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Showcase Paper

On Optimizing Hybrid Ad-hoc and Satellite Networks – the MONET Approach

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Abstract: The potential of Mobile wireless Ad hoc Networks (MANET) is significantly high. However, MANET 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 this and sometimes the only solution. Current expectations dictate that satellite will be seen not only as a component of an alternative routing path but also as part of a unique (really integrated) system.

The concept of a hybrid MANET-Satellite network is therefore a natural evolution of considering the problem of providing local and remote connectivity in a highly mobile, dynamic and often remote environment. These composite networks raise significant challenges such as: optimising network resources and link availability; providing Quality of Service (QoS) and Quality of Experience (QoE); minimizing costs and energy. The EC FP7 project MONET will address precisely these issues by considering the end-to-end optimization of resource management in a hybrid network, taking into account its impact on both the MANET and satellite segments.

Keywords: Ad-hoc networking, Satellite networks, Hybrid networks, optimization, routing, resource management.

1. Introduction

The potential of Mobile wireless Ad hoc Networks (MANET) is significantly high. 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 this remote connectivity and sometimes the only solution for the MANET to communicate with other parts of the world. Fixed Satellite Services (FSS) and Mobile Satellite Services (MSS) can 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. Current expectations dictate that satellite will be seen not only as a component of an alternative routing path but also as part of a unique (really integrated) system. Convergence of satellite and terrestrial networks is becoming a key factor in forming the foundation for efficient global information infrastructures [1].

On one hand, ad-hoc networks are characterised by dynamic topologies, limited bandwidth, energy consumption constraints, limited physical security and no centralised management. Some of the many problems they're subject to include:

- Routing information technique choice;
- Configuration;
- Management;
- Limited bandwidth which means the network management slice must be minimized 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 suitable terrestrial communication infrastructure is not available;
- Where the broadcast nature of the satellite system can be exploited (e.g. TV broadcast);
- Or 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 concept of a hybrid MANET-Satellite network is therefore a natural evolution of considering the problem of providing local and remote connectivity in a highly mobile, dynamic and often remote environment, as represented in Figure 1. 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 minimizing costs and energy [1]. 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 [4]; reconfiguration and interaction with relevant end-users in Ad hoc networks [5], integration of positioning information in communication protocols at MAC level [6];

cross-layer optimization and between WiMax and DVB-RCS satellite networks [7]; application scenarios [8]; progresses on deployment and cost-effectiveness [9]; and so on.

MONET will study these challenges, propose and develop solutions for the optimization 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.

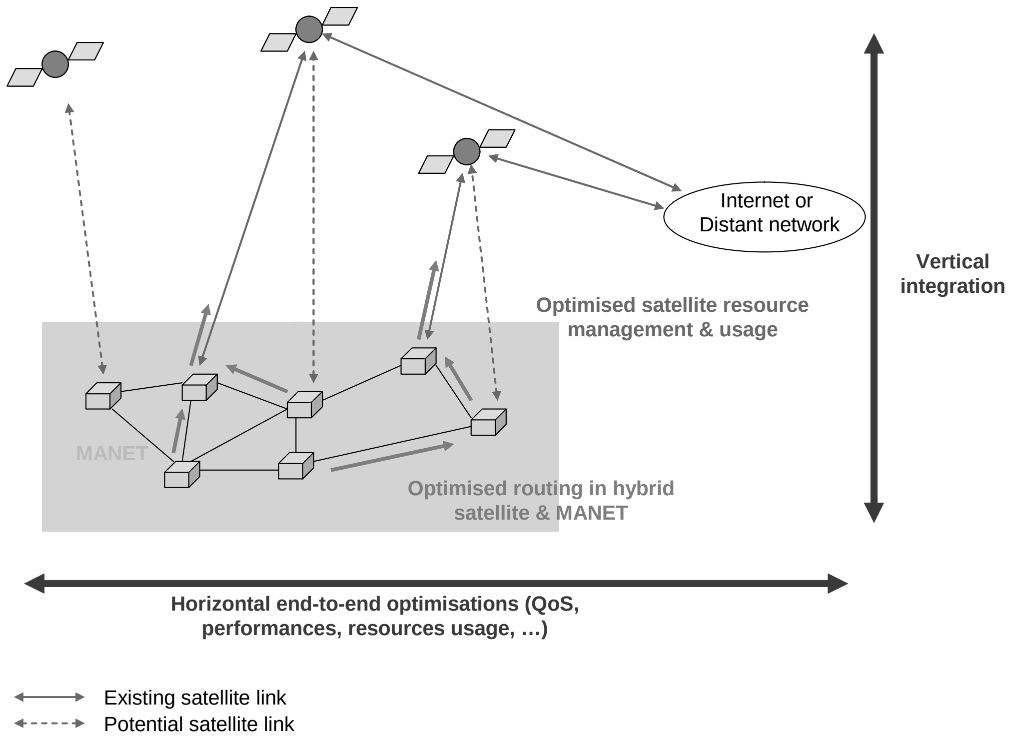

Figure 1 – Hybrid MANET-satellite network and MONET concept.

2. Objectives

The authors have established the following objectives for the foreseen research:

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

The MONET project will address these objectives 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 optimizations and proposed solutions in a scenario representative of a real life application.

3. Methodology

The first step in understanding such hybrid networks and associated challenges and potential, is the perception of the possible applications and uses for these types of networks. This will be achieved through the study of a set of scenarios and development of a concept of operations for the network. Next, in order to understand the complexity of these heterogeneous, dynamic and distributed environments, the MONET team 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 [2], 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 approach 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, minimize communication costs, minimize 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 2 and 3 represent some of these issues (selecting satellite access points either because one access point drops out of the MANET or in case the transmitting node can choose from several; mesh satellite providing relay link between two MANET).

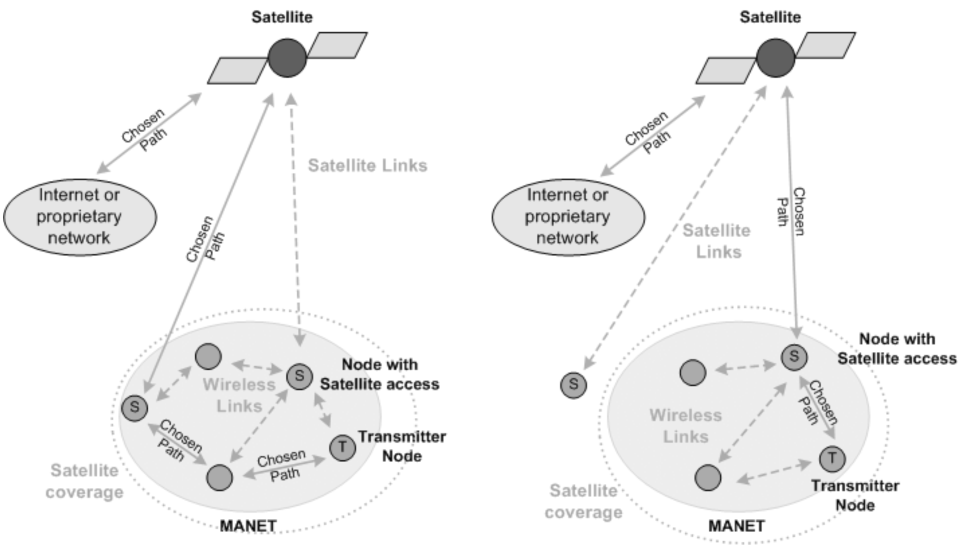

Figure 2 – Hybrid MANET-Satellite network challenge: selecting satellite access points.

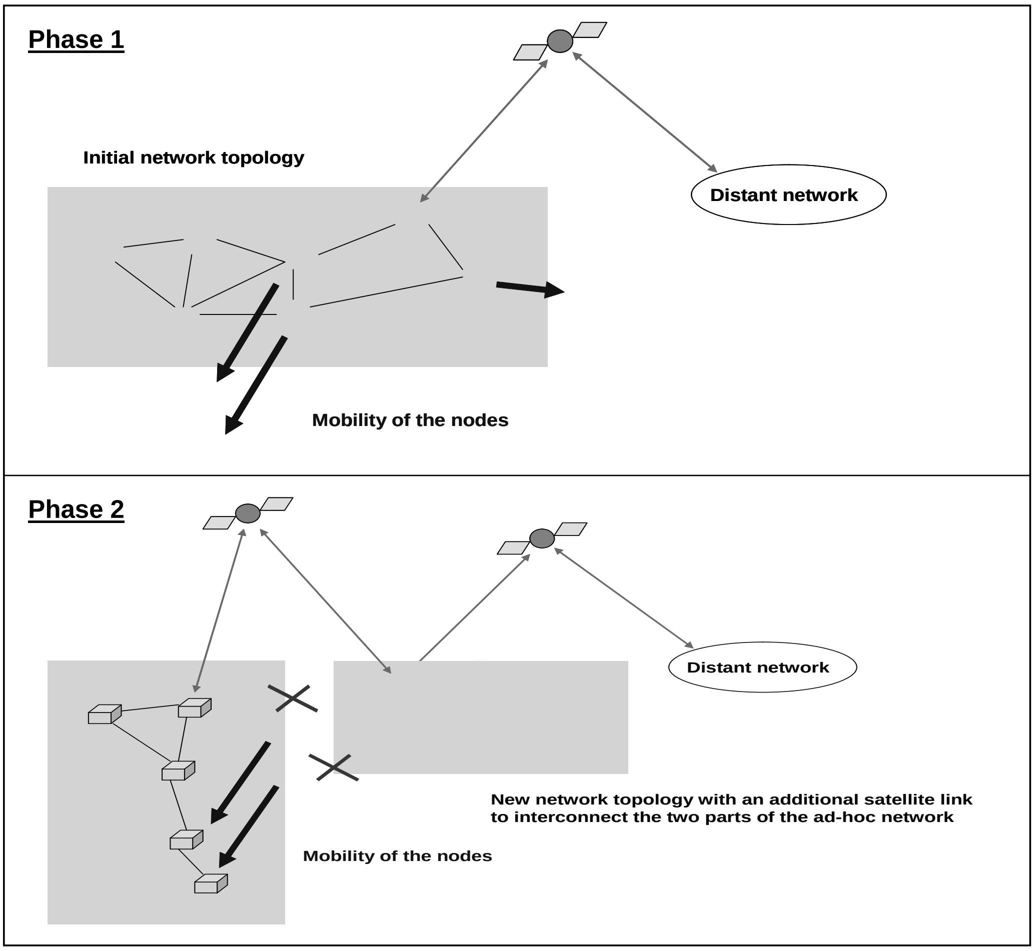

Figure 3 – Hybrid MANET-Satellite challenge: Satellite as relay between two MANET.

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 hasn't 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 [3]. 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).

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 centralized management entity that manages the access points and their organization and hand-overs between them. Therefore, the investigation of centralized versus distributed or mixed network management & 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 4.

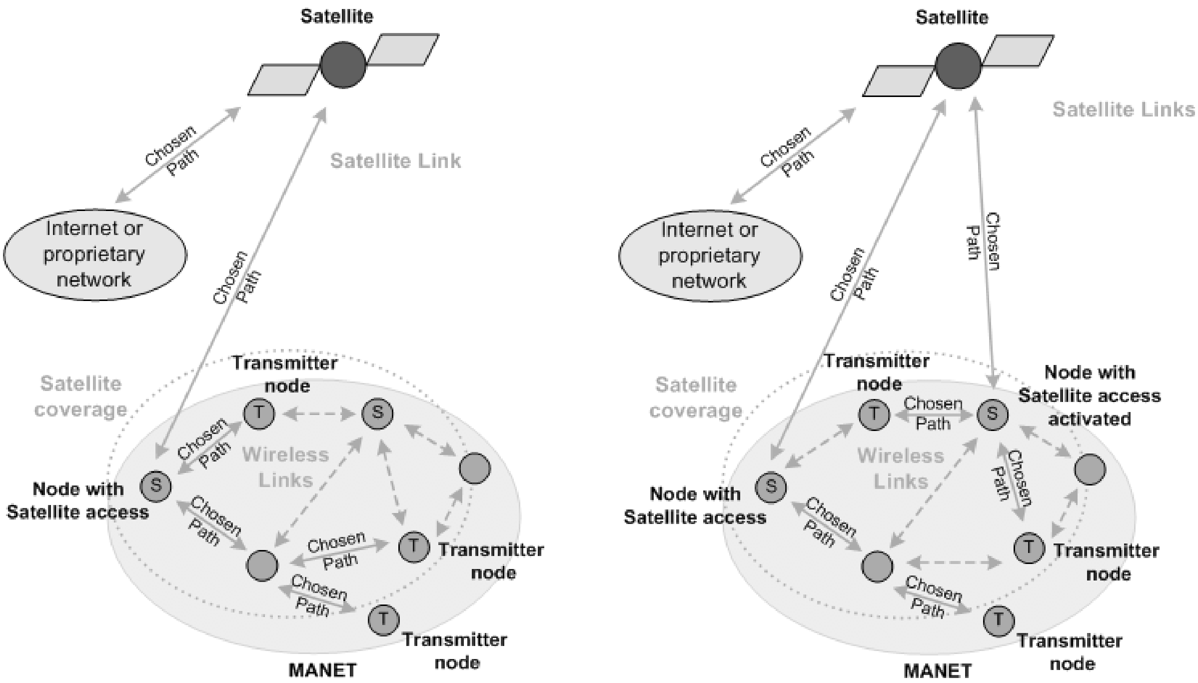

Figure 4 – Hybrid MANET-Satellite network challenge: resource management – automatic access point activation to increase throughput.

Applications can have 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 prioritization 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 optimization parameters is in itself a challenge. A hybrid network such as the one proposed in can be optimized 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 project

MONET will address the challenges described and propose solutions to solve them. The project will focus on solutions for the network and link (MAC) layers.

4. Developments

The MONET approach proposes to optimise the integration of satellite links in a MANET network. The complementarity 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 main developments the authors propose consist in:

- 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 enable or disable satellite links in order to best fit the amount of traffic to be transmitted or to reduce communication costs. The second example is to consider the satellite as a way to maintain connectivity in the wireless network when two parts of the network can not 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 the procedures aiming at optimizing the network performance, routing will be a key topic, since the network will benefit from the satellite only if the overall resources are efficiently used. The interaction 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 initialization. For the realization 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 must be granted with tight requirements in terms of QoS, security and resiliency. To face this challenge, the authors propose to develop a multi-objective optimization framework incorporating QoS constraints, capable of providing tight and well-definite control of the routing decisions over the whole network. Notably, the optimization algorithm will take decisions not only based on current network traffic and configuration, but it will rely 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 optimize the overall network efficiency, the optimization 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 [7]). In this respect, MONET 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 considers the following resource management protocols: Bandwidth on Demand; Call Control, Frame Constitution.

5. Conclusion and Expected Results

The accomplishment of the proposed objectives will bring noteworthy added value to specific application scenarios (some of them well known as MANET applications):

- Providing 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);
- Providing on demand connectivity to Airports and aircraft;
- Public Safety (providing emergency communications during/after disasters; forest fires, floods and earthquakes and coastal monitoring);

Additionally, the approach proposed by MONET will provide a wide set of economic benefits that can be summarized in four main points:

- Communications cost optimization;
- Network setup and restructuring acceleration;
- Cost efficient communications for remote or isolated areas;
- Increased performance, efficiency and resilience for hybrid networks.

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