SHERPA: An Air-Ground Wireless Network for Communicating Human and Robots to Improve the Rescuing Activities in Alpine Environments

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Abstract. Robot-based rescue systems are envisioned now-a-days as a promising solution for saving human lives after the avalanche accidents in alpine environments. To this aim, a European project named "Smart collaboration between Humans and ground-aErial Robots for imProving rescuing activities in Alpine environments (SHERPA)" has been launched. Robots with smart sensors and mobility feature are needed for achieving the goal of this project, therefore, the SHERPA networks need to consider two degrees of freedom: one is throughput for transmitting realtime images and videos and another is range for mobility. In this paper, we design a wireless network infrastructure with the objective to communicate human and robots during the rescue mission in alpine environments. Firstly, we study about the network components, scenario and topology according to this environment. Then we design the network infrastructure for communicating among network components by taking account of the two degrees of freedom. Finally, the performance of the network is analyzed by means of numerical simulations. The simulation results reveal the effectiveness of the proposal.

Keywords: Air-ground robotic networks · Alpine scenarios · WiMAX

1 Introduction

Introducing robotic platforms in a rescue system is envisioned now-a-days as a promising solution for saving human lives after the avalanche accidents in alpine environments. With the popularity of winter tourism, the winter recreation activities has been increased rapidly. As a consequence, the number of avalanche accidents is significantly raised. According to the statistics provided by the Club Alpino Italiano, in 2010 about 6,000 persons were rescued in alpine accidents in Italy with more than 450 fatalities and about thirty thousand rescuers involved, and with a worrying increasing trend of those numbers [1]. In 2010

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the Swiss Air Rescue alone conducted more than ten thousand missions by helicopters in Switzerland with more than 2,200 people that were recovered in the mountains [2]. Conveying those numbers to a global scale immediately gives the significance of the problem and the relevance of the real-world scenario.

Many features of the real-world scenario in which robotic platforms could provide an added value to potentially save lives during the rescue mission. To this aim, a European project named "Smart collaboration between Humans and ground-aErial Robots for imProving rescuing activities in Alpine environments (SHERPA)" has been launched [3]. Robots with smart sensors and mobility feature are needed for achieving the goal of this project, therefore, the SHERPA networks need to consider two degrees of freedom: throughput and range. Since the robots need to transmit realtime pictures and videos about the targeted area, high throughput need to be assured. On the other hand, since the air-robots need to move their territory in terms of kilometers, the high range of the network also need to be considered.

In this paper, we design a wireless network infrastructure with the objective of enabling wireless communications among human and robots as envisioned by the SHERPA project. More in details, firstly, we study about the network components (i.e., air and ground robots, and human) network scenario (i.e., the place where the network components are resiting) and two-tier topology according to this environment. Then we design the network infrastructure for communicating among network components by taking account of the two degrees of freedom i.e., throughput and range. Finally, the performance of the network is analyzed by means of numerical simulations. The simulation results reveal the effectiveness of the proposal.

The rest of the paper is organized as follows. In Sect. 2, we provide the related work, while in Sect. 3, we describe the overview of the network. In Sect. 4, we discuss about the network requirements and in Sect. 5, we present the considered technology. In Sect. 6, we provide the performance evaluation and finally, in Sect. 7, we conclude the paper.

2 Related Work

There are several works that address the infrastructure design for wireless mesh, sensor and ad-hoc networks [4–12]. However, there is not enough literature for designing infrastructure in alpine environments specially for communicating between human and robots during the rescue mission, only [13] addresses this issue. In [4,5], the authors design infrastructure for wireless mesh networks. In [6], the design of a wireless communications network for advanced measuring infrastructure is proposed. In [7], the authors study the application of wireless sensor networks and infrastructure design for security and privacy purpose. In [10], an infrastructure is designed for remote environmental monitoring systems.

There are some works that consider RFID for designing infrastructure in these types of network. For example, in [14], an infrastructure to work with RFID embedded in a service oriented architecture is proposed; in [15], the authors present a RFID based secure infrastructure for intelligent building management service and In [16], the authors propose an integrated architecture featured by the optimized coexistence and cooperation between Wireless Sensor Network (WSN) and RFID infrastructures.

There are some other works that consider ZigBee for designing infrastructure in these networks. In [19, 20], the authors design a monitoring and control system based on ZigBee wireless sensor network. In [21, 22], the author study ZigBee based wireless infrastructure for reliability intra-vehicular communications. In [23], the authors design and analysis a robust broad-cast scheme for the safety related services of the vehicular networks. In [24], the authors evaluate the ZigBee standard specially for cyber-physical systems, which is a class of engineered systems that features the integration of computation, communications, and control.

These traditional technologies can not fulfil the requirements of the SHERPA networks because of the necessity of the two degrees of freedom in terms of high throughput and extended range. Therefore, in this paper we assess the feasibility of WiMAX technology for enabling wireless communications among human and robots in alpine environments, which is different than all the aforementioned works.

3 Overview of the Network

In this section, first, we discuss about the network components, then demonstrate the scenario where these components are utilized. Thirdly, we provide the topology of the network and finally present the network architecture.

3.1 Network Components

Several actors/robots, such as Small-scale Rotary-Wing Unmanned Aerial Vehicles (RW-UAVs), Ground rover (GR), Fixed-Wing UAVs (FW-UAVs) and RMAX rotary-wing UAVs are involving to cooperate a human rescuer for accomplish a common goal. These actors are called the network components, as shown in Fig. 1. They are working like a team and all the members of the team are briefly discussed in the following:

Human Rescuer: A human rescuer obtains information form the robotic platform and utilizes them to accomplish the team goals. Human rescuer is called "Busy Genius" in the team. He can also communicate to the other rescuers who are involving in the same mission. He may carry the SHERPA Box that contains: (i) main computational and communication hardwares to communicate with other SHERPA actors using WiFi, WiMAX, Xbee and GSM/UMTS networks; (ii) docking/rechargeable station for the small scale UAVs; (iii) storage for the rescuer.

Ground Rover: It can carry the SERPA Box. It has ability to reach wild areas and to overtake the big natural obstacles. It can also be used as a communication relay among the SHERPA actors. It plays the role of an "Intelligent Donkey" of the team.

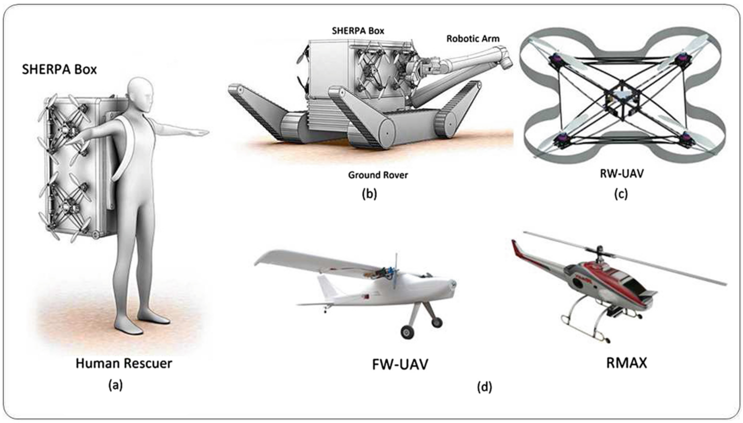

Fig. 1. The Components of the SHERPA Network.

RW-UAVs: It is characterized by limited autonomy and on-board intelligence but with incomparable capabilities in terms of capturing data (like visual information) from privileged or highly manoeuvrable positions, and following the rescuer in inaccessible areas. Its radius of action is necessarily confined in the neighborhood of the hosting ground rover due to the limited duration of the batteries. Employing multiple RW-UAVs, any tasks can be parallelized, boosting the efficiency of their mission. It plays the role of a "Trained Wasps" of the team.

FW-UAVs and RMAX: The FW-UAVs is characterized by matchless eagle-eyed capabilities that allow it to patrol large areas with a limited amount of energy. The RMAX has ability to carry remarkable payload. It can deliver the SHERPA Box and fly in the critical weather conditions. The high-altitude information captured by these vehicles enables optimization and coordination of the local activities of the team. Their radius of action is necessarily confined in the neighborhood of the rescuer. They play the role of a "Patrolling Hawks" of the team.

3.2 Scenarios

The scenario of the alpine environment is very hostile, as shown in Fig. 2. It is very difficult to move the actors during the rescue mission due to the obstacles, slopes and bad weather (wind, fog, rain). Initially the human reaches to the targeted palace along with the Ground Rover (GR), as depicted in Fig. 2(b). Then he starts the rescue mission. The RW-UAV is utilized for getting information of the small territory where the human can not reach, as demonstrated in Fig. 2(c). For the long distance area, FW-UAVs and RMAX are used, as shown in Fig. 2(d). GR is acting like a base station. The rescuer will get all the necessary information about the alpine environment through GR.

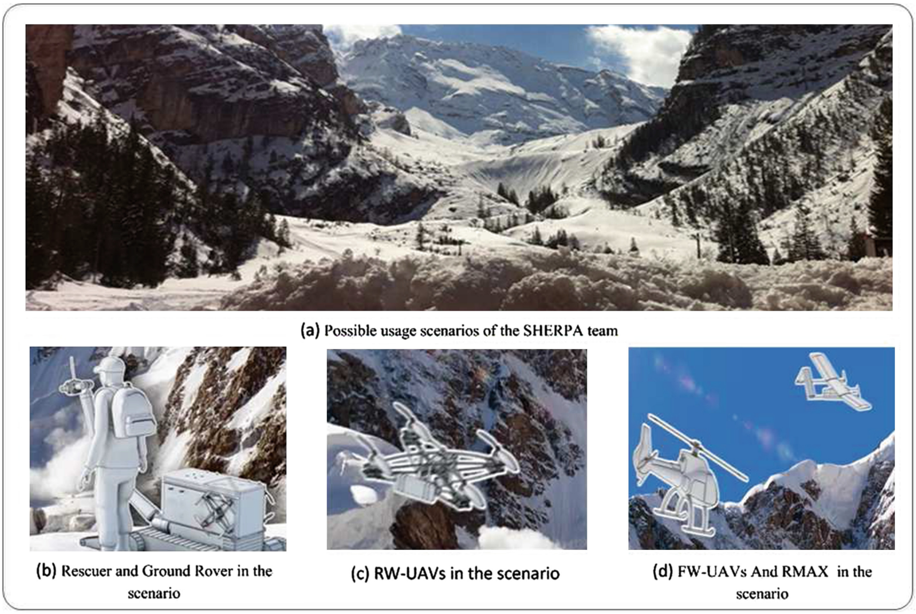

Fig. 2. The Scenario of the SHERPA Network.

3.3 Topology

Network topology is a schematic description of the arrangement of a network, including its nodes and connecting lines. In this network, we proposed two-tier topology, which is the combination of mesh and star topology, as shown in Fig. 3. We briefly discuss about these tiers in the following:

The first tier topology focuses only the intra-team communications. There is a central entity (e.g., GR) to which all the actors are directly connected. Each actor is indirectly connected to others through the GR.

The second tier topology focuses only the inter-team communications. All the GRs are connected each others through mesh connectivity. An actor can communicate with other actors from differen team through GRs.

3.4 Network Architecture

Figure 4 depicts the architecture of the SHERPA network. It is consisting of two tiers, such as information acquisition and information distribution tier. In the first tier, all the actors are collecting information from the alpine environments and in the second tier, the information is distributed among the components through the network connectivity. A rescuer can utilize these aggregate information for achieving his final goal.

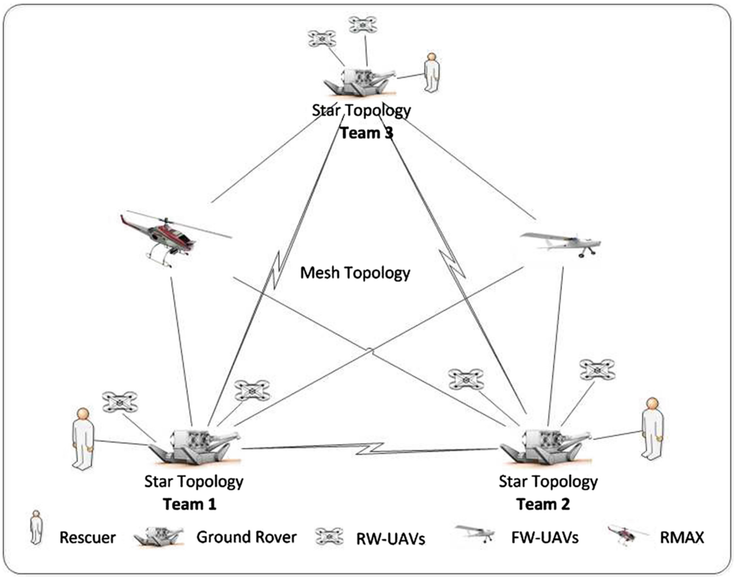

Fig. 3. The Two-tier Topology of the SHERPA Network.

4 Requirements

The most important issue to be addressed is the choice of the wireless network, through which the various actors interact with each others. Such a choice is challenging because the SHERPA network has to provide the two degrees of freedom, i.e., high throughput and range for high data rate and node mobility, respectively.

The key requirement for the proper functioning of the entire system is to be able to transmit real time pictures and video in high definition with the other members of the rescue team. It also requires that the network is established for their connection supports with a data rate that is the order of 1 Mbps, and the latency of the data is relatively low. Therefore, high throughput needs to be assured by the considered wireless technology.

Regarding the mobility, it is necessary to take into account that each actor is characterized by a highly varying speed of movement [17,18], in fact it goes from 30 m/s for FW-UAVs and RMAX, 10 m/s for RW-UAVs, 1.5 m/s the GR, and pedestrian movement for rescuer. The trajectories are also very different, for example the RMAX must be able to communicate with the other teams even it is placed at distances up to 5 km. Thus, it is an important requirement for the considered technology to provide high mobility features for the network components, and to allow for the maintenance of the connections even if the distances involved among the actors are in the order of 1 km. Furthermore, it is simple to note that, the different trajectories can be hardly predicted due to

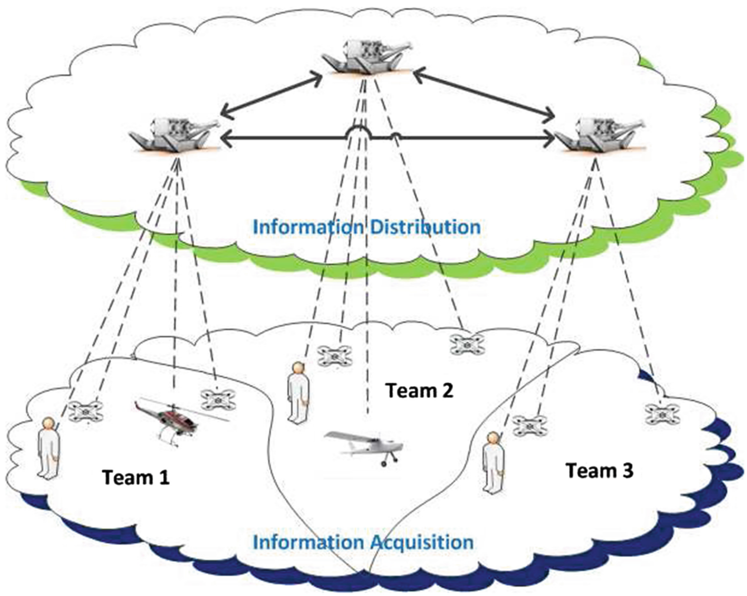

Fig. 4. The Two-tier Architecture of the SHERPA Network.

the movements of the actors. It is not also possible to increase the range of the various standards through the use of directive antennas.

Another interesting feature is the power consumption of the actors. Since the various actors being battery powered, the power available for the operations of data transmission/reception is limited. Therefore, the energy expenditure in terms of power should not be high.

Other requirements need to be taken into account when selecting the standard: *the operation band of the standard*, as the operation in the licensed band is a limit due to the verification of the availability of use and the associated cost; *the degree of diffusion of standard*, in fact, the recent standards are expensive and also lower reliability compared to the established standards.

5 Considered Technology

According to the network requirements, WiMAX standard is suitable for SHERPA network compared to the other wireless standards, such as WiFi, ZigBee, XBee and LTE, because of the following attractive features:

- *Flexibility*: it is able to support both Point-to-MultiPoint and mesh systems;
- *Safety*: it implements several techniques of encryption, authentication and security against intrusion;
- *Preparation for the management of quality of service (QoS)*: it uses different management methods depending on the types of traffic, and then characterized by specific needs;

- *High Throughput*: it ensures a high throughput using the modulation scheme defined by the IEEE 802.16 features, thanks to the good spectral efficiency of the signals;
- *Easy Installation*: it does not require special equipments for establishing the network;
- *Mobility*: it allows connections in mobile environments up to 120 km/h;
- *Cost*: low cost causes the rapid spread of this standard;
- *Coverage*: it has a capacity of very wide coverage, over 10 km. Since it is not possible that the line of sight is present in wide coverage area, the IEEE has developed and released version 802.16e that works for non line of sight communications. However, the performance is significantly reduced compared to line of sight communications.

6 Performance Evaluation

In order to evaluate the performance of the network, we have carried out couple of experiments through a discrete event simulation software, OPNET, with the relative packages for the WiMAX module. We have also adopted several metrics for measuring the performance, such as:

- Throughput: it is the total data traffic (packets/s) successfully delivered to the WiMAX MAC layer of the receiver and sent to the higher levels;
- Delay: the time spent by a packet to reach its destination (this metric accounts only for the data packets successfully received).

6.1 Experiment 1

In this sub-section, we evaluate the performance of the network by varying the number of actors/robots in the scenario. We also investigate how performance varies in presence of different service classes, such as Gold and Silver class. The adopted simulation set is defined as follows: the number of actors set is {10, 20, 30, 40, 50, 60, 70, 80}, the max and min traffic rate in Gold and Silver classes are 5 Mbps and 1 Mbps, and 1 Mbps and 0.5 Mbps, respectively, the latency is 30 ms, the speeds of the Human, RW-UAVs, FW-UAVs and RMAX are 1.5 m/s, 10 m/s, 30 m/s, respectively, the radius of the GR is 1 Km. Since GR is the base station of the network, we consider it as static for reducing the design complexity.

It is plotted the throughput and delay with the varying number of actors, as shown in Figs. 5 and 6. In terms of throughput, we note that in the both Gold and Silver classes the performance initially increases and then it reaches to the saturated point, and again performance declines. This is reasonable because more number of actors transmits more packets. However, after the saturation point the network becomes congested that causes declination of the performance. We also observe that the Silver class outperforms the Gold class, since the data load of the Gold class is higher than Silver class.

In terms of delay, the performance decreases with the increasing number of actors. This is because, the more number of actors needs to wait more time for

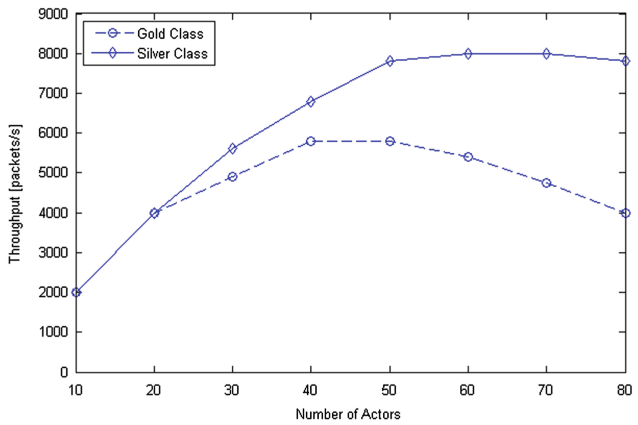

Fig. 5. Throughput vs varying number of Actors in Experiment 1.

utilizing the channel that causes delay. The Silver class again outperforms the Gold class because of the same reasoning in Fig. 5.

6.2 Experiment 2

In this sub-section, we evaluate the performance of the network by varying the radius of the Ground Rover. The adopted simulation set is defined as follows: the number of actors set is {40, 70}, the MAC service class is Gold, the max and min traffic rates in Gold class, are 5 Mbps and 1 Mbps, the latency is 30 ms, the speeds of the GR, Human, RW-UAVs, FW-UAVs and RMAX are 0 m/s,

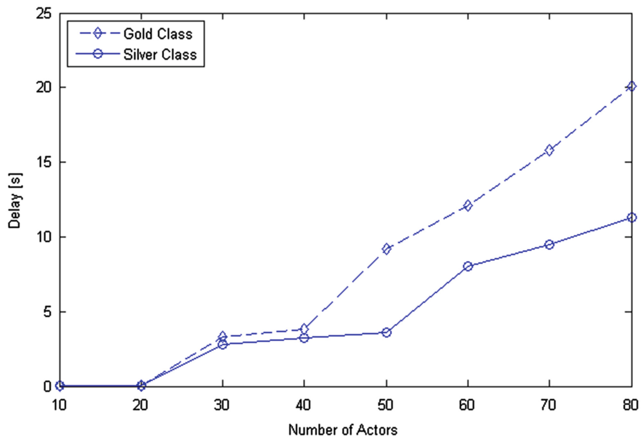

Fig. 6. Delay vs varying number of Actors in Experiment 1.

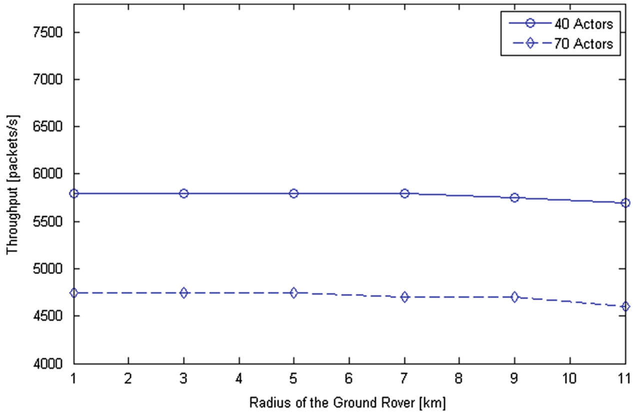

Fig. 7. Throughput vs varying Radius of the Ground Rover in Experiment 2.

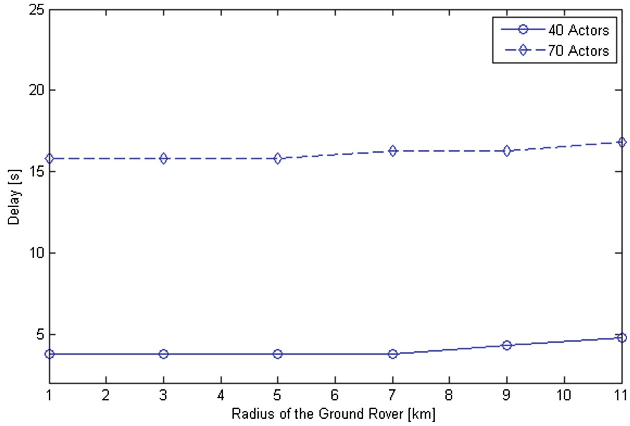

Fig. 8. Delay vs varying Radius of the Ground Rover in Experiment 2.

1.5 m/s, 10 m/s, 30 m/s, respectively, the radius of the GR set is {1, 3, 5, 7, 9, 11} km.

It is plotted the throughput and delay with the varying radius of Ground Rover, as shown in Figs. 7 and 8. In terms of throughput and delay, we note that the performance is slightly decreased when the radius is near about 10 km. This is because of the WiMAX standard, which is suitable for more than 10 km. We also observe that the less number of the actors performs better because of the same reasoning in experiment 1.

From the above discussions, we can conclude that the requirements of the network are satisfied by utilizing WiMAX standard. We will also investigate the performance by introducing the concept of cognitive radio in this scenario as a future work [25–30].

7 Conclusion

In this paper, we have designed an infrastructure for communicating human and robots during rescue mission in order to save human lives in alpine environments. To this end, firstly, we have analyzed about the communication requirements of different air and ground robots, and human rescuer. Then we have proposed two-tier network topology and architecture. We have designed a WiMAX network for communicating among network components for assuring two degree of freedom in terms of high throughput and range. The simulation results confirm the effectiveness of the proposal. In this work, we only analyze the single team communications whereas multi-team communications will be the future direction of this work.

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