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Implementation of a rapidly deployable, mobile communications system prototype for disadvantaged environments

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Abstract

Large-scale natural disasters present complex challenges for disaster relief communications. Fixed infrastructures, such as cell towers or radio base stations, may be completely destroyed during a disaster or this infrastructure may never have existed. In a disaster situation, having unreliable communications systems can put a relief personnel's safety at risk as well as make the effort much less effective. Furthermore, emergency situations require time-sensitive communications that could mean the difference between life and death. The communications system described in this paper provides a rapidly deployable, data-centric mobile communications system for all organizations engaged in disaster relief: first responders, search-and-rescue, emergency medical and health services, etc. Utilizing the IEEE 802.11b/g standard, this system creates a mobile wireless local area network through a series of "wearable routers". The routers provide local Wi-Fi access to all users within of their respective ranges, and then all of these routers are connected to each other through an ultra-high-frequency backhaul network. Ultimately, from the user's perspective the network appears to be a standard Wi-Fi network with enhanced range. The purpose of this network is to provide communications between both local and widespread users until more traditional communications systems are restored. A proof-of-concept prototype using commercial-off-the-shelf components has been realized, and the real-world performance of the system has been characterized in Boston, MA and Pittsburgh, PA. The results show that this system provides a viable solution, but requires further attention to antenna design and in-band interference.

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1. Introduction

As a niche market for communications technology, public safety includes organizations whose purpose is to enforce laws, respond and assist in natural disasters, manage large events, provide medical assistance, and perform many other functions. The various public-safety organizations across the world can be characterized into seven main groups: border security, emergency crisis, emergency medical and health services (EMHS), environmental protection, firefighting, law enforcement, and search and rescue. Together, these seven categories of public safety provide an essential public service operating at national, state, and local levels of governmental and nongovernmental organizations. These organizations operate in every environment—warm or cold, rural or urban, indoor or outdoor, dangerous or safe. This communications market sector drives some of the most demanding requirements for voice, data connectivity, messaging, push-to-talk, and security services [1].

The public-safety market is described as a niche market because it has different requirements and functions than both the commercial and military telecommunications markets. Commercial markets operate on the concept of economies of scale. Commercial devices, such as cell phones and WiFi routers, are produced and sold at such large volumes that application specific integrated circuits (ASICs), which incur large engineering non-recurring costs, become relatively inexpensive per device.

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Commercial telecommunications devices also have less stringent requirements on encryption/security and quality of service (QoS). The military telecommunications market is opposite to the commercial market in that it uses substantially larger budgets funded by governments to buy relatively smaller quantities of telecommunications equipment. As a result, the cost per communications terminal is very high, but this is justified generally by the more stringent technical requirements on reliability, anti-jamming waveforms (e.g., frequency hopping), and complex encryption/security [1].

Unfortunately, the public-safety market cannot benefit from the commercial market's economies of scale because of the lack of demand. Consumer radios and networks generally do not meet the performance requirements needed by first responders, making this equipment ill-suited for the public safety market. From a security and reliability standpoint, the public-safety market has similar requirements as military radios. Unfortunately, public-safety budgets are significantly smaller than military budgets and, thus, organizations cannot afford the high cost per communications terminal. As a result, this niche market is subjected to maintaining expensive technology many generations behind its commercial counterpart. Depending on the criticality of the situation and the availability of the primary infrastructures, sometimes commercial equipment is still used despite not meeting all of the performance requirements [1].

Depending on their current operational scenario, first responders have relied on many different technologies. In the United States, these technologies include Project 25 (APCO-25) [2] standard radios, satellite networks, avionic and marine communications, commercial cellular networks, and wireless local area networks (WLANs). The focus of the work presented in this paper is to create a rapidly deployable WLAN that is complementary with the current APCO-25 and cellular networks based on fixed base station networks. Providing public-safety personnel with broadband data-centric communications will provide new opportunities for the public-safety market. Broadband data rates provide multimedia messaging of pictures and video. With the aid of global positioning system (GPS) receivers, real-time positioning data of each user can be sent throughout broadband networks for better operational management. A command center can push annotated maps of targeted areas to users for more efficient operation. Unlike voice communications, text communications over a reliable network do not degrade by the surrounding background noise. The purpose of the network described in the following sections is to quickly provide data-centric communications in emergency situations before more traditional networks have been (re-)established.

2. ALIX-based Prototype

2.1. Purpose

The purpose of the prototype described in this section was to leverage commercial-off-the-shelf (COTS) hardware and open-source software to create a solution that could bridge a smartphone 2.4-GHz Wi-Fi radio to an ultra-high frequency (UHF) backhaul network at a much lower cost than the previously-developed non-COTS-based in-house prototype [3]. From the user's point of view, the network should look like an ordinary 802.11b/g access point—all frequency translation should be seamless and invisible to the user. The overall network architecture is a dual-frequency-band network with a client network and a backhaul network. The client network is an 802.11b/g network that interfaces between the user's mobile phone and the wearable router. The wearable router then does processing to forward this data over the UHF backhaul network. The wearable routers (i.e., nodes in the UHF network) communicate through what is notionally called a "repeater" that will receive and retransmit incoming signals to boost the range of the network.

2.2. Hardware

Each node is comprised of five major hardware elements: the system-on-a-chip (SoC) router board (PC Engines [4] ALIX.3D2), the 2.4-GHz IEEE 802.11b/g [5] transceiver module (Xagyl [6] XC24M), the UHF 802.11b/g transceiver module (Xagyl XC420M), battery (Energizer [7] XP18000A), and two antennas (Linx Technologies [8] ANT-2.4-CW-RCT-SS-ND and ANT-433CW-HWR-SMA) required for transmitting on the 2.4-GHz and UHF frequency bands. For all nodes except the UHF access point (AP), a user communicates with the node via their 802.11b/g radio in their cell phone (or other Wi-Fi enabled device). The 2.4-GHz 802.11b/g radio on the node demodulates this signal and passes it to the SoC router board to be processed and routed to the 802.11b/g UHF radio to be sent out to the UHF AP and then across the network. The UHF AP node also has both 2.4-GHz and UHF radios. The UHF radio communicates to all of the other nodes. The 2.4-GHz radio is not intended to be connected by ordinary users; it is included for debugging only. Figure 1 shows the assembled hardware of one wearable router.