Internetworking and wireless ad hoc networks for emergency and disaster relief services

André Oliveira*

TEKEVER,
Rua das Musas 3.30, 1990-113 Lisboa, Portugal
Fax: +351-213-304-301
E-mail: andre.oliveira@tekever.com
*Corresponding author

Zhili Sun

Centre for Communication Systems Research,
University of Surrey,
Guildford, Surrey, GU2 7XH, UK
Fax: +44-483-68-6011
E-mail: z.sun@surrey.ac.uk

Philippe Boutry

ASTRIUM SAS,
31 Rue des Cosmonautes, Z.I. du Palays,
31402 Toulouse Cedex 4, France
E-mail: philippe.boutry@astrium.eads.net

Diego Gimenez

ISDEFE,
C/Beatriz Bobadilla 3, 28040 Madrid, Spain
E-mail: dgimenez@isdefe.es

Antonio Pietrabissa

Dipartimento di Informatica e Sistemistica (DIS),
Università di Roma 'La Sapienza',
Via Ariosto 25, 00185, Roma, Italy
E-mail: pietrabissa@dis.uniroma1.it

Katja Banovec Juros

Administration for Civil Protection and
Disaster Relief of the Republic of Slovenia,
Vojkova 61, 1000 Ljubljana, Slovenia
E-mail: Katja.Banovec.Juros@urszr.si

Abstract: The flexibility of mobile wireless ad hoc networks (MANET) and global coverage of satellite communications presented an ideal combination to provide emergency and disaster relief services. This paper presented the concept of a hybrid MANET-satellite network developed in the on optimising hybrid ad hoc and satellite networks (MONET) project funded within the EU 7th Framework Programme (FP7). It was considered to be a natural step of providing local and remote connectivity in a highly mobile, dynamic and often remote environment for emergency and disaster relief services, such as forest fire fight, mountain rescue and coast rescue. These composite networks raise significant challenges including: optimising network resources and link availability; providing quality of service (QoS) and quality of experience (QoE); minimising costs and maximising energy efficiency, taking into account its impact on both the MANET and satellite segments.

Keywords: ad hoc networking; satellite networks; hybrid networks; routing; optimisation; resource management; internetworking; mobile wireless ad hoc networks; MANET.

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Biographical notes: André Oliveira graduated in Aerospace Engineering from the Instituto Superior Técnico in 2002 and holds a post graduation from the International Space University in space systems analysis and design. He has worked at the European Space Agency in the area of smart structures and structural control as well as non-linear multi-body dynamics. He joined TEKEVER in 2005 where he is currently responsible for the aeronautics, space, defence and security team. He defines the company's strategy for these markets and is responsible for setting up and managing research projects in the domains of advanced communications, space systems and autonomous vehicles. He is the Project Manager for MONET. His research interests include satellite communications, space systems and UAV. He is the author of seven conference papers and one journal paper.

Zhili Sun is the Chair of Communication Networking at the Centre for Communication Systems Research (CCSR), University of Surrey, UK. He obtained his PhD in Computer Science from Lancaster University in 1991 and BSc in Mathematics from Nanjing University in 1982. He is one of the Principal Investigators and Technical Co-ordinators of the MONET project and other projects in satellite areas including ESPRIT BISANTE, VIP-TEN, EU FP GEOCAST, ICEBERGS, SatLife, and SATSIX. He has been the Principal Investigator of the projects funded by the UK Research Council, European Space Agency (ESA) and industries. He has published over 125 papers in international journals, book chapters and conferences, and book entitled *Satellite Networking – Principles and Protocols* (Wiley, 2005). He edited the book *IP Networking over Next Generation Satellite Systems* (Springer, 2008) and contributed to the 5th edition of *Satellite Communication Systems: Systems, Techniques and Technology* (Wiley, 2009). He has been a member of technical committees of international conferences.

Philippe Boutry graduated from Sup'areo (Ecole Nationale Supérieure de l'Aéronautique et de l'Espace). He belongs to the Telecom Systems Department of ASTRIUM Satellite which is recognised for its work on upcoming technologies both on the satellite segment and on the user access segment. He has 25 years of experience in satellite domains, encompassing telecommunication, observation and scientific missions. He was involved in several projects as Industrial Manager or Project Leader. He is currently in charge of the satellite telecommunication system business acquisition for security applications.

Diego Gimenez is an R&D Project Manager and Telecommunication Engineer at ETSI Telecomunicación de Málaga in 1998. From 1998 to 2000, he was a Consultant Engineer in ATRAN (to CRISA-ASTRIUM and TELEFONICA); and from 2001 to 2008, as a System Engineer. Since 2010, he is one of the coordinators in the MONET and PROSIMOS projects. In 2004, he received a medal of honour from the Ministry of Defence. During 2003 to 2008, he was a Professor in CESEDEN (High Studies Centre of the National Defence) in UAV and integration within C4I networks. He is a Leader of ISI (Integral SATCOM Initiative) Security Working Group from 2006 to 2008 and Head of eISI (Spanish ISI Platform) Security Working Group since 2006.

Antonio Pietrabissa graduated with a degree in Electronic Engineering and received his PhD in System Engineering from the University of Rome Sapienza in 2000 and 2004. Currently, he holds a Post Doc contract with the University of Rome Sapienza and a member of the Technical Committee of the Consortium for the Research in Automation and Telecommunication (CRAT). His research focus is on the application of control theory methodologies to communication networks, specifically to the design of admission control, congestion control and medium access control protocols for satellite, wireless and heterogeneous networks. He is the author of 15 journal papers and about 40 conference papers on these topics.

Katja Banovec Juroš graduated with a degree in Computer Science at the University of Ljubljana in 1992. In the first two years, she was working on the field of computer network design. At the Administration for Civil Protection and Disaster Relief of the Republic of Slovenia – Ministry of Defence, where she is employed from 1996, she began to work on the field of computer administration and development of specialised computer applications for emergency services. In 2008, she was a member of a group for the Slovene EU Council Presidency. In the last two years, she covers the area of the international cooperation in the field of informatics and communication at URSZR.

1 Introduction

There is great potential of mobile wireless ad hoc networks (MANET) for many different applications. The application of MANET to areas such as emergency rescue, environmental observation, scientific investigations, commercial environments, home and enterprise networking, educational applications, entertainment, military operations and location-aware services holds great promises. The automatic adaptation of the network topology to the field context provided by MANET, make these a great asset in providing local connectivity. However, these applications often happen in infrastructure-less or remote regions where remote connectivity to the outside world has to be provided by some other means.

Satellite is one of the solutions to provide the remote connectivity and sometimes the only option for the MANET to communicate with other parts of the world. Both fixed satellite services (FSS) and mobile satellite services (MSS) can be used to provide broadband connections to the internet, enabling the exchange of voice, data and video in the field, as well as the relay of control messages and service data from service centres to MANET. Currently, satellite is considered not only as a component of an alternative routing path but also as part of integrated networks. Convergence of satellite and terrestrial networks is becoming a key factor in forming the foundation for efficient global information infrastructures (Daoud, 2000; Sun, 2005; Fan et al., 2008; Maral and Bousqust, 2009).

On one hand, ad hoc networks are characterised by dynamic topologies, limited bandwidth, energy consumption constraints, limited physical security and distributed management. Some of the many problems include:

- routing information technique choice
- configuration and management
- limited bandwidth which means the network management slice must be minimised to enable maximum 'payload' data exchanges
- changeable links which means that link quality information is mandatory to properly operate radio communications
- hidden nodes which can lead to simultaneous broadcast by two unbeknownst nodes and thus collision
- energy meaning that battery autonomy is limited
- mobility and dynamic topology.

On the other hand, broadband communications via satellite are useful in many different scenarios, especially:

- when a terrestrial communication infrastructure is not available or not economical
- where the multicast/broadcast nature of the satellite system can be exploited (e.g., satellite TV broadcast)
- where the satellite networks are complementing or backhauling other, e.g., terrestrial networks.

Examples of the benefits of satellite include IP via satellite in regions with no access to terrestrial DSL, new architectures for near-video on demand, satellite networks integrated with WiFi, WiMAX, LTE or TETRA, or satellite networks backhauling collectively mobile networks in ships, trains, or airplanes.

The MONET concept of internetworking satellite and MANET networks is therefore a natural evolution to provide local and remote connectivity in a highly mobile, dynamic and often remote environment, as represented in Figures 1, 2 and 3.

Figure 1 Forest fire fighting

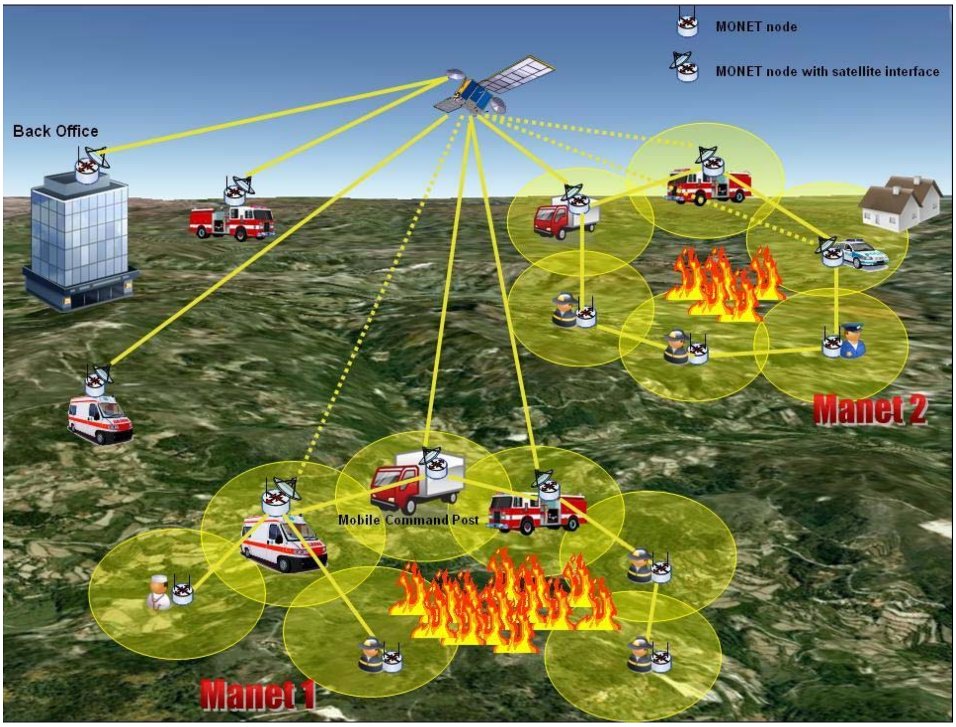


Figure 2 Mountain rescue

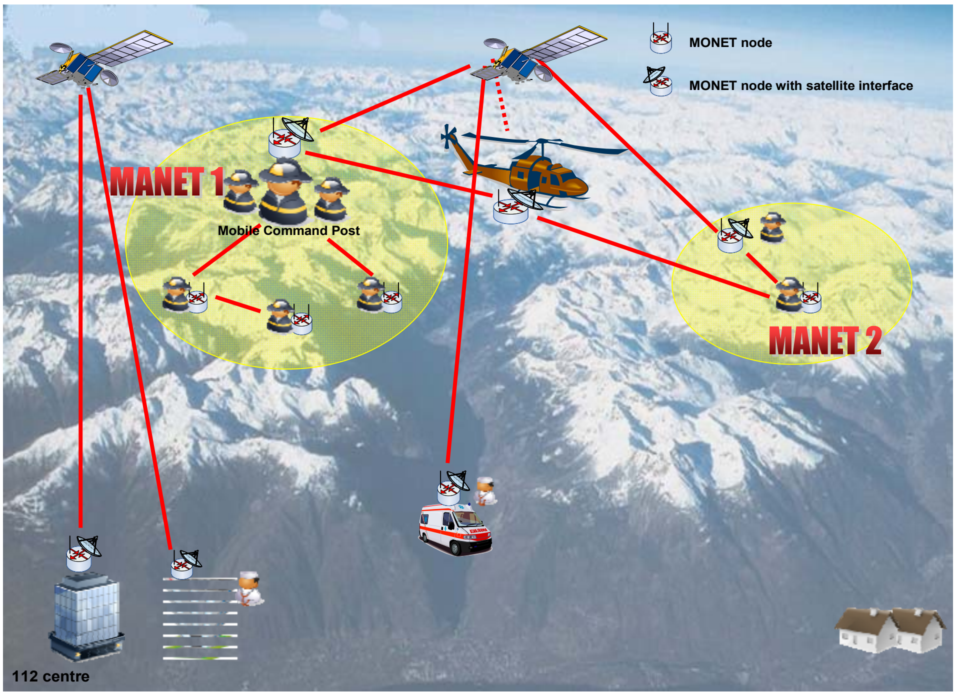
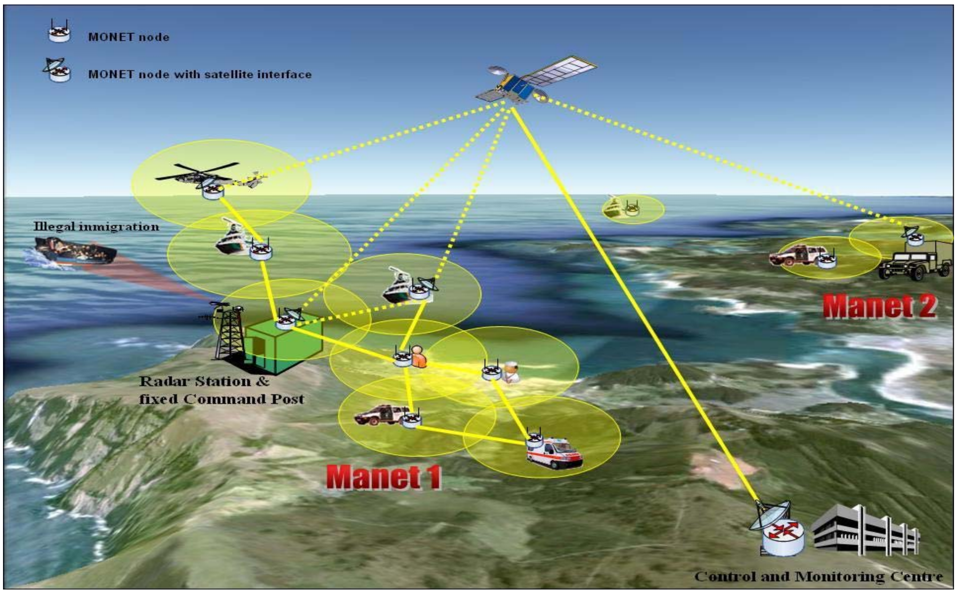


Figure 3 Coast line border control



This combination raises, nonetheless, significant challenges in terms of optimising network resources, link availability, providing quality of service (QoS) and quality of experience (QoE) (the subjective measure of a customer's experiences with a service supplier) and minimising costs and energy (Daoud, 2000). Issues such as the re-organisation of MANET to connect to satellite access points, re-organisation of the satellite access points, selection of which satellite access points to use, the use of satellite as a relay between two MANET, the adjustment of routing in accordance with the current network situation and the exchange of cross layer information to improve resource management are some of the challenges which we feel require investigation. In fact, the identified issues were only partially investigated in past projects, and MONET will build its researches on the ground of the already achieved results, such as: reconfiguration, routing and energy efficiency developments in ad hoc networks (ADHOCSYS, 2004–2007); reconfiguration and interaction with relevant end-users in ad hoc networks (WIDENS, 2004–2006), integration of positioning information in communication protocols at MAC level (WHERE, 2008–2010); cross-layer optimisation and between WiMax and DVB-RCS satellite networks (SATSIX Project, 2005–2008); application scenarios (SatNEx, 2006–2009); progresses on deployment and cost-effectiveness (Verelst et al., 2007); and so on.

MONET will study these challenges, propose and develop solutions for the optimisation of a hybrid MANET-satellite network, implement a prototype of the most promising solutions and test them in the field, in near real-life conditions.

The paper is organised as the following: Section 2 highlights the objectives of the MONET project; Section 3 explains the methodology; Section 4 presents the current development; and finally Section 5 concludes the paper and points the direction for future research.

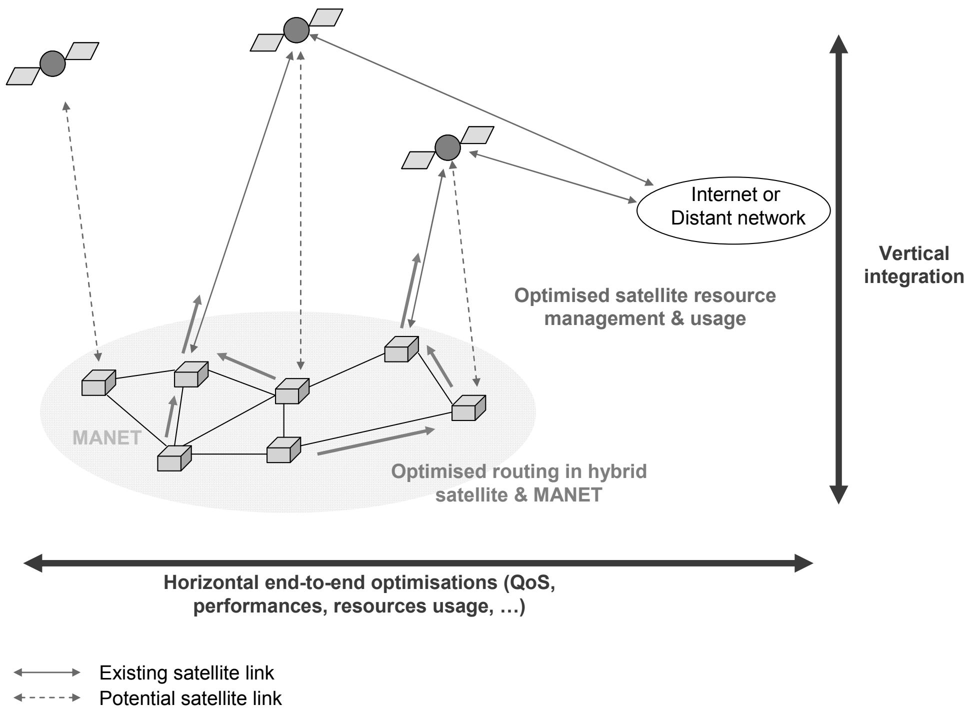
2 Objectives

The MONET project is based on the concept of internetworking of Hybrid MANET-satellite network as illustrated in Figure 4. It has the following objectives for research and development:

1. to develop a complete understanding of the problems and complexity underlying the highly dynamic and heterogeneous environment of a hybrid MANET-satellite network
2. to optimise the use of satellite access links in a MANET through mechanisms that propose and implement changes in topology and resources used
3. to provide seamless broadband services to everyone at any time in a hybrid MANET-satellite network thanks to optimised algorithms and network mechanisms
4. to overcome performance bottlenecks and roadblocks in hybrid MANET-satellite networks to enable a more pervasive and optimised network structure.

The MONET project will address these objectives in the contexts of emergency and disaster relief services and their requirements by researching, developing and validating solutions focusing on the link and network layers of the composite network. Finally, this research intends to test the feasibility of researched optimisations and proposed solutions in a scenario representative of a real life application.

Figure 4 Hybrid MANET-satellite network and MONET concept



3 Methodology

The understanding of such hybrid networks and associated challenges and potential is based on the selected scenarios as shown in Figures 1 to 3. This will be achieved through the study of these scenarios and development of a concept of operations for the network. In order to understand the complexity of these heterogeneous, dynamic and distributed environments, the MONET project will investigate protocol, functional and network architectures using complementary top-down and bottom-up approaches. The most promising investigated mechanisms and solutions will be developed, implemented and subsequently validated through a field exercise representing a real life application.

The stochastic movement of the nodes that form a mobile ad hoc network makes it likely that some partitions may occur in the wireless network without connectivity among them. Both geostationary/non-geostationary satellites can be envisaged as a 'range extension' network. As mentioned in Luglio (2007), the challenge of how to provide connectivity between nodes in the same ad hoc cluster; between nodes belonging to different ad hoc networks with the added possibility of nodes using different equipment or technologies is an important one. The MONET consortium proposes to address this through the investigation of mechanisms for the re-organisation of the MANET to connect to the access points on one hand, or the re-organisation of the access points themselves on the other hand.

Considering multiple satellite and fixed backbone links within a MANET, the issues of how to organise them, choose between them, provide a higher QoE, minimise communication costs, minimise energy consumption to ensure higher network life become important ones. Both of the issues mentioned above are closely related to routing (both unicast and multicast), or how to adjust it in accordance with the current network situation (network topology, link quality, node positions, etc.), the availability and characteristics of internet links (upstream/downstream, cost, etc.), and the network usage requirements (priority, QoS, speed, etc.)

Figures 5 represents self-organisation solution by selecting satellite access points either because one access point drops out of the MANET; or in case the transmitting node can choose from several to provide optimal connection. Figures 6 represent solution to keep the connectivity when the initial network is broken down into two MANETs.

There has been significant work done at the routing algorithms level (with solutions that face typical ad hoc networking difficulties and provide good performance). However, the inclusion of access point information, nodes positions and QoS mechanisms in the routing has not been fully explored. Providing location information may be useful in implementing advanced routing techniques, able to support QoS. Geographical routing protocols can make use of satellite positioning systems, like GPS and Galileo for the nodes to know their own location, so as to share it with the other nodes in the network (The Integral Satcom Initiative, 2006). The introduction of quality of service mechanisms according to the routing between various users and according to the constraints of each one, in particular in wireless ad hoc routing protocols (such as DSR, AODV, OLSR) has been identified as a challenge by the internet engineering task force (IETF).

Figure 5 Hybrid MANET-satellite network challenge: selecting satellite access points

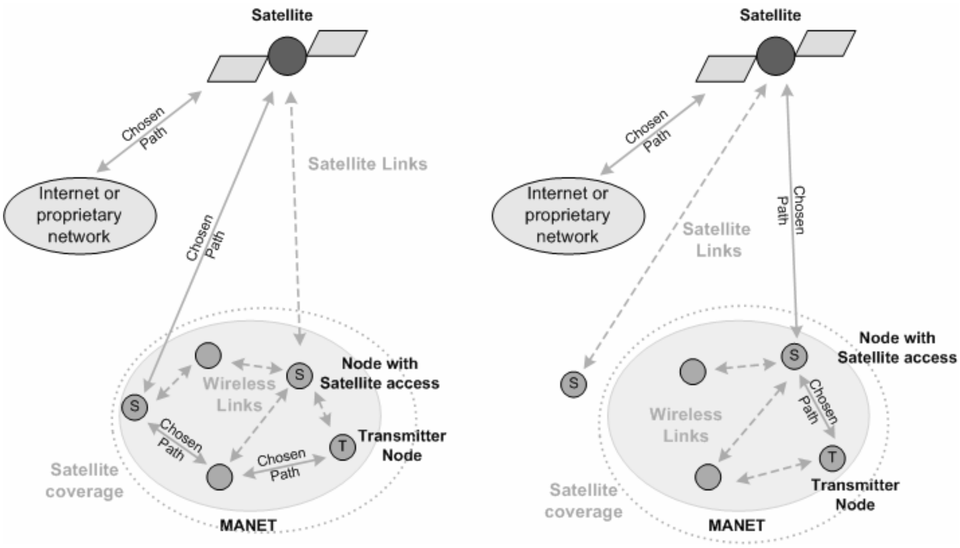
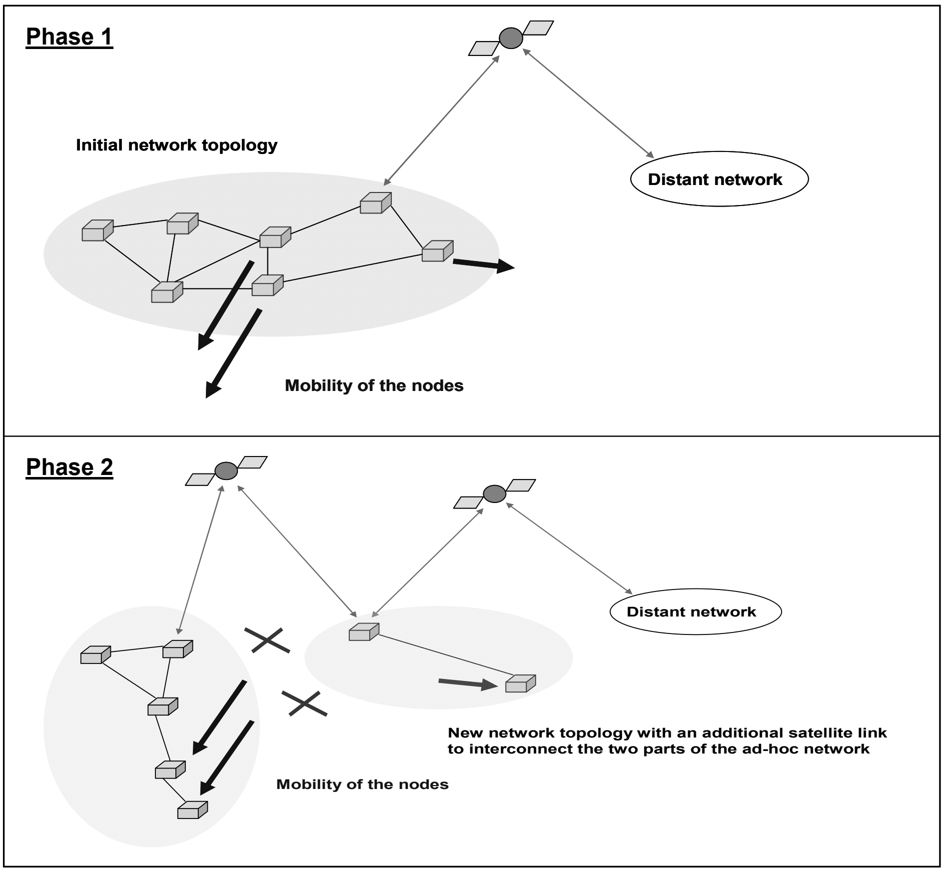


Figure 6 Hybrid MANET-satellite challenge: satellite as relay between two MANETs



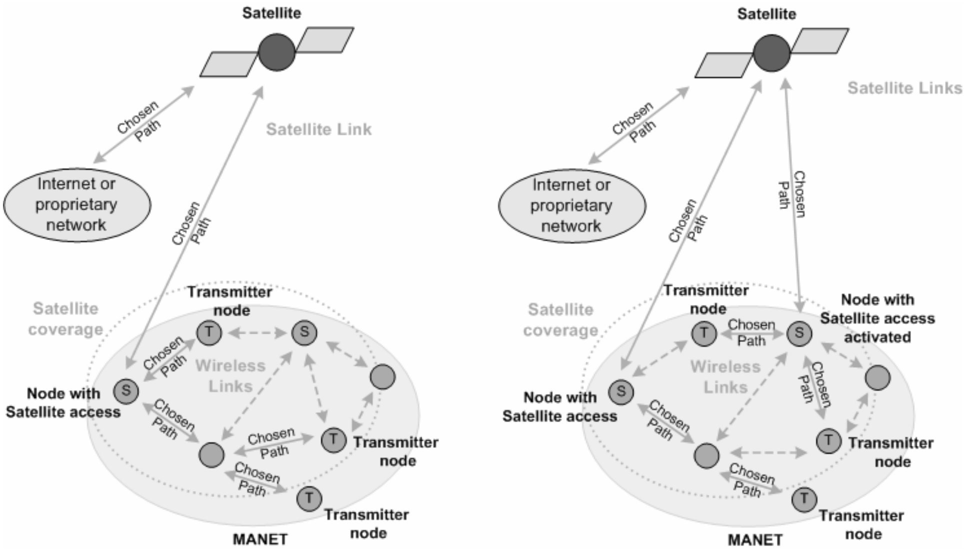
The complexity of network management will increase between the providers of network connectivity. This can be addressed through provision of substantial automation for achieving both network composition and cost efficient network operations. The autonomous functions should also operate on the network control layer, facilitating the negotiation of agreements between networks as well as their efficient verification and enforcement. Mechanisms for network management of a MANET that includes satellite links need investigation. Generally, ad hoc network node resources support network formation and management activities, in addition to data communication. The lack of infrastructure often dictates the uses of distributed network management. However, the use of the satellite access links may require a centralised management entity that manages the access points and their organisation and hand-over between them. Therefore, the investigation of centralised versus distributed or mixed network management and re-organisation as well as determination of decision mechanisms (manual or automatic) constitutes another challenge to address. Issues such as the connection/disconnection of satellite access points (e.g., to save energy or to increase throughput) as well as the choice of satellite access points (horizontal handover) are counted among the questions of interest as represented in Figure 7.

Applications can be significant differences in terms of services required which imply diverse impacts on the network organisation and usage of resources. Data services (such as file transfers, web services, email, etc.) impose low constraints on delay and latency but have high requirements in terms of reliability and integrity. Voice and video on the other hand, have serious requirements in terms of latency and delay (e.g., the high latencies associated with GEO satellites may hamper communications between emergency teams leading to misunderstandings or late reactions resulting in loss of property or life) but are relatively lax in terms of transmission errors (a few errors in the transmission will result in glitches in video or garbled speech) as the human brain has the power to fill in the gaps. Basically, video and voice require real-time exchanges to be useful. The provision of different services poses challenges in terms of QoS and QoE and the mechanisms that have to be used (such as prioritisation for example).

Other interesting issues include the impact of GEO versus LEO satellites on the composite network. The latencies of GEO satellites (approximately 240–270 milliseconds depending on the location of the satellite terminals) may raise difficulties in voice services under certain situations. The LEO delays of 30 milliseconds are in principle more amenable to the requirements of voice and video. The network must be able to perform trade-offs and choose the appropriate satellite service (if both GEO and LEO services are available) according to the desired service.

Finally, the issue of choosing optimisation parameters is in itself a challenge. A hybrid network such as the one proposed can be optimised in terms of operation and services costs, of energy consumption, of QoS, availability, etc. This issue is closely related to the application scenario and is strongly influenced by the application chosen. The MONET project will address the challenges described and propose solutions to solve them, and focus on solutions for the network and link (MAC) layers.

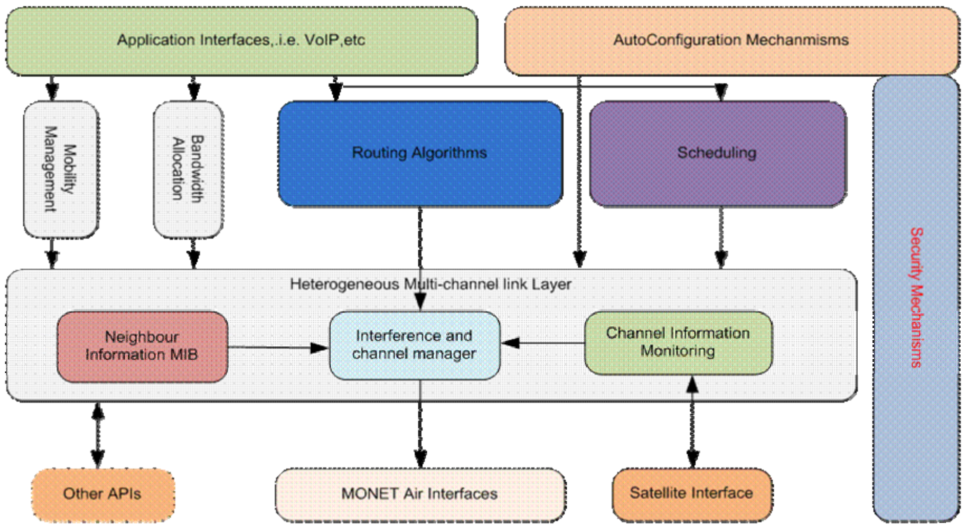
Figure 7 Hybrid MANET-satellite network challenge: resource management – automatic access point activation to increase throughput



4 Developments

The main development of the project will be focused on the network architecture and functions of the network nodes as show in Figure 8.

Figure 8 Network node architecture and functions



The MONET has developed the architecture to optimise the integration of satellite links in a MANET network. The complementary roles of the satellite segment and the wireless ad hoc network should enable the provision of high communication capability, broadband communication, reach back and interconnection of several ad hoc networks. The following are the main functions of the architecture:

- optimising the resource management and usage in the overall system. End-to-end optimised mechanisms are considered as well as local optimisation on each segment.
- taking into account the existing and potential satellite links in the routing decision, as well as other parameters like energy consumption, link quality, number of hops, etc.
- taking into account in the wireless network routing decision the specificities of the satellite segment
- managing the satellite resources in coherence with the MANET network topology and traffic. The first example is to demonstrate enable or disable satellite links in order to best fit the amount of transmitted traffic and reduce communication costs. The second example is to demonstrate the satellite as a way to maintain connectivity in the wireless network when two parts of the network cannot be connected due to distance or obstacles.
- enabling end-to-end (from the user point of view) QoS or management resources mechanisms
- providing broadband services through an integrated hybrid satellite-MANET network, seamlessly for the end-users.

Among these functions, optimising the network performance and routing will be the main focus of the project, since the system can only fully benefit from the satellite networks if the overall resources are efficiently utilised. The internetworking between the MANET and the satellite segment will be developed taking into consideration the specific characteristics of the satellite segment, such as on-demand dynamic bandwidth provision and connection initialisation. For the realisation of an intelligent routing procedure, several objectives must be pursued, such as load balancing (the traffic could be distributed among multiple link/technologies according to the congestion/delay/reliability of the candidate paths), energy-saving (to dynamically choose the most efficient technology/path), communications cost and fault-tolerance (automatic reconfiguration of the routing path in case of failure of one link/technology). The relevance of these objectives is also dependent on the characteristics of the service to be routed.

Additionally, depending on the application scenarios, specific services requirements must be guaranteed in terms of QoS, security and resiliency. To face this challenge, the project will develop a multi-objective optimisation framework incorporating QoS constraints, capable of providing tight and well-definite control of the routing decisions over the whole network. Notably, the optimisation algorithm will take decisions not only based on current network traffic and configuration, but also on traffic and network statistics (for instance on the availability of a given link or the availability of the satellite segment from an access point as well as satellite link service cost). In this way, the best routing decision will take into account also the probabilities that given paths will become unavailable or inadequate, and the algorithm will provide also the optimal re-routing strategy in case of link faults; thus, fast re-routing of critical communications can be achieved. To develop the described multi-objective fault-tolerant routing algorithm, different methodologies will be pursued. In one approach, a Markov decision process (MDP) framework will be developed; based on the MDP framework, more practical algorithms relying on approximate dynamic programming and/or reinforcement learning will be developed, evaluated and implemented. Other approaches will be investigated, such as modifications and adaptations to the IETF MANET routing protocols like AODV and OLSR to include all or some of the objectives mentioned above will also be investigated and implemented.

To optimise the overall network efficiency, the optimisation of the management of satellite bandwidth is a key task, due to satellite bandwidth cost and scarcity. Although widely studied and developed, there is no sound theoretical framework for satellite resource management procedures for next-generation systems provided with adaptive coding and modulation (ACM) (see SATSIX Project, 2005–2008). In this respect, MONET project will build up this theoretical framework by developing resource management procedures which are fully aware of ACM, thus fully exploiting the ACM potential of increasing satellite capacity and of lowering the terminal costs. MONET will implement the following resource management functions: bandwidth on demand, call control, and frame constitution.

5 Conclusions and further research

This paper presented the initial works of the EU FP7 MONET project. It highlighted the objective and operation scenarios of the internetworking satellite and ad hoc networks for emergency and disaster relief services. The accomplishment of the proposed objectives will bring noteworthy added value to specific application scenarios (some of them are well known as MANET applications), and potential benefit of the emergency and disaster relief services. To achieve these objectives, the MONET project has developed the integrated network architecture and functions based on the requirements of the emergency and disaster relief services as shown in the scenarios.

These benefits can be extended further to remote access and broadband to rural or remote areas (helping to bridge the digital divide; collaborative work and e-business; everyday operations of large field teams; health services and telemedicine); to provide on demand connectivity to airports and aircraft; as well as to emergency communications during/after disasters in scenarios of flood, earthquakes and coastal monitoring.

Further research has been planned to evaluate a wide set of economic benefits including: communications cost optimisation; cost efficient communications for remote or isolated areas; and enhancement of performance, efficiency and resilience for hybrid networks to exploit fully the benefit of internetworking of satellite and wireless ad hoc networks.

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References

ADHOCSYS (2004–2007) 'Internet access to people living in rural and mountainous areas', available at http://www.adhocsys.org/.

Daoud, F. (2000) 'Hybrid satellite/terrestrial networks integration', *Computer Networks*, Vol. 34, pp.781–797.

Fan, L., Cruickshank, H. and Sun, Z. (2008) *Ip Networking over Next-Generation Satellite Systems*, Springer.

Luglio, M., Monti, C., Roseti, C., Saitto, A. and Segal, M. (2007) 'Interworking between MANET and satellite systems for emergency applications', *International Journal of Satellite Communications and Networking*, Vol. 25, pp.551–558.

Maral, G. and Bousqust, M. (2009) *Satellite Communication Systems: Systems, Techniques and Technology*, 5th edition, Wiley.

Satellite Communications Network of Excellence (SatNEx) (2006–2009) available at http://www.satnex.org.

Satellite-based Communications Systems within IPv6 (SATSIX) Project (2005–2008) available at http://www.ist-satsix.org.

Sun, Z. (2005) *Satellite Networking: Principles and Protocols*, Wiley.

The Integral Satcom Initiative (2006), *ISI Strategic Research Agenda*, version 1.1, January.

Verelst, G., Zapata, M., Durin, B., Isoard, A. and Inigo P. (2007) 'TWISTER success stories and recommendations on hybrid satellite-wireless solutions for broadband coverage in rural an remote areas', presented at *BBEurope*.

Wireless Deployable Network System (WIDENS) (2004-2006) available at http://www.comlab.hut.fi/projects/WIDENS/.

Wireless hybrid enhanced mobile radio estimators (WHERE) (2008–2010) available at http://www.kn-s.dlr.de/where/.