Interfacing Satellite Systems and Ad hoc Networks for Emergency Applications

Michele Luglio, Cristiano Monti, Antonio Saitto and Michael Segal

Abstract— **Mobile ad hoc networks (MANETs) are characterized by their intrinsic capability to be set up without needing any kind of infrastructure, allowing a high degree of flexibility both at technological level and at application and service level. For this reason they are particularly useful in environment where no fixed network infrastructure is available. For example, they are well suitable for emergency application, when fixed telecommunication infrastructures, whereas present, can be seriously damaged or destroyed.**

Satellite networks also work without terrestrial infrastructure, excluding one gateway localized inside the footprint, and are easy to be set up too. For the same reasons also satellites can be fruitfully be utilized in case of emergency.

Nevertheless, these two technologies are not in competition, as they might appear, but absolutely complementary. In fact, ad hoc mobile networks are characterized by very small terminals, low consumption, limited capacity per user terminals and, most important, they can work in a very limited coverage range. On the contrary, satellite systems work with medium/large dimension, medium/high power user terminals and very wide coverage areas. Moreover, the MANET are very suitable to work also in indoor environments while the satellite systems can not work in NLOS (no line of sight) environments.

In the frame of the Savion project it is investigated how to set up an integrated system composed of a satellite segment and a MANET in which each segment plays a complementary role with respect to the other aiming to improve the degree of service.

Starting from the state of art of both systems, after having introduced target applications and services of the integrated system, this paper presents the main achievements of the project in terms of network design, focusing in particular on the main issues concerning the development of the interface between the MANET and satellite systems.

Keywords: MANET, emergency, satellite, interoperability

I. Introduction

EMERGENCY operations, due to natural and antropic causes, in remote or disastrous areas require fast deployment of communications capabilities, keeping communications of voice and data, within each rescue team (among all team members) and among the teams all the time and have a full command and control communication system.

Very often the deployment of a physical infrastructure is quite hard, the need for a full mesh network is impracticable due to the requirement of the line of view, while the interface of the local network to the remote command and control center is difficult to be set up.

Many ad hoc networks architectures designed and proposed in the recent past two years have two major drawbacks limiting their uses for emergency rescue teams: the former is the difficulty of using a data network for voice, which is the key communications resource during emergency operations, the latter is a low efficiency of the connectivity protocols, mostly due to IP- architecture, which is not optimized for the radio communication channel.

In addition the link to the remote center may be often unreliable for many reasons due to security and possible outages, consequence of the disastrous event.

The proposed solution is based on to two basic concepts.

- A new "ad-hoc network" architecture, called SAVION, which uses a dedicated protocol for allowing a full meshed configuration, optimized for voice (peer to peer and common channel), but allowing data and images communication, communications via self-configured relay terminals to overcome the lack of the line of view.
- An easy interface with two types of satellite terminals:
  - o Narrowband mobile terminal (GSM-satellite) to allow communications for team members far away from any other gateway access;
  - o Broadband terminal, (based on the use of a standard Ethernet interface) very small and light, easy to transport and install for those cases, where a base camp is available.

This architecture has been proposed to fire fighters, medical emergency units, police and others, to be tested on the field and a real operational scenarios.

The paper presents in section II the reference scenario, in section III the interoperability between a MANET and a satellite system describing the two components and then possible solutions and technologies. Then in section IV the most important achievements of the Savion project in terms of system architecture and relevant technical choices. Finally, in section V conclusions are drawn.

II. Reference Scenario

The reference scenario concerns a team or several teams

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each composed of approximately ten units deployed in a potentially wide area. For example in case of fire up to one hundred firefighters, divided in small teams, can be involved around the wood area or a building with some team inside and some outside. In case of search and rescue different teams can be deployed to search in different directions.

In these scenarios, the primary requirement in most of disaster relief and search and rescue activities is to exploit voice and data communication among multiple rescue teams deployed in remote or disaster area, providing the capability also among all of the team members at any time and having a full command and control communication system from remote site. Thus, the main service requirement in the described communication scenario is to allow full mesh data and voice oriented communications.

The mentioned service requirements can be met utilizing a wireless ad–hoc network with access to existing satellite communication equipment network for command and control at a very low cost and high reliability.

The ad hoc wireless network communication system enhances capabilities of existing radio links. The network is based on one side on a small sized and light Generic Radio Controller (GRC), that can be integrated with any handheld, Analog or Digital, radio device, and on the other side on the capability of simple and scalable connection (narrow and broad band) to a robust and reliable satellite interface to the control center, based on a mobile satellite or VSAT terminal.

The system is oriented to both SAR and Governmental applications. As concerns Search and Rescue, the involved organizations worldwide demand Mission-Asset-Management in real-time in remote locations where critical data, and data updates are available. The solution allows mission-assets such as a VSAT terminal to be shared among team members seamlessly. For Governmental applications the current tactical radio market is going through a shift. While most governmental tactical radio manufacturers, are focused on the future digital radio development, there are currently millions of tactical radios which need an upgrade to bring data and voice communication capabilities to the single soldier in the platoon. Digitized, and networked communications for the single soldier, as well as digitizing human intelligence at the single soldier level, are listed as top-priorities by governmental organizations world-wide.

III. INTEROPERABILITY BETWEEN MANET AND SATELLITE

A. MANET

A mobile ad-hoc network (MANET) is a auto-configuring network of mobile nodes connected by wireless links, the union of which form an arbitrary topology. No fixed infrastructure is needed. The nodes are free to move randomly and organize themselves arbitrarily; thus, the network's wireless topology may change rapidly and unpredictably. Such a network can operate in a standalone fashion, or may be connected to the larger Internet. Minimal configuration and quick deployment make ad hoc networks suitable for emergency situations like natural or human-induced disasters, military conflicts, emergency medical situations etc.

Wireless mobile networks are characterized by several constraints, such as bandwidth, latency, delay, power and mobility. These constraints make it difficult for the system software to provide guaranteed QoS at levels required by many distributed and collaborative applications [1][2][3]. Further, mobility adds a new dimension to the distributed computing paradigm which has implications for specification, design, verification, and implementation of both system and application software [4]. A challenging issue is to determine the interface and the guarantees that system software can efficiently provide to developers of both location-independent and location-dependent applications on mobile networks [1][5][6].

In wireless networks, cluster based schemes have been proposed which segregate the network into manageable sets for routing maintenance, location management, and facility location. The general approach for segregate the network into manageable sets for routing maintenance is to build a sub-graph whose "leaves" are called heads with any two heads being not too far apart. In addition, we want to minimize the cost for connecting to the nearest head, that is, to minimize the sum of the distances from the nodes that do not belong to the backbone to the heads. In other words, a possible solution can be building a backbone tree then divide the non-graph nodes into clusters while the head functions as gateways to access the wired backbone for all its cluster nodes. At each cluster, a spanning tree rooted at the head is used for message delivery, where the tree internal nodes serve as relays for the benefit of the distinct stations. It should be pointed out that the standard approach up today was in minimizing the number of backbone nodes following the idea that a small number of backbone node may lead to better guaranteed QoS in transmitting voice or data in such networks. However, this is not always true. For example, if one is expected a large number of underlying changes in the network topology, it is conceivable to assume that our computed small backbone will fail with a high probability and became unconnected. In order to overcome this difficult in this work applied a new approach that aimed in backbone formation and its size depending on network and nodes' conditions, thus, not necessarily trying to be minimal in terms of size.

Another issue needed to be specifically addressed is a clock synchronization mechanism. The frequent temporary network partitions in sparse ad hoc networks are serious problem for classical clock synchronization algorithms which rely on two important assumptions: the ability to periodically exchange messages between nodes that have to be synchronized and the ability to estimate the time it takes for a message to travel between two nodes to be synchronized. The influence of the clock drift on the quality of synchronization may dominate over the influence of the message delays. This is the case in those ad-hoc networks where communication is sporadic not only in the sense of unpredictable, but also in the sense of infrequent. Using time stamp generation of local clocks and correlation sequences led to fast clock synchronization scheme.

As an immediate consequence of such both such constructions, our network was able to obtain extremely efficient routing algorithm satisfying high QoS requirements and constraints.

B. Satellite

The satellite systems are characterized by the capability to cover very large areas and to ensure long haul connection and long range mobility even in impervious areas such as mountain, woods, deserts, open sea where terrestrial infrastructures cannot be set up. Moreover, a satellite network can be easily and quickly set up once the space segment is available. Last but not least, satellite communications are very robust with respect to natural disasters or terrorist attack not needing any terrestrial infrastructure and can ensure a very high degree of business continuity due to the very high reliability of electronics components (both on board the satellite and on ground) that in addition are even redundant.

In this view, the satellite segment is in charge to interconnect different groups of ah hoc network terminals among one another or to guarantee access to terrestrial fixed networks in order to reach remote locations such as the headquarter. To reach this goal three kinds of connectivity can be envisaged:

- narrowband link for voice and very low data rate services,
- medium capacity links for small sources aggregated traffic,
- broadband link for high data rate exchange.

Narrowband link (up to 10 kbit/s) can be guaranteed utilizing lo data rate systems such as Globalstar, Iridium, Thuraya or Aces. These systems offer GSM like service, i.e. voice and very low data rate connectivity, through either a Low Earth Orbit constellation (the first two) or a geostationary satellite. In this respect, the kind of visibility is different and must be evaluated as a function of the environment.

Medium capacity links can be ensured with last generation Inmarsat portable systems (GAN, R-GAN and BGAN) or Globalstar enhanced modem. The former, based on geostationary satellite, offer up to 144 kbit/s or 512 kbit/s data communication with standard interface and protocols (Ethernet, Bluetooth, USB). The latter consists of eight basic modems multiplexed to reach up to 64 kbit/s able to work in Packet Data mode, establishing an IP session through an IP address assignment to the modem (statically or dynamically depending on the application), which can send Traffic Data using protocols determined by the application (TCP or UDP or FTP, etc.) [8].

Broadband connectivity can be ensured utilizing commercial satellite systems at Ku or Ka band with DVB RCS (or DVB RCS like) standard, VSAT proprietary standard or SCPC links. In DVB-RCS the forward link (from hub to RCSTs) air interface is compliant with DVB-S achieving a maximum data rate (layer 2) of 38 Mbit/s. In the return link (from RCSTs to hub), the MF-TDMA discipline is adopted and the RCST can transmit typically at a rate up to 2 Mbit/s using a QPSK modulation [9]. In both links compliancy with IP interface is guaranteed. VSAT proprietary standards can guarantee up to 10 Mbit/s capacity adopting full mesh topology, thus minimizing RTT.

Trade off comparison between mobility, transportability and capacity requirements in operational scenarios must be carried out.

C. Interface

The interface between the ad hoc network and the satellite system must be in charge to process both data and voice signals. The interface can be implemented at IP layer, implying that the digital voice signal must be packetized as data signal in compliance to IP standard. An IP gateway as shown in figure 1 can meet the requirement.

In that case, the Mobile Unit is assumed to utilize the standard pin (MIC and Speaker) to forward the digital voice signal to the IP Gateway. The Gateway is in charge to adapt the voice signal to IP protocol and is interfaced with the broadband satellite modem through an Ethernet Port. In order to send the data via satellite link, the mobile terminal utilizes a RS-232 Port connected directly to the RS-232 Port of the satellite modem, as shown in Figure 1. Alternatively, through the RS-232 port of the IP Gateway, it is possible to transport also the data signals on IP.

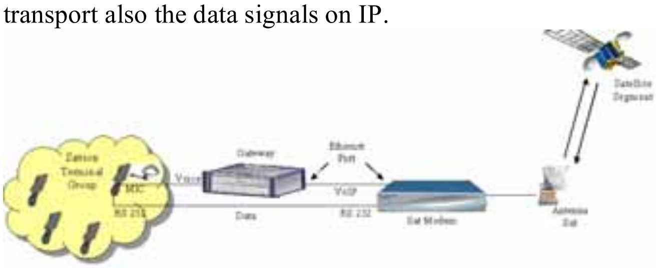

Figure 1: Physical interface between MANETS and a broadband satellite system

As concerns the narrowband solution, the satellite terminal is required to have both RS232 and MIC standard interfaces available to directly connect the terminal of the terrestrial ad hoc network, as shown in Figure 2.

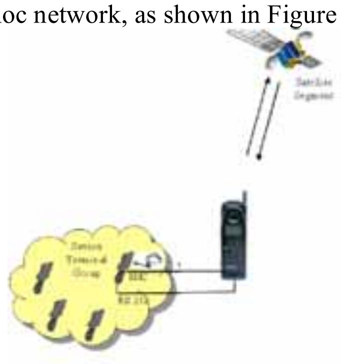

Figure 2: Physical interface between MANETS and Globalstar satellite system

IV. THE SAVION PROJECT

A. Requirements

In this project volunteer fire brigades of Trento (northern Italy) have been involved to define requirements and test the final system. On the basis of their expressed needs, requirements have been classified in terms of network coverage area, network virtual infrastructure, service and network communication capabilities.

To evaluate coverage requirements, we considered the path loss over the channel given by the following model [7]:

$$L(d) = L_{OneSlope}(d) + M_w = l_0 + 10\gamma \log(d) + M_w$$

where l_0 is the path loss at 1 m distance, γ is the power decay index or the path loss exponent, d is the distance between the transmitter and the receiver, M_w takes into account the features of the propagation environment (i.e. presence of walls, doors, trees, etc.).

Assuming that the users are uniformly distributed in a bi-dimensional plane three different classes of distance with respect to the features of the operational area have been considered:

- Class 1 (outdoor areas without obstacles) with maximum distance ~150 m;
- Class 2 (outdoor areas with few obstacles) with maximum distance ~ 80 m;
- Class 3 (indoor areas with many obstacles) with maximum distance ~ 10 m;

As far as the network virtual infrastructure is concerned it must be self-consistent and will not rely on static or designated infrastructure of any kind. The network should dynamically update itself according to rapid changes in the network topology.

The service requirements are:

- radio communications, in the satellite segment from 1 to 8 voice channel for narrow band and more than 8 for wide band;
- database access (of the station for data research, dangerous substances or telephonic numbers or other), small chunks in narrow band satellite segment while no problem for those to wide band;
- images transfer to the station about the event situation: images not real-time in narrow band satellite segment while in those to wide band is possible to have moving images real-time;
- survey of position of operators with personal code;
- download of maps with the route of covered areas; very slow in narrow band satellite segment;
- transmitting operator health monitoring data;
- telephony.

Communication capabilities must be compliant with service requirements, that means to allow data rates from a few kbit/s for voice channels up to some Mbit/s for image and video transfer or aggregate traffic from several users.

B. Overall system architecture

The system is composed of two main segments: the ad hoc network and the satellite network (see Figure 3). Furthermore, the main components are:

- Terrestrial segment
- Satellite segment
- IP Gateway

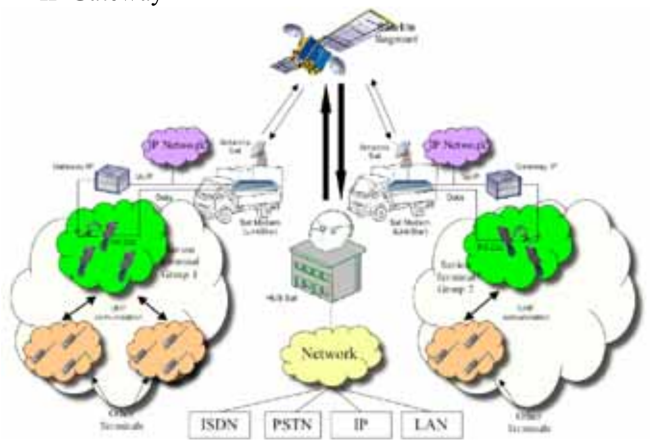

Figure 3: System architecture

1) Terrestrial segment

The MANET that was selected allows to have dynamic topology, self organizing, and self-healing (with less than 1 second network set-up time). The mobile unit works on the 2.4 GHz spread spectrum band and uses standard short distance transceiver with an advanced algorithm and voice compression system. The system is capable of receiving and transmitting data and voice up to 1 mile. Due to the system's mesh networking capabilities, it operates in very harsh environments and conditions where regular radio transmission fails. Parallel, and simultaneous Voice and Data communications are also allowed.

Savion MANET is also able to connect to different kinds of end units, using different standard interface as RS232, USB, MIC and Speaker pin.

Moreover the mobile unit can allow up to 100 users, uniformly spread over an area of 2 km^2 (outdoor), to be interconnected all on the same frequency, allowing extreme bandwidth efficiency. The limit of the number of users is given by the delay occurring in each hop. This requirement is very strong in time sensitive applications like the voice communications. The communication channel can support both data (asynchronous) and voice (synchronous) communications with a total bandwidth of 1 Mbit/s.

The unit can work as stand-alone with voice and data capabilities (based on smart RF networking system) or connected to another radio device. The Generic Radio Control unit allows to remotely access the network and select parameters (channel selection, volume, frequency, broadcast or addressed communication selection & full priority selection ability).

Two typical operation modes can occur: Unit Network Discovery or Request of Transmission. In the former case after a group of units have been activated, the network takes at most 5 seconds to be ready for any type of communication. In the latter case any transmission request will be forwarded with a Push-To-Talk mode (for voice) and data user interface (for data) implying a communication activation request. This request will command the network to create a communication path for the connection type requested (like Broadcast, P2P, grouping etc). The network will handle and serve more than one voice/data request simultaneously.

Finally other features of the Savion unit are:

- Real-time performance, using the Mesh network topology,
- Low energy consumption,
- Low power transmissions (long working life),
- Connection with other radio devices,
- Wireless smart interface to hand/headsets PDA, GPS.

2) Satellite segment

At this stage of the project development two satellite segments have been identified to meet long haul communication and service requirements.

As concerns the narrowband link, Globalstar system has been selected to provide voice and very low data rate channels. The enhanced Globalstar modem can provide up to 64 kbit/s capacity to carry aggregate voice channels or allowing small image transfer. SAT600 terminal is equipped with MIC standard interface and with a car kit. The RS232 serial port can be utilized with DTA accessory to carry data traffic.

As concerns the broadband solution, the VIASAT Linkstar satellite modem in DVB RCS (or DVB RCS like) configuration has been selected. The Linkstar utilizes an Ethernet interface to transfer the VoIP and the data signals in the satellite segment.

Other solutions can be further investigated and traded off before the end of the project.

3) IP Gateway

The IP gateway is used to interface the MANET and the satellite system. It is able to convert over IP (internet protocol) format the data and voice from the Savion network. In this way, through the satellite system, it is possible to connect the network to another remote MANET, to a remote LAN or to interconnect users belonging to different networks.

C. Field Trials

An extensive field trials campaign is scheduled in the frame of the project.

The first test campaign regards the “road accident”. This test involves six operators each one equipped with a mobile terminal deployed up to 20 m apart. The truck, equipped with the VSAT satellite antenna, is near the team. All the operators of the team can communicate among them through the Savion MANET network. The size of images to transfer to the base station is 800 kBytes (photo of the accident). We can utilize the enhanced Globalstar channel, to send up to 2 images, or the linkstar for more than 2 pictures. If the size of video to transfer to the base station is 35 MBytes only the linkstar channel can be utilized. The test will last 30 minutes.

Another field trial refers to People Research involving 50 operators belonging to 8 different teams. The distance among operators will be about 10-15 m while the different teams are 30-50 meters apart. Each operator is equipped with a MANET unit and each team leader will have a Satellite G* Terminals. The truck, equipped with the VSAT satellite antenna, will be near at least one aid team.

All the operators of the same team can communicate among them. Each team leader can communicate with the base station utilizing narrowband satellite channel. The two teams can communicate between them through the satellite channel. File, image and video transfer on the radio link will be performed. In particular, in order to transfer data (about 200 kBytes) any satellite channel will be utilized while to transfer about 800 kBytes, the enhanced Globalstar channel can be utilized.

Finally, if the size of video to transfer to the base station is about 35 Mbytes, we will utilize only the wideband satellite channel.

V. CONCLUSIONS

At present a prototype of an innovative “ad hoc-network” has been implemented and performance have been verified in a reduced configuration.

The Interface with the two satellite terminals have been designed and implementation and tests are going to be run during the next 3 months. In addition to this interface the Savion network can be interfaced to a standard UHF radio for additional connectivity with and among different rescue teams. Full demonstration will be placed in the second half of the year.

Preliminary results have been very promising and the next phase will include demonstration with the substantial participation of the Fire Brigades of Trento in real operational situations.

REFERENCES

[1] Y. Ben-Shimol, A. Dvir and M. Segal, "SPLAST: A novel approach for multicasting in mobile ad hoc networks", 15th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, Barcelona, Spain, 5-8 September 2004, Vol. 2, pp. 1011–1015, 2004.

[2] V. Bharghavan, "Challenges and solutions to adaptive computing and seamless mobility over heterogeneous wireless networks", Journal Wireless Personal Communication: Special Issue on Mobile Wireless Networking, Vol. 2, pp. 217–256, 1997.

[3] B. D. Noble, M. Price and M. Satyanarayanan, "A programming interface for application-aware adaptation in mobile computing", Technical Report CMU-CS-95-119, School of Computer.

[4] S. K. S. Gupta and P. K. Srimani, "An adaptive protocol for reliable multicast in multi-hop radio networks", 2nd IEEE Workshop on Mobile Computing Systems and Applications, 25-26 February, 1999, New Orleans, Louisiana, USA, pp. 111–122.

[5] P. J. McCann and G. C. Roman, "Compositional programming abstractions for mobile computing", IEEE Transactions Software Engineering, Vol. 24, No. 2, pp. 97–110, 1998.

[6] E. Pagani and G. P. Rossi, "Reliable broadcast in mobile multi-hop packet networks", IEEE international conference on Mobile computing and networking, pp. 34–42, 1997.

[7] Andrea Borrelli, Franco Mazzenga, Cristiano Monti, Marco Vari, “Channel Models for IEEE 802.11b Indoor System Design”, Communications, 2004 IEEE International Conference on, Vol. 6, 20-24 June 2004, pp. 3701 – 3705.

[8] M. Luglio, G. Nicolai, L. Splendorini, F. Vatalaro, L. Zuliani, Combined use of Italsat and Globalstar for Monitoring and Disaster Recovery Purposes, 7th Ka Band Utilization Conference, Santa Margherita Ligure, Italy, September 26-28, 2001, pp. 77-84.
[9] ETSI, "Digital Video Broadcasting (DVB); Interaction Channel for Satellite Distribution Systems", EN 301 790, V1.3.1, 2003.