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The Network Infrastructure for the ROBEX demonstration mission space

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The demonstration mission space of the alliance Robotic Exploration of Extreme Environments (ROBEX) was a campaign on Mt. Etna in summer 2017. The network infrastructure and parts of the ground segment for this demonstration mission space were set up by the Mobile Rocket Base (MORABA) of the DLR. The ground segment included a control center which was based near Catania, Italy. Various terminals allowed for controlling a lander, a robotic rover and several experiment carriers which have been placed in 23 km air-line distance on Mt. Etna. The distance was bridged by a radio link between the control center and a base camp at the demonstration site. From the base camp a shorter radio link of several hundreds of meters to the lander was established, and from there, the signal was distributed using several access points.

Introduction

The Helmholtz alliance *Robotic Exploration of Extreme Environments* (ROBEX) brings together space and deep-sea research. From 16 institutes involved in space and marine research, the project partners are jointly developing technologies for the exploration of highly inaccessible terrain, such as the deep sea and polar regions, as well as the Moon and other planets. Although both communities – space and deep-sea research – face different scientific questions and technological challenges, common methods and technological solutions are developed and exchanged within the alliance. In order to validate the developed methods and technologies, two demonstration missions for space and deep-sea were planned and conducted.

The Mobile Rocket Base (MORABA) of the DLR institute of Space Operations and Astronaut Training prepares and implements scientific sounding rocket campaigns. Sounding rockets offer a unique and versatile experiment platform for aeronomy and microgravity research. The MORABA group Mobile Infrastructure operates mobile tracking radars for trajectory determination and ground stations for data reception and command transmission. Within ROBEX, the

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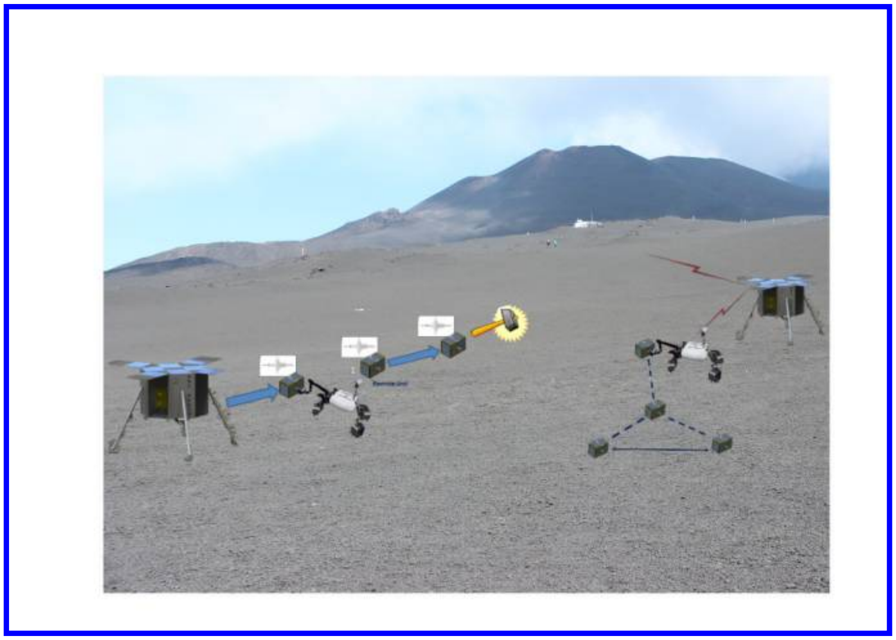

Fig. 1 Left: Active seismic experiment. Right: Passive seismic experiment.

demonstration mission benefited from these experiences through the setup and operation of an appropriate network infrastructure.

Mission scenario

For the demonstration mission space, two dedicated scenarios from the ROBEX lunar scientists were chosen [1, 2]. The first scenario is an active seismic experiment shown on the left side of figure 1. Here, a rover unloads the modular experiment carrier *Remote Unit* from a lander. The design and structure of the Remote Unit are described in reference [3]. The concept for this carrier is inherited from DLR's Mobile Asteroid Surface Scout (MASCOT), currently en route to its target asteroid on-board JAXAS's Hayabusa 2 mission [4, 5]. After unloading of the Remote Unit, the rover navigates to the first measurement point, deploys and positions the Remote Unit. At a different location on the test field, an active seismic signal is generated. The response of this signal is measured by a seismometer integrated in the Remote Unit and subsequently transmitted to the ground segment where it is analyzed. Then, the rover picks up the Remote Unit and navigates to the next measurement point. The sequence of deployment, positioning, measurement and picking up is repeated several times until all measurement points have been visited. Reference [6] describes the rover technology and the autonomous execution of robotic mission tasks in detail.

The second scenario depicted on the right side of figure 1 is a passive seismic experiment. Here, the rover unloads and deploys autonomously four Remote Units forming a Y-shaped seismic network. Comparable experiments have been conducted in the course of the Apollo program [7] with the important difference that astronauts deployed and activated the experiments manually. In contrast, the overall aim of the ROBEX alliance is the development and demonstration of robotic technologies which operate and interact autonomously under harsh environmental conditions. In case of a lunar mission, main research questions are the internal structure and the composition of the upper layer, the lunar regolith. Other questions are the existence and composition of a central core of the Moon and if there is any seismic activity. Mount Etna on Sicily (Italy) has been selected as a terrestrial analog site for the ROBEX demonstration mission. The region is characterized by constant micro seismicity induced by volcanic activity and deep earthquakes that are localized in a similar depth as expected on the Moon. Furthermore, the Moon analog site fulfills criteria regarding the geologic context, and the topography and morphology are representative of lunar surfaces. Finally, the site allowed the setup of the required logistic and operational infrastructure.

Fig. 2 (a) Perspective view on mount Etna. (b) Map of the entire area with the RF relay and coordinates of control center, relay station and lander. (c) View from La Montagnola towards test site marked by an ellipse. (d) Installation of a relay antenna (RF Link 1) on La Montagnola.

Field test network

In September 2016, a field test was organized. It took place at the same site where the demonstration mission was planned. Major objectives of this field test were the testing of the infrastructure and core components which had to operate smoothly one year later in the demonstration mission. This includes the setup and test of a radio link from the ground segment to the demonstration site. The ground segment was established at the coast-line close to the city of Catania. A hotel accommodated the control center and the ground station.

Primarily, it was assumed that there was no direct line-of-sight between ground station and test site on Mt. Etna. Therefore, it was decided to establish a relay station on La Montagnola which is a hill located less than one kilometer away from the demonstration site and visible from both, the ground station and the test site. Thus, two radio links had to be setup, one from the ground station to the relay station on La Montagnola, and the second link from the relay station to the demonstration site. Figure 2a gives an overview of the entire area. The two radio frequency (RF) links and the positions of the three stations are marked in figure 2b. Figure 2c displays the view from La Montagnola towards the test site, and the installation of the relay station is shown in figure 2d. The radio components which have been purchased for the field test and the demonstration mission operate in the 5 GHz band and establish a wireless local area network (WLAN) using the IEEE 802.11 standard [8]. Following activities with respect to the network infrastructure have been performed during the field test:

- Installation of a relay station on La Montagnola
- Installation of RF equipment, including provisional control center

- Test of communication network (control center – relay station – test site)

For the relay station, two parabolic antennas, network and power supply equipment were transported and setup on La Montagnola. The power supply comprises solar panels, storage batteries and a battery-state-of-charge monitoring device connected to the network. After having installed the components of the entire network, several tests of the communication links have been performed. A data rate of around 50 Mbps was measured for the complete link ground station – relay – test site. The measured bit rate complies with the required bandwidth which is mainly used for the transmission of video and multidimensional data of the rover. During one of the network tests, a signal coming directly from the ground station was picked up at the demonstration site. The direct line-of-sight could later be confirmed by visual observation from near the coast-line when the view on Mt. Etna was not obstructed by clouds.

Demonstration mission network

The ROBEX demonstration mission space took place between the 12th of June and 7th of July 2017. Having confirmed a direct line-of-sight between ground station and demonstration site, the relay station was obsolete and the link configuration could be simplified. Figure 3 shows the layout of the network as it was installed and operated during the demonstration mission.

In the control center, several network switches and one router connect the workstations of the various teams to the ROBEX demonstration mission network. From the control center, the systems of the lander, the Remote Units and the rover are monitored and controlled. Furthermore, scientist supervise and analyze the performed measurements. One workstation is used for the management of the network infrastructure and for the operation of a TeamSpeak server. TeamSpeak is a proprietary Voice over Internet Protocol (VoIP) application for audio communication between users. Here, it allows an efficient communication of team members within and between the demonstration site and the control center. Finally, internet access is provided within the entire network which turned out to be useful for the preparation of the demonstration mission.

From the ground segment, a direct radio link was established to the demonstration site. The air-line distance of this link was about 23 km. In figure 3, this link is marked as *Radio Link 1*. It is implemented by two parabolic antennas, one installed on the roof of the hotel, and the other one on top of a shipping container used as a base camp shelter on the demonstration site. Within the base camp, cable based and wireless network connection is provided. Therefore, all mission components can – independently of the control center – be monitored and controlled from the base camp. Since the distance from the base camp to the test site is only a few hundred meters, this is a useful feature for the preparation and testing of the mission components. From the base camp, a second link marked as *Radio Link 2* in figure 3 establishes the connection to the lander on the test site. From there, two access points provide network connections to the rover and to the Remote Units.

As of 2017, novel transceivers were available and have been installed for *Radio Link 1* and *2*. Unlike standard WLAN, the new hardware uses a Time Division Multiple Access (TDMA) protocol. Inter alia due to this technical upgrade, much higher data throughputs are achieved. In this configuration, a data rate of around 150 Mbps have been measured for the complete link ground station – base camp – test site (lander). This rate corresponds to a bandwidth three times higher than required for the operation of the demonstration mission. Thus, a comfortable margin in bandwidth is obtained and at the same time the technical capabilities have been sounded for possible future demonstration missions. Regarding the surface-to-surface communication between lander, rover and Remote Units, the local terrain may also influence the reliability of the links. Results as obtained by Hwu et al. [9] indicate that topography, signal frequency, antenna location and surface material composition may significantly influence the propagation characteristics of surface networks. Even though the ROBEX demonstration mission used WLAN primarily because of compatibility and cost reasons, it is a subject of current research if WLAN and Long Term Evolution (LTE) networks can be used for a lunar communication infrastructure [10].

Figure 4 gives an overview of the different sites and components established for the ROBEX demonstration mission. The pictures on the top show elements of the ground segment and the bigger picture below displays the demonstration site with the base camp on the upper side and the test site on the lower side of the slope. On the test site, the planned positions of the seismic network are indicated in figure 4 and an inset shows rover and lander next to each other. The

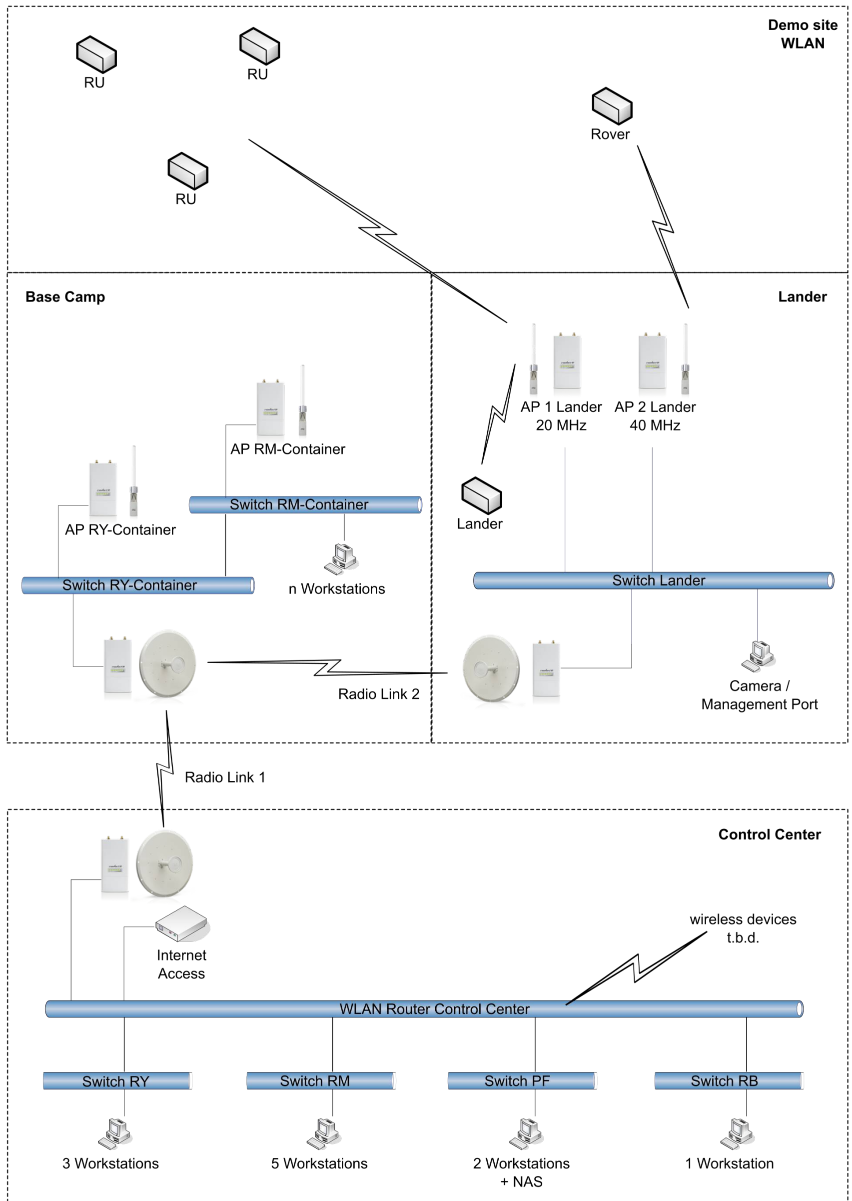

Fig. 3 Layout of the ROBEX demonstration mission network

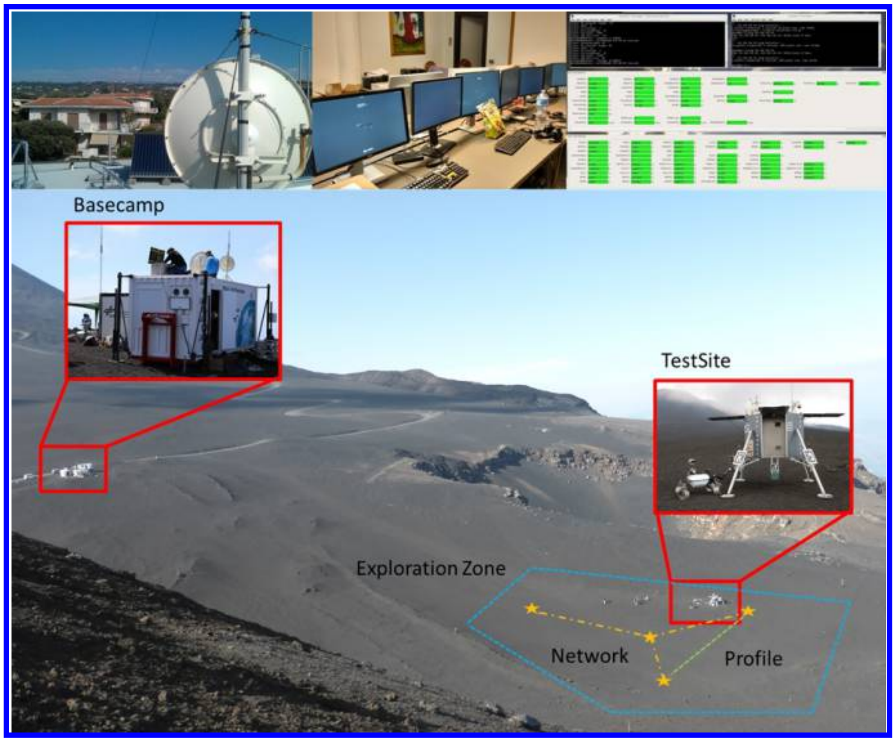

Fig. 4 Top: Ground segment with antenna, control center and command & control interface. Bottom: Overview of demonstration mission site with base camp and test site.

base camp is not considered as a part of the actual demonstration mission and was installed mainly for logistic and preparatory reasons. More particularly, the proximity to the test site allows manual intervention during setup and testing of the demonstration mission. Furthermore, the base camp can serve as an alternative control center as stated above.

Analogous to a real space mission, rover, lander and Remote Units have independent power supplies provided by batteries and / or solar panels. The power supply of the base camp components is provided only during the time period when personnel are present. However, monitoring of the lander housekeeping data was also requested for periods when no personnel are present in the base camp. Therefore, an Uninterruptible Power Supply (UPS) comprising a storage battery and solar panels was installed in the base camp for a continuous operation of the radio links.

Conclusion

The network infrastructure of the ROBEX demonstration mission space has been proven to provide a reliable and fast link between the ground segment and the test site. The WLAN standard provides maximum connectivity of network elements and flexibility for the operation of various applications. This includes software such as audio applications which are not part of the robotic scenario but essential for the preparation of the demonstration mission. The used audio application simplifies communication substantially, in particular between control center / base camp and test areas with poor mobile network coverage. Finally, an UPS allowed the continuous operation of the radio links and the preparation of the demonstration mission benefited a lot from the availability of an internet access on the demonstration site.

Acknowledgments

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