

MANET: A RELIABLE NETWORK IN DISASTER AREAS

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Abstract

The role of telecommunications in disaster reduction is critical in order to improve the timely flow of crucial information needed for appropriate assistance to be delivered before, during and after the disaster. The breakdown of essential communications is one of the most widely shared characteristics of all disasters. The collapse of communications infrastructure, due to the collapse of antennas, buildings, power etc is the usual effect of disaster. This paper describes a communication network that is appropriate, suitable and reliable in any disaster: - Mobile Ad hoc Network (MANET). A mobile ad hoc network is formed dynamically by an autonomous system of mobile nodes that are connected via wireless links without using the existing network infrastructure or centralized administration. The ease of deployment and infrastructure less nature of the network are some of reasons why MANET is recommended in disaster area.

Keywords: Mobile Ad hoc Network, Disaster, Wireless Networks, Routing

Introduction

Disasters are of varying intensity and occurrence ranging from less frequent like earthquake, volcanic eruption to more frequent like floods, fire, drought, cyclones, landslides besides industrial reaction and epidemics. Disasters kill at least one million people each decade and leave millions more homeless (ITU, TDBEC). When disaster strikes, communication link are often disrupted, yet for disaster relief workers, these links are essential in order to answer critical questions as to how many people have been injured or died, where the injured are located and the extent of the medical help needed. In disaster and emergency situations, communications can save lives.

The collapse of communications infrastructure, due to the collapse of antennas, buildings, power etc is the usual effect of disaster. The breakdown of essential communications is one of the most widely shared characteristics of all disasters. Whether partial or complete, the failure of communications infrastructure leads to preventable loss of life and damage to property, by causing delays and errors in emergency response and disaster relief efforts (Townsend and Moss, 2005). Yet despite the increasing reliability and resiliency of modern communications networks to physical damage, the risk associated with communications failures remains serious because of growing dependence upon these tools in emergency

operations. One solution to this problem is the use of wireless communication systems.

In wireless networking, there are two main architectures: infrastructure networks and mobile ad hoc networks (MANETs). Infrastructure networks include cellular networks and wireless local area networks. Users are connected via base stations/access points and backbone networks. Although users can handover between base stations or access points and roam among different networks, their mobility is limited within the coverage areas of the base stations or access points. This is illustrated in figure 1. Ad hoc networks on the other hand, exclude the use of a wired infrastructure. Mobile nodes can form arbitrary networks “on the fly” to exchange information without the need of pre-existing network infrastructure. Ad hoc networks can extend communication beyond the limit of infrastructure-based networks.

A mobile ad hoc network (MANET) is defined by the Internet Engineering Task Force (IETF) as an autonomous system of mobile nodes connected by wireless links in which each node operates as an end system and a router for all other nodes in the network (IETF, MANET). As illustrated in figure 2, it is a collection of wireless mobile nodes which dynamically form a temporary network without the aid of any established infrastructure or centralized

administration. These characteristics make MANET suitable for mission-critical applications, such as disaster recovery, crowd control, search and rescue and automated battlefield communications.

In a general mobile network which consists of wireless access networks and interconnecting backbone networks, the mobile terminals are connected to the base stations (access points) by wireless access networks, and the base stations are connected to the wired backbone networks (Woerner, and Howlader, 2001). There are drawbacks to these systems when large-scale disasters, such as earthquakes, occur. Communications may be impossible if the base stations or other elements of the infrastructure comprising these networks are damaged by disasters. Even if the infrastructure is not damaged, spikes in traffic and congestion may render communication virtually impossible. It is very important and necessary that communication networks be restored in such areas. Repairing the infrastructure could be time wasting, expensive and

lead to unnecessary loss of lives and property. The use of Mobile ad hoc network in such disaster areas becomes imperative. The ease and speed of deployment, cost effectiveness of setting up a MANET, its outstanding terminal portability and mobility makes mobile ad hoc network of great use in disaster areas (Bauer et al, 2004).

Communication and sharing of information in emergencies are important and should not be taking lightly as lives could be either lost or saved depending on the actions taken. MANET can enable communication among temporarily assembled user terminals without relying on the conventional communication infrastructure. Therefore, it is important to configure a communication network that offers sufficient QoS after a catastrophic disaster using an ad hoc network to help protect people. We therefore present an overview of Mobile Ad hoc Network (MANET), its characteristics and features that render it highly useful and reliable in disaster areas.

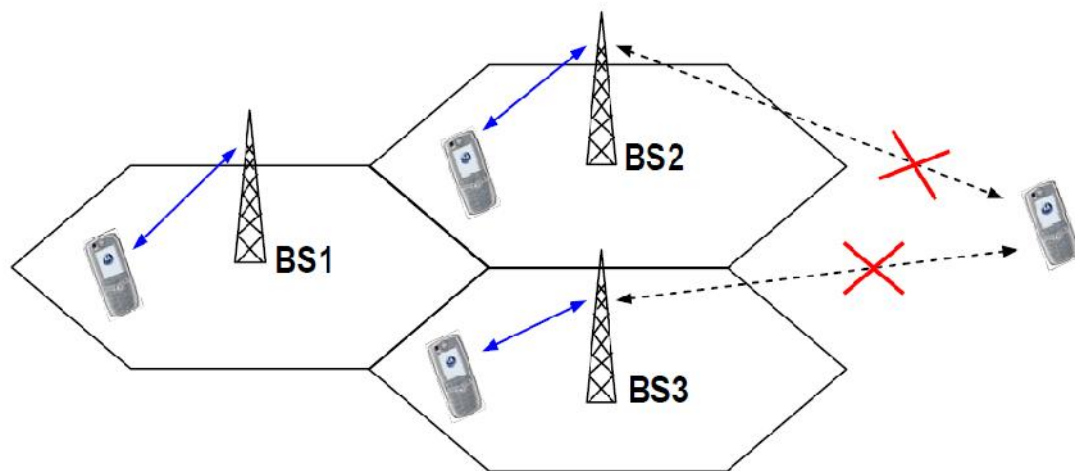


Figure 1: Infrastructure wireless network.

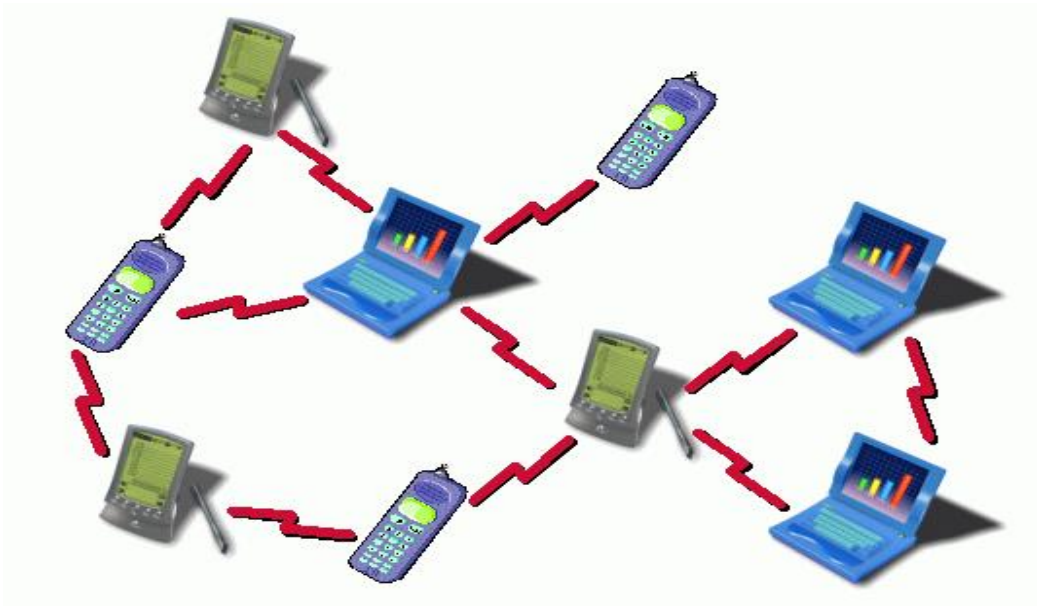


Figure 2: Mobile infrastructure-less wireless network

Manet features

MANET has the following features that make it a useful and reliable network in disaster areas:

Autonomous terminal: In MANET, each mobile terminal is an autonomous node, which may function as both a host and a router. In other words, besides the basic processing ability as a host, the mobile nodes can also perform switching functions as a router. So usually endpoints and switches are indistinguishable in MANET (Abolhassan, Wysocki and Dutkiewicz, 2004).

Distributed operation: The control and management of the network is distributed among the terminals since there is no access point or base station for the central control of the network operations. (Chakrabarti and Mishra, 2001) The nodes involved in a MANET should collaborate amongst themselves and each node acts as a relay as needed, to implement functions e.g. security and routing.

Ease of deployment: MANET does not depend on any established infrastructure or centralized administration. Each node operates in distributed peer-to-peer mode, acts as an independent router and generates independent data. This makes it possible to apply Ad hoc networking anywhere there is little or no communication infrastructure or the existing

infrastructure is expensive or inconvenient to use. Ad hoc networking allows the devices to maintain connections to the network as well as easily adding and removing devices to and from the network (Corson and Maker, 1999).

Multihop routing: Basic types of ad hoc routing algorithms can be single-hop and multihop, based on different link layer attributes and routing protocols. In MANET, there are no default routers available; every node acts as a router and forwards each other's packets to enable information sharing between mobile hosts (Murthy and Garcia, 1996).

Dynamic network topology: Since the nodes are mobile, the network topology may change rapidly and unpredictably and the connectivity among the terminals may vary with time. MANET adapts to the traffic and propagation conditions as well as the mobility patterns of the mobile network nodes (Royer and Tohc, 1999). The mobile nodes in the network dynamically establish routing among themselves as they move about, forming their own network on the fly.

Network scalability. Currently, popular network management algorithms were mostly designed to work on fixed or relatively small wireless networks. Many mobile ad hoc network applications involve large networks with tens of thousands of nodes, as

found for example, in sensor networks and tactical networks. Scalability is critical to the successful deployment of these networks (Campbell, Conti and Giordano, 2003). The steps toward a large network consisting of nodes with limited resources are not straightforward, and present many challenges that are still to be solved in areas such as: addressing, routing, location management, configuration management, interoperability, security, high capacity wireless technologies, etc.

Light-weight terminals: In most cases, the MANET nodes are mobile devices with less CPU processing capability, small memory size, and low power storage (Chang and Tassiulas, 2000). Such devices need optimized algorithms and mechanisms that implement the computing and communicating functions.

MANET applications

The application of MANET system is not only limited to disaster areas but with the increase of portable devices as well as progress in wireless communication, ad hoc networking is gaining importance with the increasing number of widespread applications. Ad hoc networking can be applied anywhere there is little or no communication infrastructure or the existing infrastructure is expensive or inconvenient to use. The set of applications for MANETs is diverse, ranging from large-scale, mobile, highly dynamic networks, to small, static networks that are constrained by power sources. Table 1 gives a brief description of the various application areas of MANET.

Table 1: Mobile Ad hoc Network Applications

Application	Possible Services
Emergency Services	<ul style="list-style-type: none"> • Search and rescue operations • Disaster recovery • Replacement of fixed infrastructure in case of environmental disasters • Policing and fire fighting • Supporting doctors and nurses in hospitals
Tactical Networks	<ul style="list-style-type: none"> • Military communications and operations • Automated battlefields
Commercial and Civilian environments	<ul style="list-style-type: none"> • E-commerce: electronic payments anytime and anywhere • Business: dynamic database access, mobile offices • Vehicular services: road and accident guidance, transmission of road and weather conditions, taxi cab network • Sports stadiums, trade fairs, shopping malls
Home and enterprise networking	<ul style="list-style-type: none"> • Home/office wireless networking • Conferences, meeting rooms • Personal area networks (PAN), Personal networking (PN) • Networks at construction sites
Education	<ul style="list-style-type: none"> • Universities and campus settings • Virtual classrooms • Ad hoc communications during meetings or lectures
Entertainment	<ul style="list-style-type: none"> • Multi-user games • Outdoor internet access • Robotic pets
Sensor networks	<ul style="list-style-type: none"> • Home applications: smart sensors and actuators embedded in consumer electronics • Data tracking of environmental conditions, animal movements, chemical/biological detection • Body area networks (BAN)

MANET enabling technologies

Ad hoc networks can be classified, depending on their coverage area, as: Body (BAN), Personal (PAN), Local (LAN), Metropolitan (MAN) and Wide (WAN) area networks. Ad-hoc single hop BAN, PAN and LAN wireless technologies are already common; these technologies constitute the building blocks for constructing small, multi-hop, ad hoc networks that extend their range over multiple radio hops. For these reasons, BAN, PAN and LAN technologies constitute the enabling technologies for ad hoc networking.

A body area network is strongly correlated with wearable computers. A wearable computer distributes on the body its components (e.g., head mounted displays, microphones, earphones, etc.), and the BAN provides the connectivity among these devices. The communicating range of a BAN corresponds to the human body range, i.e., 1–2 m. As wiring a body is generally cumbersome, wireless technologies constitute the best solution for interconnecting wearable devices (Conti, 2003).

Personal area networks connect mobile devices carried by users to other mobile and stationary devices. While a BAN is devoted to the interconnection of one-person wearable devices, a PAN is a network in the environment around the persons. A PAN communicating range is typically up to 10 m, thus enabling the interconnection of the BANs of persons close to each other, and the interconnection of a BAN with the environment around it. The most promising radios for widespread PAN deployment are in the 2.4 GHz ISM band (IEEE 802.16, WG). Spread spectrum is typically employed to reduce interference and bandwidth re-use.

Wireless LANs (WLANs) have a communication range typical of a single building, or a cluster of buildings, i.e., 100–500 m. A WLAN should satisfy the same requirements typical of any LAN, including high capacity, full connectivity among attached stations, and broadcast capability (Ebert et al, 2000).

Table 2: MANET enabling technologies

Technology	Theoretical bit rate	Frequency	Range	Power Consumption
IEEE 802.11b	1,2,5.5 and 11 Mbit/s	2.4 GHz	25-100 m (indoor) 100-500 m (outdoor)	~30 mW
IEEE 802.11g	Up to 54 Mbit/s	2.4 GHz	25-50 m (indoor)	~79 mW
IEEE 802.11a	6, 9, 12, 24, 36, 49, and 54 Mbit/s	5 GHz	10-40 m (indoor)	40 mW, 250 mW or 1W
Bluetooth (IEEE 802.15.1)	1 Mbit/s (v1.1)	2.4 GHz	10 m (up to 100 m)	1 mW (up to 100 mW)
UWB (IEEE 802.15.3)	110 – 480 Mbit/s	Mostly 3-10 GHz	~ 10 m	100 mW, 250 mW
IEEE 802.15.4 (e.g. Zigbee)	20, 40, or 250 Kbit/s	868 MHz, 915 MHz or 2.4GHz	10-100 m	1 mW
Hiper LAN2	Up to 54 Mbit/s	5 GHz	30-150 m	200 mW or 1 W
IrDA	Up to 4 Mbit/s	Infrared (850 nm)	~10 m (line of sight)	Distance based
HomeRF	1 Mbit/s (v1.0) 10 Mbit (v2.0)	2.4 GHz	~50 m	100 mW
IEEE 802.16	32 – 134 Mbit/s	10 – 66 GHz	2-5 km	Complex power control
IEEE 802.16a	Up to 75 Mbit/s	< 11 GHz	7-10 km	
IEEE 802.16e (Broadband Wireless)	Up to 15 Mbit/s	< 6 GHz	2-5 km	

The availability of appropriate networking standards enhances the success of a network technology. Table 2 gives a brief description of various MANET enabling technologies, however, currently, two main

standards are emerging for ad hoc wireless networks: the IEEE 802.11 standard for WLANs, and the Bluetooth specifications for short-range wireless communications (IEEE 802.11,WLAN).

Bluetooth

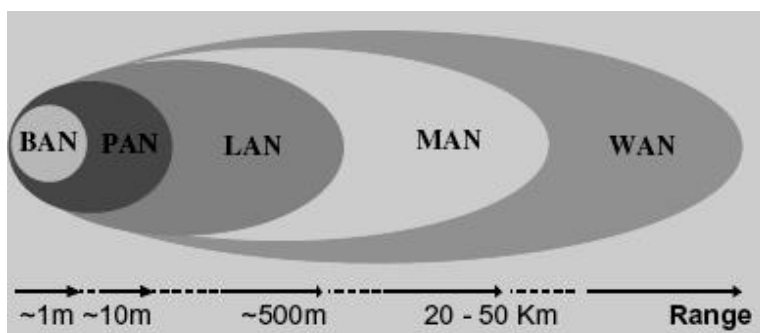


Figure 3: Bluetooth range

The Bluetooth system can manage a small number of low-cost point-to-point, and point-to-multi-point communication links over a distance of up to 10 m with a transmit power of less than 1 mW. It operates in the globally available unlicensed ISM (industrial, scientific, medical) frequency band at 2.4 GHz and applies frequency hopping for transmitting data over the air using a combination of circuit and packet switching (Conti, 2003).

The Bluetooth technology is a de-facto standard for low-cost, short-range radio links between mobile PCs, mobile phones, and other portable devices. The Bluetooth Special Interest Group (SIG) releases the Bluetooth specifications. Bluetooth specifications were established by the joint effort from over two thousand industry leading companies including 3Com, Ericsson, IBM, Intel, Lucent, Microsoft, Motorola, Nokia, Toshiba, etc. under the umbrella of Bluetooth SIG. In addition, the IEEE 802.15 Working Group for Wireless Personal Area Networks approved its first WPAN standard derived from the Bluetooth Specification. The IEEE 802.15.1 standard is based on the lower portions of the Bluetooth specification (IEEE 802.15, WPAN). A Bluetooth unit, integrated into a microchip, enables wireless ad hoc communications, of voice and data between portable and/or fixed electronic devices like computers, cellular phones, printers, and digital cameras (IEEE 802.16, WG). Due to its low-cost target, Bluetooth microchips may become embedded in virtually all consumer electronic devices in the future.

IEEE 802.11 Networks

In 1997, the IEEE adopted the first wireless local area network standard, named IEEE 802.11, with data rates up to 2 Mbps. Since then, several task groups (designated by the letters from *a*, *b*, *c*, etc.) have been created to extend the IEEE 802.11 standard. Task groups *802.11b* and *802.11a* have completed their work by providing two relevant extensions to the original standard, which are often referred to with the friendly name of Wireless Fidelity (Wi-Fi). The *802.11b* task group produced a standard for WLAN operations in 2.4 GHz band, with data rates up to 11 Mbps and backward compatibility (IEEE 802.11, WG). This standard, published in 1999, has become an “overnight success”, with several IEEE 802.11b products available on the market currently. The *802.11a* task group created a standard for WLAN

operation in the 5 GHz band, with data rates up to 54 Mbps. Among the other task groups, it is worth mentioning the task group *802.11e* (attempting to enhance the MAC with QoS features to support voice and video over 802.11 networks), and the task group *802.11g* that is working to develop a higher speed extension to the *802.11b*. The IEEE 802.11 standard defines two operational modes for WLANs: infrastructure-based and infrastructure-less or ad hoc (IEEE 802.11, WLAN). Network interface cards can be set to work in either of these modes but not in both simultaneously. Infrastructure mode resembles cellular infrastructure-based networks. It is the mode commonly used to construct the so-called Wi-Fi hotspots, i.e., to provide wireless access to the Internet. In the ad hoc mode, any station that is within the transmission range of any other, after a synchronization phase, can start communicating (Cali, Conti and Gregori, 2000).

Issues with MANET

Although, MANET is recommended as a reliable network in disaster areas, and regardless of its other attractive applications, the features of MANET introduce several challenges that should be resolved. These include routing protocol, security and power consumption.

Since the topology of the network is constantly changing, the issue of routing packets between any pair of nodes becomes a challenging task. Most protocols should be based on reactive routing instead of proactive. Multicast routing is another challenge because the multicast tree is no longer static due to the random movement of nodes within the network. Routes between nodes may potentially contain multiple hops, which is more complex than the single hop communication. A routing protocol that is dynamic and easily adapts to the constant changing of the topology of the network is needed (Murthy and Garcia-Luna-Aceves, 1996). Instead of assuming a uniform traffic distribution within the network and maintaining routing between all nodes at all times, the routing algorithm should adapt to the traffic pattern on a demand or need basis. If this is done intelligently, it can utilize network energy and bandwidth resources more efficiently, at the cost of increased route discovery delay (Gupta and Kumar, 2000).

In addition to the common vulnerabilities of wireless connection, an ad hoc network has its particular security problems due to for example, the nasty neighbor relaying packets. The feature of distributed operation requires different schemes of authentication and key management. Wireless link characteristics introduce other security problems, because of the limited wireless transmission range, the broadcast nature of the wireless medium (e.g. hidden terminal problem), mobility-induced packet losses, and data transmission errors (Jung and Vaidya, 2002).

MANET could experience energy constrained operation because batteries carried by each mobile node have limited power supply, processing power is limited, which in turn limits services and applications that can be supported by each node (Kravets and Krishnan, 1998). This becomes a bigger issue in mobile ad hoc networks because, as each node is acting as both an end system and a router at the same time, additional energy is required to forward packets from other nodes. For most of the light-weight mobile terminals, the communication-related functions should be optimized for lean power consumption (Das, Castaneda and Yan, 2000). Conservation of power and power-aware routing must be taken into consideration.

Conclusion

Mobile Ad hoc Network can be used in emergency/rescue operations for disaster relief efforts, e.g. in fire, flood, or earthquake. Emergency rescue operations take place where non-existing or damaged communications infrastructure and rapid deployment of a communication network is needed. Information is relayed from one rescue team member to another over a small handheld device.

Most of the times, disaster don't announce themselves and people are usually caught unaware, the establishment of infrastructure communication network will almost be impossible especially in remote areas where one had never existed, therefore, MANET offers the best approach to the solution in terms of communications and the importance of communications during a disaster cannot be over emphasized.

This paper has provided a comprehensive overview of a network that is reliable for, and recommended to be used in disaster areas,

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