems [YAN 02]. Some of the proposed systems demand infrastructure to be in place in indoor buildings before the disaster and such requirement limits the applicability of the solution.

6.3.2.3. *Emergency service using cellular phone*

Currently nearly three billion people around the world use cell phones. Emergency service is provided via 911 in USA, or 112 in European countries. In order for this service to work, users must have access to a phone service, and must be in a cellular coverage area. There are two types of cell phone systems commonly used: those with inbuilt GPS receivers and those without. A phone system with a GPS receiver functions as follows. When a subject is in need of emergency, he/she dials 911 (or 112 in Europe). The GPS inside the phone sends out the signal and computes the location information of the mobile phone. This information is transmitted to the mobile switching center and then appropriately routed to the nearest rescue station. The GPS performs the determination of the location using a satellite module in these systems. For the systems that do not have the satellite connectivity, such as GSM-based phones, the network determines the location of the coordinates (latitude and longitude). In these systems when a user dials out 911, the serving base station and its neighboring base station exchange messages with the phone and determine the distance offset. The network then performs the hyperbolic lateration process to determine the location of the phone.

Hyperbolic lateration is a location tracking method that uses the difference between the signal arrival times from a device to three or more reference points. The accuracy of this system varies from 100 to 300 meters. As in the GSM-based system, accuracy is limited to latitude and longitude, and it does not work for multiple floors. In order to compute the location of mobile phone with reasonable accuracy, these systems need a minimum of three base station signals, and these base stations must be non-collinear with respect to the mobile phone; otherwise the location accuracy will be very poor. Also, this solution is expensive and works only when cellular infrastructure is available.

6.3.2.4. *Sensor-based networks wilderness scenario*

The Connectionless Sensor-Based Tracking System Using Witnesses (CENWITS) [JIN 07], Yushan Nation Park (YushanNET) [JAR 97] and SenSearch [CAS 03] architectures use a wireless sensor-based scheme for SRO. They use GPS and sensors to track the location of hikers in wilderness scenarios. They are based on a connectionless architecture in which the nodes in the network use the store-and-forward mechanism to communicate with the base station and the nodes need not be connected to the network all the time. The CENWITS architecture is designed for specific scenarios, such as search and rescue operations where civilians are lost while hiking. The network consists of wireless sensors (WS), GPS transceivers, location points (LP) and access points (AP). The operation in the network can be explained as follows:

1) Each sensor is assigned a unique identification (ID), and a person is required to carry a GPS receiver and WS. The GPS receivers are used to give the exact coordinates, and the information is transferred via the WS.

2) While mountain climbing, if an individual, say Jack, comes across another person, for example Jane, moving in the opposite direction, the sensor carried by each person detects the other sensor and they exchange location information that is recorded in their local sensor storage.

3) Later, when Jane meets another person, for example John, the information about Jack's location is also exchanged with John. The process of meeting people and exchanging the stored location information of all their previous interactions with other people is called "witnessing".

The drawback of the sensor-based approach is that it demands infrastructure and expects the person to carry the devices. This makes the solution less applicable.

6.3.3. *Shortfall of the existing solution*

The existing solutions for DRN and SRN assume the infrastructure to be in place, and that survivors are already equipped with cellular or mobile device to communicate with the rest of the world or with the crew members. A disaster can occur in any part of the world and there may not be any cellular infrastructure prior to disaster in such places. Thus, survivor-to-survivor and survivor-to-crew member communication will not be possible. Past events have shown that even when a survivor has these mobile devices, the deployment of a DRN takes a long time, and by the time the DRN becomes operational the batteries of survivors were drained and this results in no communication from survivors. Also, since it is not a common practice for everyone to have their phone in hand (or a near-by place) while sleeping, if the disaster takes place at night, any solution that requires the potential victims to have disaster-related devices with them will not work. Similarly, in a wilderness scenario, the battery might die or the phone could be lost. So, in reality, it is not a valid assumption that the civilians will be holding their mobile phone before and after the disaster. The previously proposed solutions have several shortcomings and their rescue efforts will take time and may result in loss of lives due to the long deployment time.

The architectures and process flows for the existing solutions were described earlier. After a disaster incident, the DRN is deployed for the crew members only. Communication is established (or allowed) between crew members, and then the crewmembers have to search for the victims and rescue them one by one. The subsequent rescue operation often involves manual search for survivors in disaster areas, which means that it will take time before the actual rescue operation can take place. A solution is required that permits the survivors to quickly report their locations to the crew members or to an onsite Command Center so that they can be rescued on time. It is essential that a survivor has a phone to establish his/her presence quickly to the Command Center, and this will enable the SAR team to rescue him/her quickly. There is a need to introduce concurrency in operation to decrease the time in search operations.

To improve the disaster relief operation, new process and procedures are introduced [LAK 11]. A new procedure introduces the distribution of phones and how the survivors use those phones to report their locations automatically to the Command Center for speedy rescue operations.

The problems that need to be solved can be posed as follows:

1) Using the DRN, how can a survivor communicate with SAR team and reveal his/her location information?

2) Using DRN, how can the SAR team know the survivor’s location and find an optimal path for rescue operation?

These issues are addressed in the next section.

6.4. Portable disaster recovery wireless network architecture

PDRN provides a communication infrastructure that enables survivors to communicate with crew members within a disaster area [LAK 11, NAR 12]. The PDRN architecture consists of one or more access points (APs), a gateway (GW) node, PDRN phones and an on-site command centre. In the PDRN, when a disaster occurs, inexpensive PDRN phones are randomly dispersed over the disaster area by, for example, being dropped off from a helicopter or by a UAV. Also, access points are deployed at the periphery of the disaster area, and some can be dropped inside the disaster area by the same mechanism that is used to drop off the phones. They are designed to communicate with a Command Center that is also located outside the disaster area. Once a PDRN phone hits the ground, it uses a built-in GPS functionality to locate its coordinates. It then attempts to communicate with the Command Center via one or more access points to register its location coordinates and thereafter begins to continuously emit a beeping sound that is designed to attract wandering survivors. Thus, because the exact location of a beeping device is known to the Command Center once a survivor reaches any such device, his/her location is completely known at the Command Center from where a rescue team will be dispatched to rescue them. Also, it is assumed that once a survivor reaches a beeping phone and talks to the Command Center with the phone, the phone will stop beeping. The architecture of the PDRN is shown in Figure 6.2.

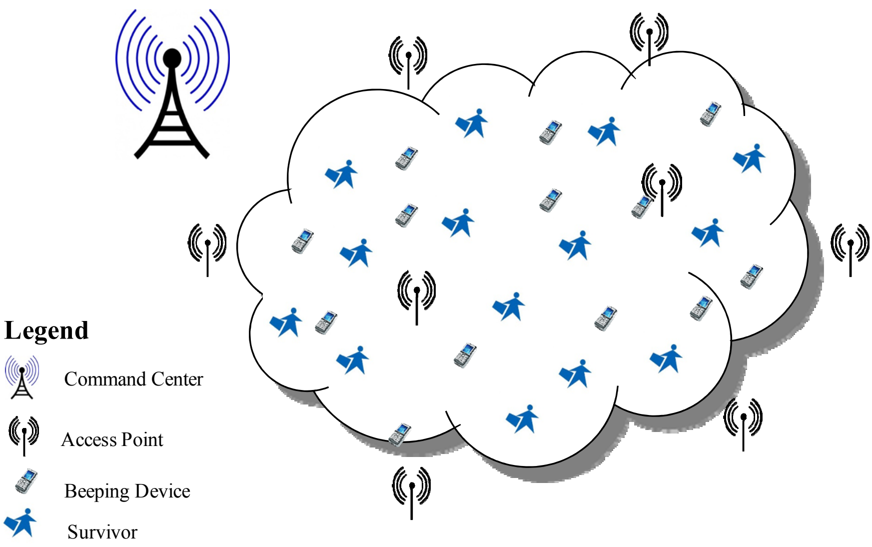

Figure 6.2. *PDRN architecture*

The effectiveness and efficiency of the solution depends on the following criteria whose analysis is provided in remainder of this section:

– What are the possible approaches that a survivor may take to reach a phone?

– How much time does it take a survivor on the average to reach a phone?

6.5. Modeling and simulation of survivor movement

There are two ways to model the movement of survivors when they are looking for beeping phones in the network. These are the random walk and the Levy walk. Different random walk models have been discussed in [LAK 11] and [NAR 12]. In this chapter we discuss Levy walk models.

A Levy flight is a mathematical description of a cluster of random short moves connected by infrequent longer ones. Thus, it consists of random walks interspersed by long travels to different regions of the walk space. Mathematically, the sequence of random movements of length L has a probability distribution function (PDF) $f_L(l)$ that obeys the power law; that is,

$$f_L(l) \propto l^{-\gamma}, \qquad 0 < \gamma \leq 3 \tag{6.1}$$

This PDF is said to have a heavy tail because large values of L are more prevalent than in other distributions such as Poisson and normal distributions. L has an infinite variance over the range of values of γ in equation [6.1]. Typically, each flight is followed by a pause time whose duration also has a power-law distribution.

Levy flights have been applied to a diverse range of fields such as those that describe animal foraging patterns [VIS 96, BAR 05, RAM 04, BRO 35], the distribution of human travel [BRO 06], the stock market [MAN 95], some aspects of earthquake behavior [CAR 06], anomalous diffusion in complex systems [BLU 89, CIR 05, RUB 08], epidemic spreading [JAN 99, DYB 09] and human mobility [RHE 08].

There is a difference between Levy flights and Levy walks. In a Levy flight, the walker visits only the endpoints of a jump, the notion of velocity does not come up and the jumps take very little time. Alternatively, we say that the Levy flight has an infinite velocity. This means that in a Levy flight, the walker is only either at the end of the jump or at the beginning; there is no stop in between the jump. However, in a Levy walk, the walker follows a continuous trajectory from the beginning of the walk to the end and this leads to a finite time being needed to complete the walk at a finite velocity. Thus, the concept of velocity is the major difference between the two; in the case of the Levy flight, the velocity is infinite, and in the case of the Levy walk, the velocity is finite.

One of the advantages of the Levy walk over the random walk is that the probability of a Levy walker returning to a previously visited site is smaller than that in the random walk. Polya proved that a random walker on a one-dimensional or two-dimensional surface returns to the origin with probability of 1. Thus, a random walk represents a mobility model in which the walker tends to hover around its starting point. This means that random walk models have the problem that random walkers tend to return to their starting points very often. Also, the number of sites visited by *n* random walkers that start at the same point is much larger in the Levy walk than in the random walk. The *n* Levy walkers diffuse so rapidly that the competition for target sites among themselves is greatly reduced compared to the competition encountered by *n* random walkers. The latter typically remain close to the origin and hence close to each other.

This dispersive feature of the Levy walk is advantageous in the PDRN network where factors such as the concentration of survivors and the distribution of phones are considered. Irrespective of survivors' locations, each survivor's trajectory is likely to be different, and hence when competing to reach the dispersed phones, a Levy walk model ensures that the probability that two or more of them are heading for the same phone will be greatly reduced. Thus, with respect to the PDRN, the Levy walker will occasionally take long steps and thus is more likely to reach the vicinity of a beeping phone than a random walker.

6.5.1. *Random motion with reward*

In the PDRN, a walker (or survivor) starts out walking aimlessly (or in a random manner) until he/she reaches the vicinity of a *beeping zone*. A beeping zone is an area within which a survivor hears the beeping of a phone. Theoretically, in both the random walk and the Levy walk, the walker must complete the stipulated length of the walk process before stopping to generate the next length of the walk. Since the Levy walker occasionally takes long flights, he is more likely to "leap" over a beeping phone than a random walker. This means that when a Levy walk is used, the value of the next step is likely to fall beyond a point where a phone is located than at that position. Thus, even though the Levy walker takes short steps most of the time, the few longer steps are likely to result in his leaping over of a beeping zone. This means that a walk is not likely to come across a phone. Similarly, if a pure random walk is used, then theoretically the choice of the next direction cannot be influenced by the fact that it might lead to a location that is further from the beeping device than the current location.

To improve the performance of the system, we introduce a *reward-based* (or *rewarded*) random motion that follows one of the two models until the walker is in the vicinity of a beeping phone. Under the reward-based scheme, when the random walker enters a beeping zone, he/she switches to a biased random walk. Specifically, when the walker enters a beeping zone, he/she makes a deliberate attempt to avoid going in directions that lead to a decrease in the volume of the sound of the beeping phone. Thus, in a classical walk the walker is walking aimlessly while in a rewarded walk, he/she is attempting to walk purposely toward a beeping phone. While there are different types of biased random walk (see [LAK 11], for example, for the different types), we assume that the walker uses a symmetric random walk with a slight modification. The modification is that if at the end of the current step the intensity of the sound of the beeping device is less than what it was at the previous location, the walker returns to the previous location and will practice a non-reversing random walk that prevents him from choosing a direction that leads to the previous location. For example, if the direction that led to the decrease in the intensity of the beeping was to the right, when the walker returns to the point from where he/she took that step to the right, he will have only three choices: left, up and down. He/she will follow this strategy until he/she reaches the phone. The right becomes a forbidden direction.

6.5.2. *Levy walk models of PDRN survivor*

We consider the following types of Levy walk [IBE 13]:

1) Classical Levy walk, which involves four parameters, namely the step size, time taken during each step, the waiting time between steps and the direction for the next step. The step size is based on the Levy distribution and a survivor chooses a random location that is uniformly distributed between 0 and 360 degrees from the current position. The step time is based on Levy distribution, waiting time between steps is random and there is no correlation between the four parameters.

2) Symmetric Levy walk, which is essentially a Levy lattice walk. In this walk the survivor moves in one of the four directions: east, west, north or south. After each step, the survivor chooses the next location with equal probability, and moves in one of the four directions based on probability outcomes. The step size and step duration are based on the Levy distribution, and after each step a survivor waits a random time before the next one. The step size, step duration, direction and waiting time are independent parameters.

3) Non-reversing Levy walk [DOM 58], which is similar to the symmetric Levy walk except that here the survivor will not immediately go back to the previous location where he came from. This does not prevent him from going back to a

previously visited site, as in a traditional self-avoiding walk; but he cannot do so immediately after leaving the site, which is why we define the model as a relaxed version of the traditional scheme. In this walk, the step size and step duration are based on the Levy distribution, and after each step a survivor waits for random time. The step size, step duration, direction and waiting time are independent.

4) Alternate Levy walk, which requires a survivor to alternate between *x* and *y* directions for each step. Unlike the symmetric Levy walk where directions are chosen independently at each step, this scheme requires a movement in the *x*-axis to be followed by a movement in the *y*-axis, and vice versa. The step size in each direction and step duration are based on the Levy distribution, and after each step a survivor waits a random time. The step size, step duration and waiting time are independent.

6.5.3. *Simulation*

In a Levy walk simulation, a survivor is likely to leap over barriers, which may lead to the survivor leaping over the beeping area. To solve this problem, a hybrid model is used that utilizes the Levy walk until a survivor comes in the district of a beeping zone where he switches over to a form of the random walk. The phones that are dropped in disaster area are at discrete locations.

Because a random walk can cause a survivor to bypass a beeping phone if the step length does not terminate at the phone, we define a reward-based random walk as follows. When a survivor comes within the beeping zone of a phone, he switches to a biased random walk such that he is more likely to move in the direction that leads to an increasing loudness of the phone than in a direction with decreasing loudness. After each step, he spends a random waiting time before taking the next step. The waiting time between flights is assumed to have a Levy distribution.

The following are the different walk model considered for simulation:

1) Levy walk-to-Levy walk model (LEVY->LEVY) in which the walker always performs the classical Levy walk even when he gets into a beeping zone.

2) Levy walk-to-reward-based Levy walk (LEVY->RLEVY) in which the walker initially performs the classical Levy walk until he gets into a beeping zone when he switches to the reward-based Levy walk.

3) Symmetric Levy walk-to-symmetric Levy walk (SYM-LEVY->SYM-LEVY) in which that walker always performs the symmetric Levy walk even when he gets into a beeping zone.

4) Alternating Levy walk-to-alternating Levy walk (ALT-LEVY->ALT-LEVY) in which the walker always performs the alternating Levy walk even when he gets into a beeping zone.

5) Levy walk-to-reward-based symmetric random walk (LEVY->RSRW) in which the walker initially performs the classical Levy walk until he gets into a beeping zone when he switches to the reward-based symmetric random walk.

6) Levy walk-to-reward-based alternating random walk (LEVY->RARW) in which the walker initially performs the classical Levy walk until he gets into a beeping zone when he switches to the reward-based alternating random walk.

7) Levy walk-to-reward-based non-reversing random walk (LEVY->RNRSRW) in which the walker initially performs the classical Levy walk until he gets into a beeping zone when he switches to the reward-based relaxed self-avoiding random walk.

8) Alternating Levy walk-to-reward-based alternating Levy walk (ALT-LEVY->RALT-LEVY) in which the walker initially performs the alternating Levy walk until he when he gets into a beeping zone when he switches to the reward-based alternating Levy walk.

9) Symmetric Levy walk-to-reward-based symmetric Levy walk (SYM-LEVY->RSYM-LEVY) in which the walker initially performs the symmetric Levy walk until he when he gets into a beeping zone when he switches to the reward-based symmetric Levy walk.

10) Non-reversing Levy walk-to-non-reversing Levy walk (NR-LEVY->NR-LEVY) in which the walker performs the non-reversing Levy walk even when he gets into a beeping zone.

11) Non-reversing Levy walk-to-reward-based non-reversing Levy walk (NR-LEVY->RNR-LEVY) in which the walker initially performs the relaxed self-avoiding Levy walk until he when he gets into a beeping zone when he switches to the reward-based relaxed self-avoiding Levy walk.

6.5.4. *Simulation result*

Several configurations are possible and described in [LAK11, AKP 13]. For simulation results described in Figures 6.3–6.6, the following are the configurations of survivor and phone distributions:

– both the survivors and the phones are uniformly distributed;

– both the survivors and the phones are normally distributed;

– the survivors are normally distributed and the phones are uniformly distributed;

– the survivors are uniformly distributed and the phones are normally distributed.

The performance measures are the mean first passage time (MFPT) and the percentage of survivors who reach a beeping phone and thus are rescued. MFPT is the mean time it takes for a survivor to reach a beeping phone from the beginning of the search process.

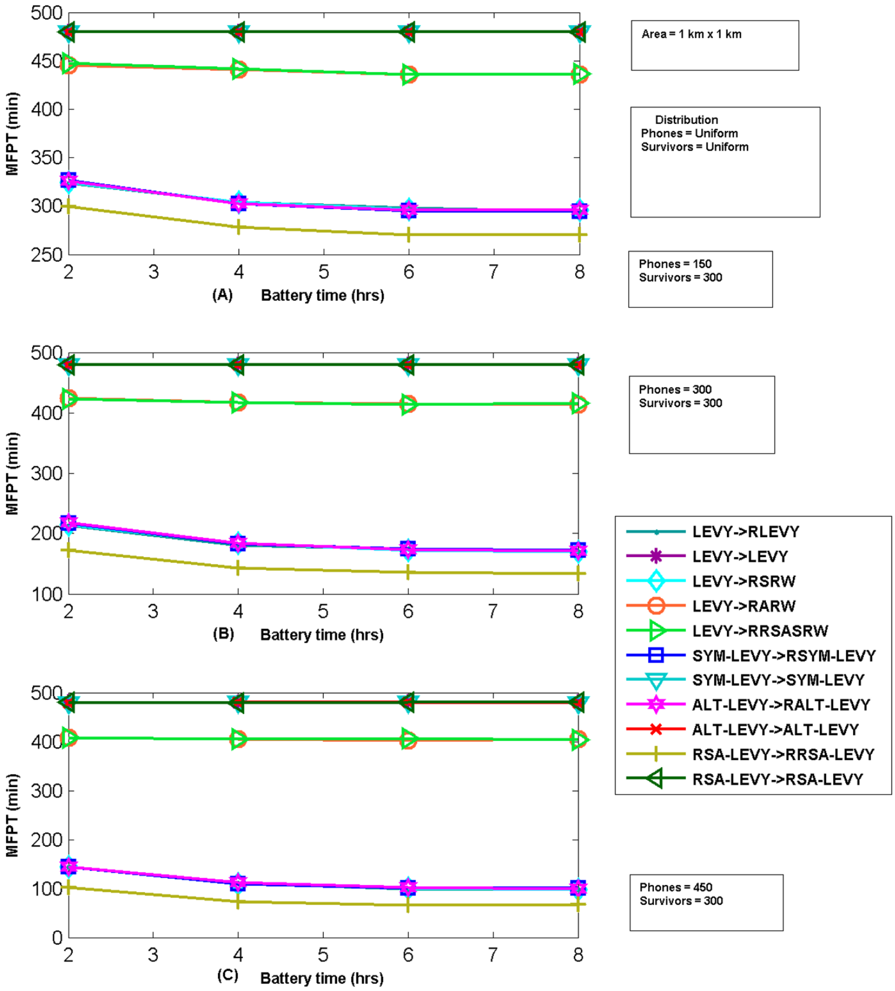

Figure 6.3. *MFPT of Survivors reaching a target when Area = 1 km x 1 km, both Phones and Survivors are uniformly distributed and constant number of Survivors*

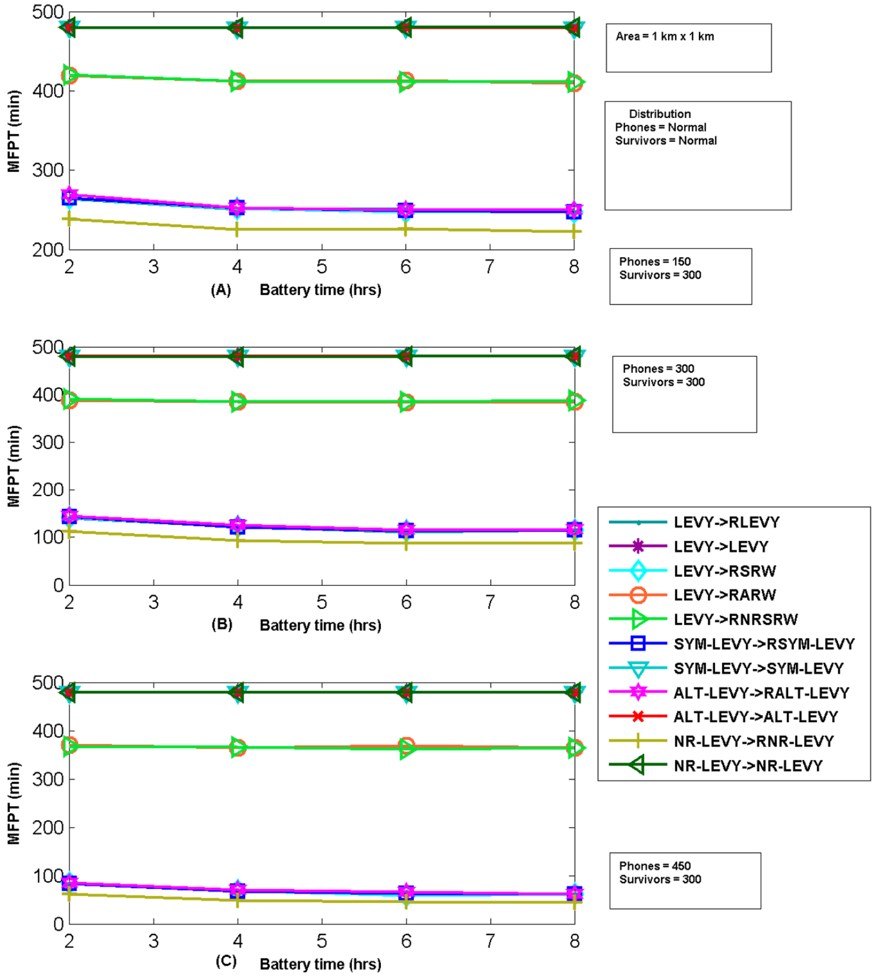

Figure 6.4. *MFPT of Survivors reaching a target when Area = 1 km x 1 km, both Phones and Survivors are normally distributed and constant number of Survivors*

From these results it is observed that switching from a Levy walk type to a rewarded Levy walk type provides some performance improvement over switching to an unrewarded Levy walk type. When a walker does not switch over to a rewarded walk in the beeping zone, he "ignores" the beeping of the phone and thus continues to wander about aimlessly until he/she "accidentally" stumbles across a phone. Thus, ignoring the beeping phone results in a poor performance, as expected. Also, models that start with a modified Levy walk type tend to perform better than those that start with classical Levy walk. It is interesting to observe that the Levy walk-to-rewarded Levy walk combination is among the worst performers, which reinforces the statement that the best performance is obtained by starting initially with a modified Levy walk type, which includes the non-reversing Levy walk, the symmetric Levy walk and the alternating Levy walk.

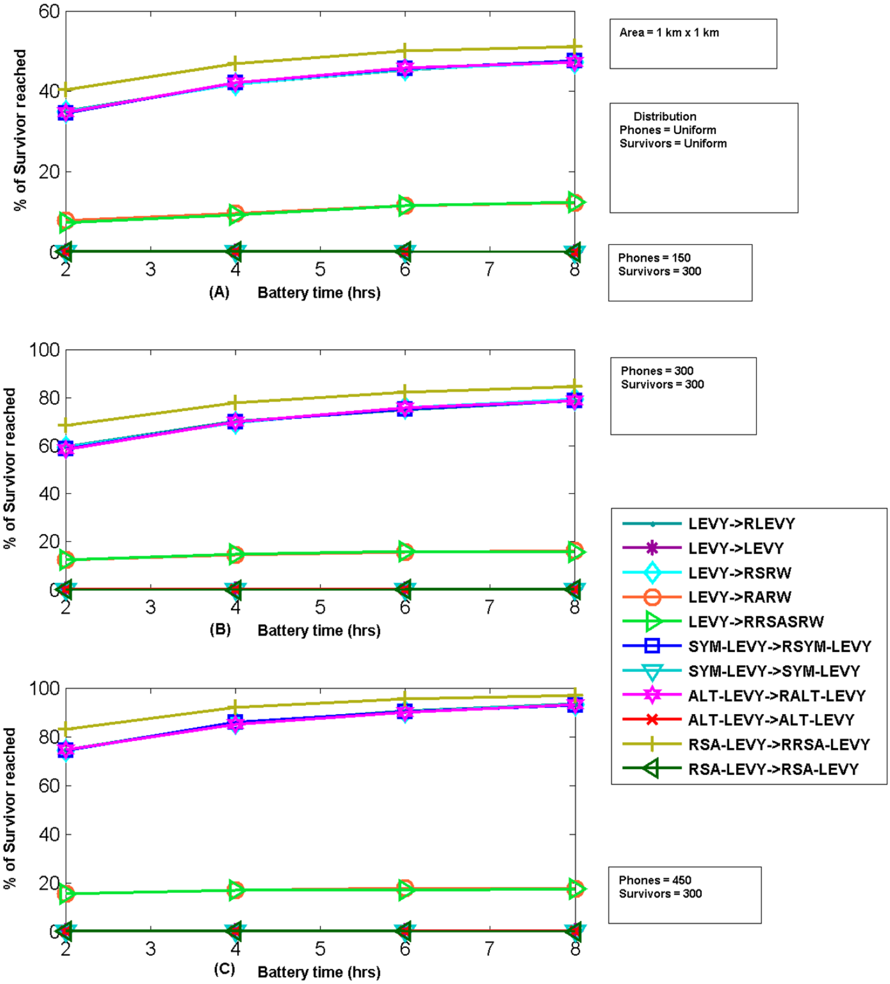

Figure 6.5. *Percentage of Survivors reaching a target when Area = 1 km x 1 km, both Phones and Survivors are uniformly distributed and constant number of Survivors*

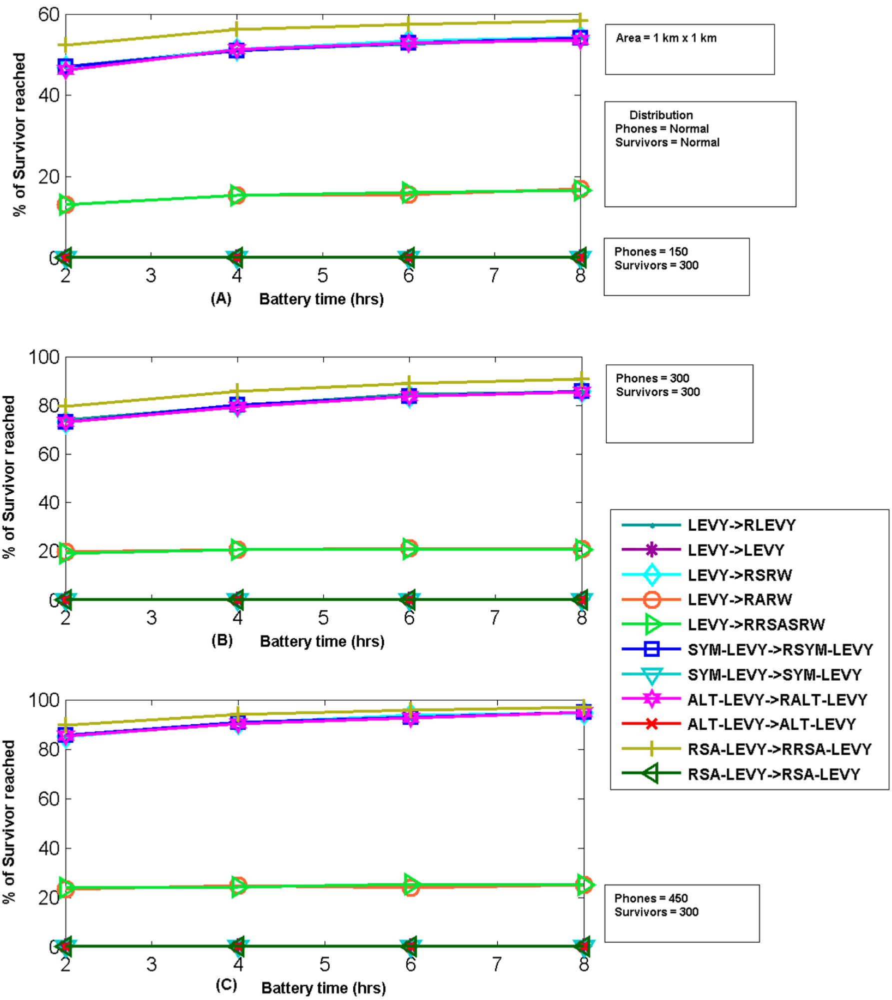

Figure 6.6. *MFPT of Survivors reaching a target when Area =1 km x 1 km, both Phones and Survivors are uniformly distributed and constant number of Survivors*

The results also indicate that the distributions of the phones and survivors have an impact on both MFPT and percentage of survivors rescued. Specifically, the best results are obtained when both the phones and survivors are normally distributed within the disaster area, followed by when both are uniformly distributed. There is not much distinction when one of them is normally distributed and the other is uniformly distributed. This observation is important for rescue operation planners because they need to drop more phones in areas of suspected concentration of victims than in other areas.

It is also observed that for a fixed number of phones, the performance of the system improves as the number of survivors in the area decreases, which is to be expected. Similarly, for a fixed number of survivors, the performance of the system improves as the number of phones dropped in the area increases, which is also to be expected.

Finally, the battery life of the phones has an impact on the performance of the system. Specifically, as the battery life increases, the percentage of rescued survivors increases. However, as the battery life increases, the MFPT first decreases and later remains constant or shows only a modest decrease.

In [LAK 11] and [AKP 13], it is shown that the results obtained for all parameter combinations. To summarize the result, it is observed that the Levy walk performs better and mimics the human mobility model. Furthermore, when battery life increases, more percentage of survivors get rescued. Also, knowledge of distribution of survivors is important when they are distributed normally; both MFPT and percentage of survivors rescued is higher.

6.6. Conclusion and future work

In this chapter we examined various network architectures that are applicable for disaster recovery operations and search-and-rescue operations. As such, each solution has its own strengths that contribute toward disaster relief operations. We also identified the gap in disaster recovery process and described PDRN solution. Using PDRN, different types of random walks are simulated to see how to quickly one can rescue trapped survivors. For future study: (1) the concept of PDRN and survivor modeling is genericthis can be applied to public safety and emergency network solutions such as UAV, LTE D2D wireless networks and need further studies; (2) also, in PDRN, the optimal path to rescue the survivor is research problem and needs to be explored further.

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