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Disaster management and mitigation: the telecommunications infrastructure

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Among the most typical consequences of disasters is the near or complete collapse of terrestrial telecommunications infrastructures (especially the distribution network—the 'last mile') and their concomitant unavailability to the rescuers and the higher echelons of mitigation teams. Even when such damage does not take place, the communications overload/congestion resulting from significantly elevated traffic generated by affected residents can be highly disturbing. The paper proposes innovative remedies to the telecommunications difficulties in disaster struck regions. The offered solutions are network-centric operations-capable, and can be employed in management of disasters of any magnitude (local to national or international). Their implementation provide ground rescue teams (such as law enforcement, firemen, healthcare personnel, civilian authorities) with tactical connectivity among themselves, and, through the Next Generation Network backbone, ensure the essential bidirectional free flow of information and distribution of Actionable Knowledge among ground units, command/control centres, and civilian and military agencies participating in the rescue effort.

Keywords: disaster management, network-centricity, Network Enabled Capability, Next Generation Network, mobile and satellite telecommunications

Introduction

Population growth, urbanisation, industrial expansion and the development of complex ground and air transportation systems greatly enhance the risk of major disasters caused by human activity. The ancient threats of floods, earthquakes and hurricanes today cause considerably greater damage than they did only a century ago (O'Brien et al., 2006; Winchester, 2006). Moreover, many major natural disasters directly or indirectly affect the entire nation or even the entire globe (O'Brien et al., 2006; Walter, 2005). While the management of each disaster, no matter how large, may be considered as a series of contiguous, closely interlinked local operations, national and international consequence mitigation requires coordination of a large number of national and international agencies with vastly different profiles, cultures, political (and religious) backgrounds, and operational philosophies (Bui et al., 1999; Burkle, 2001; De Ville de Goyet, 1995; von Lubitz and Wickramasinghe, 2006a and 2006b). Moreover, the issues involved are exceedingly complex, and often reside outside the generally accepted definition of disaster relief.

The intricacy of problems within the broad spectrum of large scale disaster management, the need for their timely solution, and the wealth of knowledge required

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to address a wide range of often conflicting demands presented by the environment of mega-disasters, demand improved means of information and knowledge extraction from the existing historical sources. Facilitation of communication within the disaster-struck area and with the external national and international agencies involved in consequence management constitutes a critical problem, along with the ability to provide timely and relevant information and guidance to the affected population (Barker and Maxwell, 1995; Bui et al., 2000; Ei Sun Oh, 2003; Folts, 2002; Shibata et al., 2003).

In order to execute the required tasks at a time when the need for reliable information/knowledge is critical, the involved Information/Knowledge Management (I/KM) organisations must be both competent and capable of rapid synthesis and dissemination of Actionable Knowledge (see von Lubitz et al., 2007), and also be able to generate such knowledge under extreme stress caused by the chaotic and unpredictable character of the operational environment. Moreover, the I/KM nodes (von Lubitz and Wickramasinghe, 2006a) must be supported by a disaster-resilient telecommunications infrastructure that is used for dissemination and exchange of operationally relevant inputs from outside and within the disaster area. To address these problems, we have proposed in our previous papers (von Lubitz and Wickramasinghe, 2006a and 2006b) implementation of network-centric-type operations (NCO) as the principal component of mega-disaster management. We have also suggested that, rather than implementing the concept of network-centric operations developed by the US defence establishment, the Network Enabled Capability (NEC) approach is more suitable for adaptation to joint civilian/military applications (von Lubitz et al., in press).

Practical implementation of NEC addresses some of the fundamental issues of disaster management: determination of operationally critical elements, coordination of rescue teams and their activities during and immediately after the critical event, and the tactically appropriate allocation of resources based on real time information obtained from the disaster area. Currently, much of such information is derived from often incomplete and sketchy voice communications, which result in a partial understanding of the ground situation and consequent operational and tactical errors. The problem of inadequate information acquisition/exchange among the rescuing units/agencies is aggravated by the almost inevitable collapse of the disaster non-resilient telecommunications platforms (see, for example, Amin, 2002; Baker et al., 2004; Bodson and Harris, 1992; Little, 2002).

The continuing prevalence of non-resilient systems is among the most serious obstacles in complex emergencies and large-scale disaster management operations (Burkle, 1999; Cooper and Block, 2006; Tang et al., 2006), and, as evidenced by recent mega-disasters (for example, Cooper and Block, 2006; Dengler and Preuss, 2003; Durrani et al., 2005), the development of telecommunication capability that guarantees multimodal data transmission (voice, data, imagery, videos) under severely non-optimal conditions (when the traditional telecommunications networks or part of them are unavailable due to damage or congestion) is of paramount importance.

The required system must ensure uncompromising quality of bidirectional communications, provide operational flexibility, require minimal operating and maintenance expertise, and, finally, be readily deployable. The present paper describes such system based on Commercially-Off-the-Shelf (COTS) components, and which, due to its scalability, can be fielded in any environment characterised by compromised telecommunications.

Next Generation Network

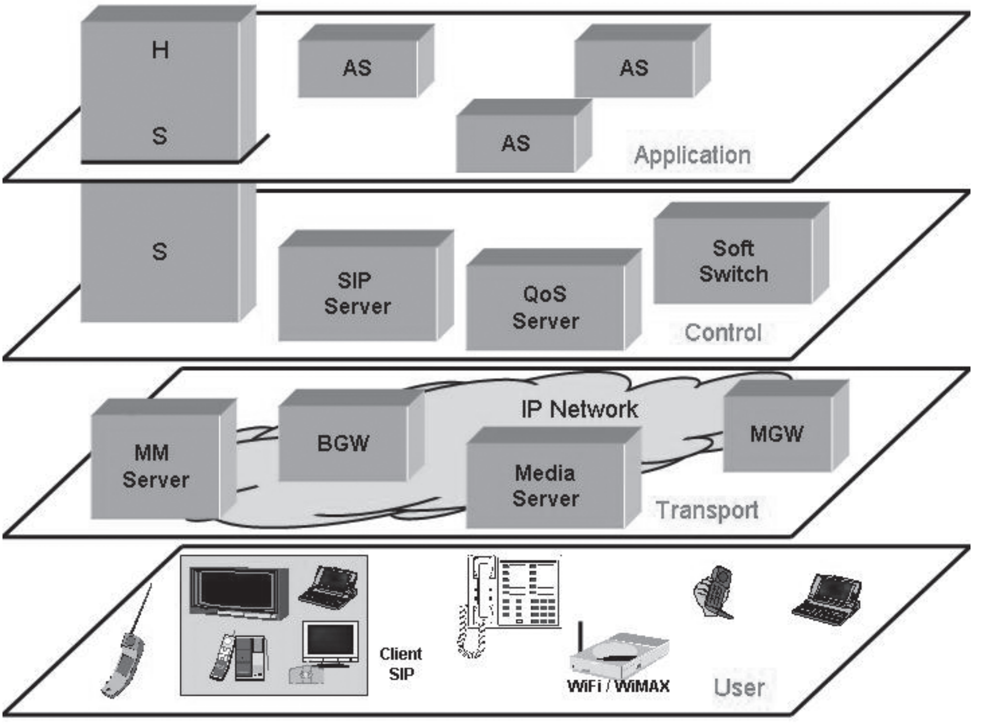
The convergence of telephone services is based on the functional separation of three main components: information transmission, service logic, and content definition that can be provided by a unique actor or by different actors. The concept of Next Generation Network (NGN) evolved from the convergence of voice services, traditionally served through circuit switched networks, and the data services, traditionally provided through packet switched networks. The transformation resulted in an infrastructure, based on the IP protocol, that is capable of providing combined multimedia, voice and data services (triple-play—Voice + Data + Video). Thus, NGN (De Nitto et al., 2004; Znaty and Dauphin, 2005) is not an additional and highly unique network but rather a functional conglomeration of different, interoperating networks existing under the umbrella of roaming agreements (fixed-fixed, fixed-mobile, mobile-mobile) that permits mobility of the user (*roaming*) and of user-associated services (*nomadism*).

NGN capabilities encompass a number of operational and technical characteristics such as client self definition of services, plug and play networking technology, and reduction in Capital (CAPEX) and Operational (OPEX) Expenditures (for example, Akhgar et al., 2006). Consequently, NGN is probably the best candidate to realise the telecommunications backbone connecting (in a fully federated, network-centric approach) the broadest variety of current platform-centric components through an end-to-end, multi-service, multi-access, secure, reliable and fully IPv6 worldwide network (von Lubitz et al., 2007).

From an architectural point of view, one of the main characteristics of the NGN is the sharp separation of the network functionalities from service functionalities, which makes services independent of the underlying technologies, and accessible through different networks. In fact, the goal of NGN is to provide the capabilities that enable creation, deployment and management of all kinds of services, a task that demands decoupling of service creation/deployment infrastructure from the transport infrastructure.

The layered generic architecture of an NGN (De Nitto et al., 2004; see also Figure 1) is composed of four layers: user/access, transport, control and application/service. All constituent functionalities (such as quality of service, robustness and fault tolerance, reliability and availability, data protection and integrity, security and confidentiality) typically needed by networked applications can be implemented (when not provided as a default) directly in the services built end-to-end on top of the Application Servers (AS) of the NGN.

Figure 1 NGN layered architecture



The *Application Layer* (von Lubitz et al., in press; Znaty and Dauphin, 2005) hosts the service logics and guarantees their efficient execution on dedicated AS. The *Control Layer* provides functionalities related to the management of session, billing, user profiling, traffic shaping, service policies and other features. The *Transport Layer,* through specialised Gateways (GW) and Servers, interconnects the control entities, the control segment with the applications segment, and the User Equipment with the network. Finally, the *User Layer* is composed of the User Equipment to access the offered services, considered an integral part of the multimedia network. The Information Level (HSS) collects all the data necessary for the management and provision of services towards the client and therefore the broadband user's profile, the subscribed services, and the respective service profiles.

Satellite access point

Despite the fact that different categories of disasters (such as earthquake, flooding, terrorist event) lead to different consequences, most disasters have many common elements. Probably the most typical of these commonalities is the collapse of terrestrial telecommunications infrastructure, particularly the 'last mile' connectivity. Even when the destruction is only partial, network overload/congestion caused by the vastly increased residential in- and outbound traffic has a deleterious effect on operational communications. The post-disaster telecommunications difficulties are not restricted to wired/fixed networks but affect the wireless ones just as intensely: after a short radio path, wireless communication systems eventually connect to a ground segment through an access point. Nonetheless, wireless technology is probably the only modality offering the chance for a relatively rapid post-disaster reconstruction of at least an embryonic version of a functional and capable telecommunications infrastructure (Uchida et al., 2004; von Lubitz et al., in press).

In practical terms, the reconstruction of functional post-disaster telecommunications architecture requires initial establishment of full connectivity among all field elements and their associated equipment, followed by a link to the NGN backbone which, in turn, provides connectivity to the rest of the world (systems, data/information/knowledge, people, organisation). COTS Geosynchronous Earth Orbit (GEO) satellite-based triple-play solutions are already available at very affordable prices, and can be rapidly transported (even by helicopter when roads are not usable) and easily deployed by rescue and/or emergency teams (Youst and Mazzei, 1998).

As an example of fully mobile field telecommunications systems (Tarabochia 2005), the MOBSAT Satellite Access Point (SAP) depicted in Figure 2, which can be hauled by a car or carried by helicopter, provides connectivity and multimedia services to Wireless-Fidelity (Wi-Fi) users located in its coverage area. The users are identified/authenticated, and then authorised to access the resources provided by the system. The Wi-Fi Local Area Network (LAN), the WiMAX (Worldwide Interoperability

Figure 2 The MOBSAT Access Point providing Wireless LAN IP connectivity to a GEO satellite

Photos: Courtesy of BIP Italia di Tarabochia Marcello.

for Microwave Access) Access Point and a suitable Cisco 2507 Router contained in the two 19-inch internal racks provide 30 Voice over Internet Protocol (VoIP) telephone/Fax full-duplex channels, Internet Access Point (POP) and peer-to-peer (P2P) link, broadband ADSL (Asymmetric Digital Subscriber Line) for e-mail, file transfer and videoconferencing services, audio and television signals (both DVB-S and MPEG4 streaming) handling, remote control for data acquisition and monitoring, interfaces to Digital Enhanced Cordless Telecommunication (DECT), discrete radio relay links, two-way radio, and copper or fibre-optic cable (such as Ethernet, E1). Moreover, through an intelligent controller, Global Positioning System (GPS), and magnetometer and inclinometer devices, the Ku band (Φ 1.2 m) self-pointing antenna is able to point and track a satellite, and to maintain both up- and download communications. All equipment interfaces with the system by using Session Initiation Protocol (SIP)—that is, the protocol adopted by NGN standard for the User Equipment (UE) segment. MOBSAT has a full power autonomy (12 hours) through its set of internal batteries and its on-board gasoline powered generator, which can also be used to feed (12–24 V DC and 220–380 V AC) auxiliary external equipments.

Due to its characteristics (ease of use/transportation/deployment, capacity, autonomy, reliability, low management and maintenance costs, and configuration flexibility) a typical MOBSAT unit adequately satisfies the essential telecommunications needs encountered during disaster containment and consequence management operations. Among the most important aspects of MOBSAT is its inherent capability for collation and interagency distribution of the relevant traffic that, under the commonly encountered circumstances, continues to be conducted using unit/agency specific platforms and distribution networks (for example, disparate frequency radios, agency-specific wireless and fixed LANs: see Cooper and Block, 2006; Hutchinson, 2005; NIST, 2004). Hence, the use of MOBSAT technology permits enhanced coordination of emergency healthcare, civil protection and law enforcement, transmission of public-relevant news and information, and remote control and data acquisition

Figure 3 MOBSAT coverage area and satellite connection to NGN

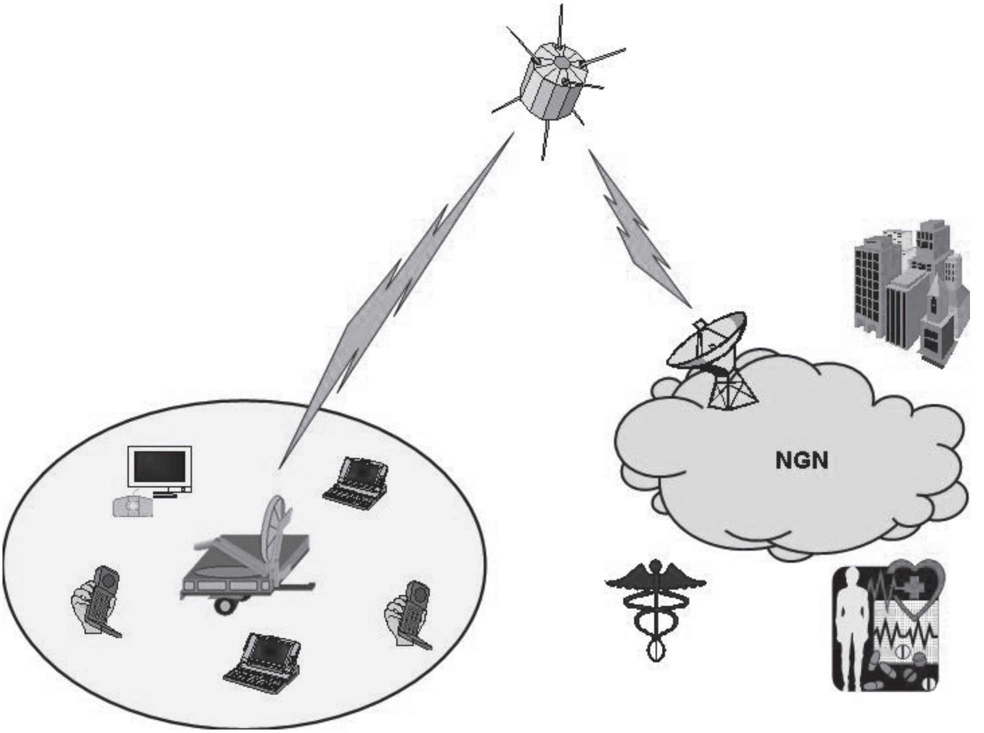
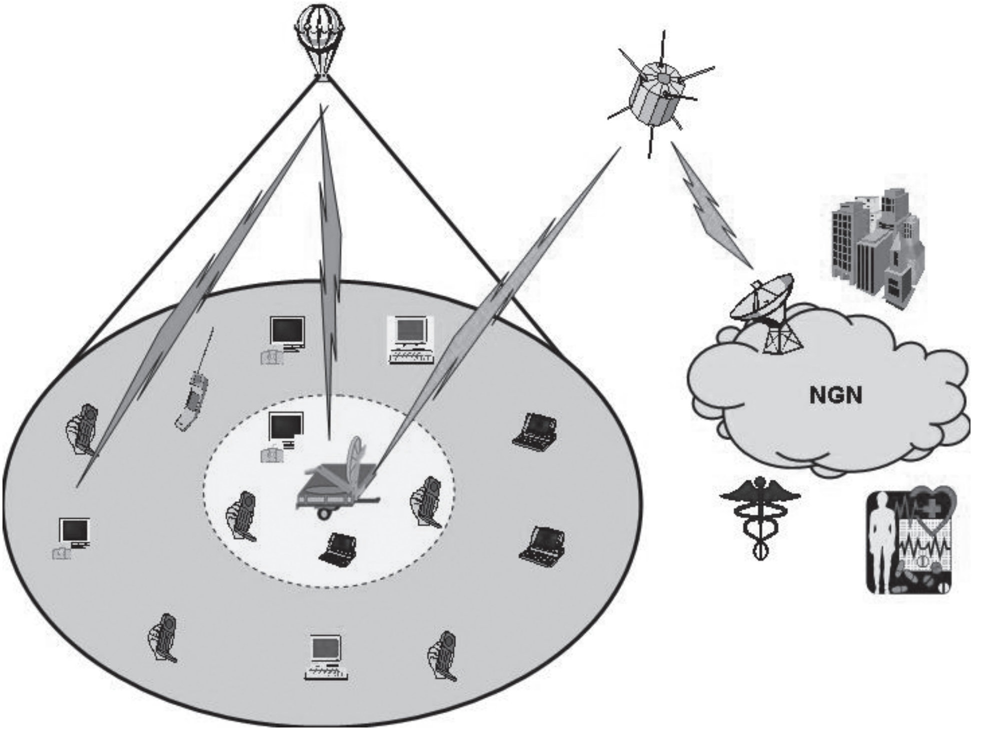


Figure 4 Ground Anchored Balloon carrying a WiMAX repeater to provide MOBSAT medium-size coverage

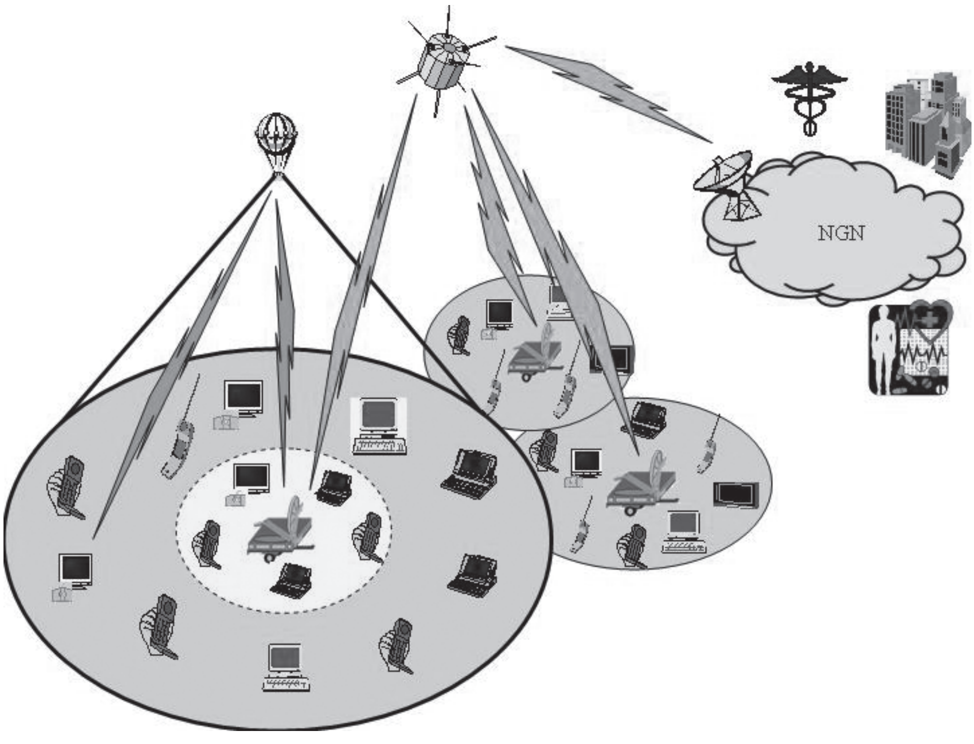


(monitoring, Supervisory Control And Data Acquisition, known as SCADA). Studies are currently under progress to interface MOBSAT (in roaming mode) with Global System for Mobile Communications (GSM) and Universal Mobile Telecommunications System (UMTS) micro-cells (Tarabochia, 2005).

The main advantage of GEO satellite based technology relates directly to the very large coverage area that is made possible. Since the footprint ('illuminated' ground area) of a single GEO satellite is around 15,000 km diameter, only three GEO satellites (plus two for the polar areas) are enough to provide transmission area coverage of the entire planet; therefore the architecture reported in this section can be easily deployed anywhere since an up/down GEO satellite link *already exists* at *any* location on the planet where the proposed system could conceivably be deployed (Knouse and Castruccio, 1981; Patricelli, 1998a). The area covered by a single MOBSAT is, on the other hand, a circle with the radius of approximately 1 km (Figure 3) although, when needed, the coverage can be enlarged up to 8–10 km by using system-provided WiMAX repeaters/relays that can be placed on top of hills, buildings located around the field, or on-board special air vehicles such as a helicopter or a ground anchored balloon (Figure 4).

In the case of a disaster involving a larger area, where a higher number of network resources (such as communication channels, computing and routing capability) are needed, it is also possible to deploy several MOBSATs (Figure 5), each one serving

Figure 5 Three MOBSAT Access Points (one with dedicated air vehicles) configured to provide larger coverage

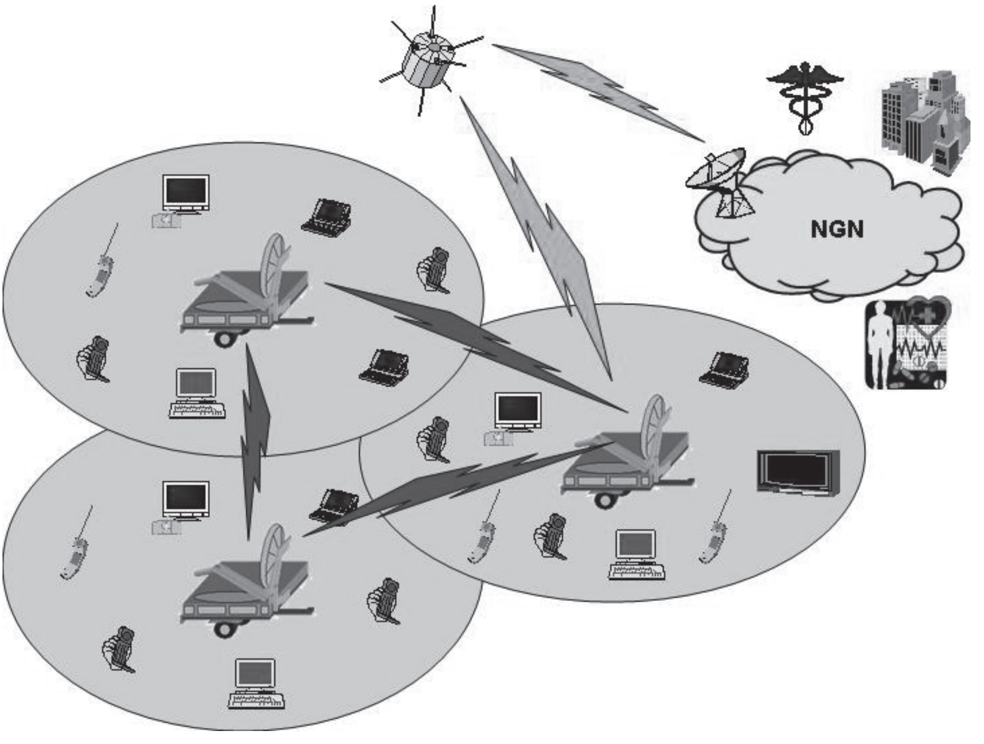


(through its dedicated air vehicle) a specific area, and autonomously connected to the NGN through its own satellite up/down link(s).

As convenient as GEO satellite-based architecture may be, it is also associated with undeniable drawbacks: due to its distance from the earth (approximately 36,000 km), not only is high power needed to feed the antennas (approximately 70 decibel of signal attenuation has to be overcome), but there are also delays in communications (one to two seconds round-trip). Moreover, the low throughput compares poorly with that commonly provided by the terrestrial networks (Patricelli, 1998b). In order to mitigate these shortcomings, the MOBSAT Wireless LANs can be bridged to other telecommunications architectures (Tarabochia, 2005), as, for instance, in a configuration that meshes wireless network topology (Figure 6). In the latter case, local communications (which typically handle 70 per cent of the whole traffic) are routed internally while only the external ones are distributed via the satellite up/down links to the NGN backbone, which, in turn, provides connectivity with the outside world (systems, data/information/knowledge, people, organisations).

A fully-meshed architecture allows several MOBSATs to connect in a P2P mode to each other through only a single satellite loop, thereby keeping the overall delay of local communications to less than 300 ms (as in a fixed network). Moreover, in situations where high signal fading (signal attenuation due, for instance, to heavy

Figure 6 Three MOBSATs Access Points (without dedicated air vehicle) bridged in a full-meshed architecture



rain) occurs in the area served by a SAP, link robustness/reliability/availability can be provided by automatic switching of the satellite connection (up/down links) to another SAP belonging to the meshed infrastructure.

The drawbacks of GEO satellite-based solutions can also be overcome by the direct use of an alternative transponder installed, for example, in an airborne vehicle instead of a satellite. The same approach (or as an addition to the satellite-based one) would be the solution of choice when higher link robustness/redundancy are needed. Finally, although not yet provided by MOBSAT Satellite Access Point technology, one may envisage the development of additional functionalities such as embryonic roaming voice capability among the different covered areas similar to that commonly provided by cellular radio-mobile systems (GSM/GPRS, UMTS).

Once the distribution network (last mile) has been rebuilt by using one of the proposed architectures, it is the responsibility of the application platform's pre-emptive scheduling policies (implemented on top of the application layer of the NGN) to allow the incoming high-priority traffic to take precedence over the low-priority traffic. The precedence scheduling is the final step that assures the availability of correct and reliable (from both content and quality points of view) information (obtainable through correct and automated integration and interpretation from multiple trusted sources) at the ground-user level at the critical time of need.

Discussion

Fundamental requirements of disaster management include not only the operational command/control but also adequate coordination of the tactical deployment of rescue teams both during the event and during the immediate recovery period. All these tasks require access to precise, real time information from the ground teams to outside sources, combined with a rapid dissemination of reliable, tactically relevant information from outside sources and command centres to the ground units. It may seem obvious that, in similarity to the modern battlefield, disaster rescue/consequence mitigation operations demand reliable, robust and highly efficient communication among the deployed units. Yet many recent disasters and disaster management exercises have clearly demonstrated that the rescue efforts are greatly hampered by incompatibility of the telecommunications systems, disparate procedures followed by individual organisations involved in the proceedings, incompatibility of organisational cultures, and complex information flows, where the relevant data/information/knowledge do not reach ground operators directly. Instead, a 'filtering' process takes place—typically at the higher/executive levels of command and control—and the disseminated information is second hand, often inadequate, and at times entirely wrong (see, for example, Cooper and Block, 2006).

To alleviate some of the problems centring on inadequacy or inaccuracy of the information disseminated within the operational environment of disaster management activities, we have proposed the implementation of Network Enabled Capabilities (NEC). NEC (and its closely related but more complex and expensive Network-Centric Operations, NCO) are based on free flow and exchange of information within the complex, multilayered network that provides ready, unconstrained access to the relevant data/information/knowledge (von Lubitz et al., in press; von Lubitz and Wickramasinghe, 2006a and 2006b). We have also suggested that NEC-based operations are closely coupled to effective, operations-oriented Information/Knowledge Management entities (I/KM nodes of the network), which will facilitate extraction, organisation, compilation and dissemination of Actionable Knowledge (von Lubitz et al., in press). However, if network-centric principles are to have a meaningful applicability, particularly in environments where the usual telecommunications platforms are either disrupted or overloaded with traffic that is operationally irrelevant, new approaches are needed that will substitute for the disabled infrastructure. The substituting equipment must be characterised by a number of critical functionalities:

- it must be simple in use and require minimal field maintenance;
- it must be operational by personnel who are unskilled in advanced telecommunications;
- it must be rugged enough to permit all-weather, rapid tactical ground/vertical deployment by means of non-specialised, locally available means (such as light haul trucks/light lift helicopters);
- it must be multimedia (data/voice/video) capable;
- it must be capable of sustaining heavy, bi-directional, multi-channel traffic (high bandwidth capability and bandwidth redundancy).

Compared to other solutions based on fixed stations, the architecture proposed in the present paper not only satisfies all the required criteria, but also permits quick restoration of the damaged distribution network to its pre-disaster capacity. It is also more flexible, lighter, easier to deploy and cheaper; in its smallest configuration, a MOBSAT unit hauled by a common car and eventually a balloon are all that is needed.

Some of the problems and their solutions discussed in this paper attracted prior attention in the context of healthcare. The issue is just as urgent there as it is in disaster management, particularly as the two fields often merge (see, for example, BMJ Editorial, 1994; Garshnek and Burkle, 1998; Garshnek and Burkle, 1999; von Lubitz et al., 2002). The novelty of ideas presented in the paper centres on the integration of a wide range of equipment and systems—which, in their currently used form, are cumbersome and not easily managed by non-expert people—into a single, flexible unifying platform endowed with physical mobility and ease of operations. It is a frustrating yet common fact that during emergencies the telecommunications systems of different rescue teams fail the test of interoperability not because of defects or primitive technology but because the *used technologies are entirely incompatible* or because *operators are inadequately trained in their use*. A host of other problems—such as transportation difficulties, equipment power feeds and/or failures, lack of adequate environmental ruggedness—also play a significant role. Hence, there is undeniably an urgent need for a highly integrated and flexible system, whose acquisition and use are cost-limited, and which is easily deployable, capable of withstanding the rigours of the disaster environment, and, very importantly, can be operated by anyone (without needs of training or licensing). The present paper describes such a system. Satellite telecommunication buggies and trailers already exist but, typically, for military applications only. None have the level of integration and operation provided by the proposed solution.

Most importantly, however, the efficiency and effectiveness of our proposed approach has already been tested, both in operations and in simulations, in the adverse winter environment of the 2006 Winter Olympic Games in Turin and during the Italian Civil Protection Agency Service exercises simulating a catastrophic eruption of Vesuvius.

During Turin's Winter Olympic Games in 2006, the MOBSAT was used by the Region of Piemonte's Civil Protection to monitor (live) the most important events: acquisition of real time images (webcam) and connection by satellite link of the Civil Protection's operational room with all the operators located in the Games' area. In addition to the Wi-Fi distribution around the MOBSAT station, allowing access to the network through laptop computer, a Tetra wireless telephone repeater provided voice channels in areas not covered by the service (such as alpine ski fields and some of the athletic sports venues). Adverse weather conditions (snow and very low temperatures) that affected a number of events during the games did not jeopardise either the satellite connection or the effectiveness of the services requiring connectivity provided by the MOBSAT.

MOBSAT's use proved equally important during the simulation of a calamitous seismic event in Naples in 2006. Operationally, the unit was employed using the same principles as those tested during the Olympic Games in Turin earlier in the year. The MOBSAT station allowed the connection of the Civil Protection's operational room with the operational scene utilising the full range of multimedia and telephone internet connections, and operating in complete autonomy (power supply and control) from public networks. The towing capability of the unit allowed it to be moved with extreme ease on both motorways and secondary roads, while the easy and fast set-up of the station reduced deployment time to a matter of minutes—as opposed to several hours, as required when traditional methods of connectivity re-establishment are used (requiring hard wiring, antenna deployment, and so on).

As described above, telecommunications traffic generated by catastrophic events or crisis situations (such as civil unrest or preventive evacuations) overloads both the networks and the local telecommunications infrastructure in a way that is, typically, outside the realm of normal forecasting. Even more importantly, the aspect of this communications traffic that has previously been *entirely overlooked* is the *inward* flow—that is, the reverse of the ordinary conditions. There is a need in these situations for a sudden capacity to handle telecommunications from the periphery to the centre (for acquiring data, images, reports and other information), but until now this need has been overlooked. Even under normal operational conditions, networks are geared toward distribution rather than collection and integration of the incoming flow. Practical field experiments have shown that MOBSAT and similar military units can handle high intensity, high volume, bi-directional traffic in full autonomy from any outside support, providing a stable platform for the acquisition of data from the disaster site, and transport of information and knowledge from the operational rooms and decision-making centres to the ground units. The independence of these units makes them particularly suitable for deployment in NEC-governed operational environments (von Lubitz et al., in press).

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