Computer Communications 34 (2011) 847–861

Contents lists available at ScienceDirect

Computer Communications

journal homepage: www.elsevier.com/locate/comcom

Experimental and simulation analysis of a WiMAX system in an emergency marine scenario

Rosario G. Garroppo, Stefano Giordano, Davide Iacono, Luca Tavanti *

Department of Information Engineering, University of Pisa, Italy

ARTICLE INFO

Article history:
Received 30 April 2010
Received in revised form 7 October 2010
Accepted 9 October 2010
Available online 15 October 2010

Keywords:
WiMAX
Satellite link
Voice over IP (VoIP)
Marine emergency network
Mean Opinion Score (MOS)

ABSTRACT

The paper presents several experimental and simulation activities aimed at providing a proof-of-concept for a marine emergency network in which the main components are a WiMAX system and a satellite link. WiMAX represents quite a novelty for the marine environment and its integration with the satellite link turns out to be remarkably efficient and greatly contributes in improving the utility and usability of the emergency network. These concepts are proved through a series of tests and analysis. Firstly, we report an experimental analysis of the coverage range of the WiMAX system in the marine environment in terms of both RSSI and throughput. Then, we discuss the feasibility and performance of a joint WiMAX-satellite path (in terms of throughput and perceived quality of VoIP calls), and report an experimental study that verifies the robustness of the WiMAX links under the interference of typical marine equipments such as radars. Finally, we present a simulation study targeted at evaluating the maximal capacity of the system in terms of VoIP calls under different WiMAX system configurations.

1. Introduction

The WiMAX technology has notably increased its popularity in the last years, thanks to the growing demand for wireless network access and services. However, WiMAX can also be used for building a network infrastructure in particular areas or scenarios, where other solutions are not as much cost-effective or cannot be employed due to technical limitations. Among these, we focus our attention on the use of WiMAX for emergency scenarios in marine areas.

In this kind of application, we can distinguish two possible cases: near the shore (e.g. in harbour areas), or in the open sea. In the first case, the network connection can be provided by some technologies already present in the area, such as the cellular system. However, the coverage range of 3G cellular technologies (e.g. UMTS) is limited to few kilometers, which may not be enough even for operations outside the port, whereas 2G base stations (e.g. GSM, GPRS) offer very low data rates. In the second case, a satellite link represents the only available network connection. However, the satellite link has very high costs and bounded data rate.

Thanks to its large radius of coverage (in the order of up to 40 km), and to the high data rate it can guarantee (up to a maximum of 70 Mbps), WiMAX turns out to be an appealing technology for the coverage of ports, as it can provide a cheap network access and service availability not only to moored ships, but also when the ships are well off-shore. In addition, the possibility of employing WiMAX in disaster areas to pool all the men and equipments of the rescue forces (civil defence, army, police, firemen, etc.), makes the study and the development of optimization protocols for this communication system of fundamental importance.

The reference scenario we are taking into account recreates a typical dual-use response (military and civilian) to natural disasters. We think to the intervention of an Emergency Task Force (ETF), based on the Italian Navy LPD (Landing Platform Dock) Class ship with Civil Defence assets embarked, reaching the operations area in few hours after a disaster event. Assets may include helicopters, naval and land vehicles for monitoring and first aid, emergency systems (e.g. medical equipment, power generators, deployable telecommunication systems), monitoring systems (e.g. deployable sensor networks for remote survey of land and marine seismic activity), etc.

In the example, the LPD ship also plays the role of on-Field Operational Centre (FOC), being fitted with UHF (Ultra High Frequency) radio and satellite (Satcom TLC, Total Long-term Care) systems covering civilian and military carriers, in order to accommodate complex tasks and keep a connection with the general head quarter (HQ). We then consider the intervention of various small vessels, e.g. motor lifeboats to reach men or things in the sea or on impervious areas of island coasts. The operators of these boats communicate with the coordinating operators on board of the FOC ship, using classical terminals, such as UHF radios, which provides voice services only. However, in this precise feature, we can detect a notable limitation and criticality of the system: the boat operators can

* Corresponding author. Tel.: +39 050 2217592.
E-mail address: luca.tavanti@iet.unipi.it (L. Tavanti).

0140-3664/$ - see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.comcom.2010.10.004

not communicate directly with the HQ, but must rely on the services and availability of the FOC ship operators.

The analysis of this typical example of emergency management led us to consider a particular network architecture to allows the exploitation of the satellite link, which is usually reserved for communications between the FOC ship and the HQ only, to the other vessels as well. However, we must take into account that a satellite link for every boat could be expensive, and in some cases not even technically feasible. To solve this problem, we can assume that every boat is equipped with a WiMAX terminal and that these terminals are connected with the FOC ship, which hosts a WiMAX Base Station (BS) and the satellite link. Under this assumption, the boat operators can start multimedia sessions with the FOC ship operators, and, in addition, directly with the HQ, exploiting the satellite link by means of the WiMAX system.

The main contribution of the paper is the discussion of the results obtained during some experimental activities aimed at providing the proof-of-concept for the marine emergency network scenario described above. Specifically, to validate the choice of WiMAX in a marine scenario, we implemented a 2.5 GHz mobile WiMAX test-bed, having the ''Istituto Vallauri'' of the Italian Navy as HQ. The used WiMAX equipment is compliant with the IEEE 802.16e standard [1], and works in the Time Division Duplexing (TDD) mode. The test-bed was used not only for experimentally testing the functionally of this network architecture, but also to carry out a measurement campaign aimed at assessing the system performance. In particular, the study is focused on the evaluations of the effects of different parameters (i.e. WiMAX user profiles, interference of devices on the ship, diverse traffic patterns) on the system performance and specifically on the perceived Quality of Service (QoS) of the voice over IP (VoIP) communications.

The measurements were carried out on board of Italian Navy units to evaluate the actual performance of the whole system when working with a marine propagation channel. These channel conditions are very different from the typical urban and suburban radio-propagation scenario, because the signal is affected by reflection and refraction on the surface of the sea. Moreover, the mobile user antenna is not stable, but oscillates together with the ship because of the waves. Therefore, even though the propagation is in line of sight, all these effects may degrade the communication between the ship and the BS.

The analysis of the measured data suggested that a two-ray path-loss model could be used to replicate the behavior of the observed marine channel. We thus focused on such a propagation model, which was later used to perform the simulation study. It is worth noting that during the measurements, carried out in different days, we observed similar sea conditions, i.e. calm, and that we always worked in the same area, i.e. the sea port of Leghorn. Therefore, the employed two-ray model may well not be a general propagation model for the marine scenario. A thorough analysis aimed at the definition of a general propagation model for the marine scenario is out of the scope of the paper, as this kind of analysis would imply a vast measurement campaign in different sea conditions and geographic areas (e.g. in [2], the propagation model considers two kinds of seas: warm sea, such as the mediterranean sea, and cold sea, such as the north sea). However, the considered two-ray propagation model fits the RSSI data acquired during our experimental activities and thus permits to produce simulation results that fits the measured WiMAX performance accurately enough, as shown in [3].

Then, another experimental activity has been devoted to assess the impact of interferences on the system performance. In detail, we accounted for interferences on either the BS or the mobile station (MS) produced unintentionally by devices that can be commonly found on board of the ships or boats under study (e.g. radars, dud devices).

Finally, the capacity of the system in terms of maximum number of supported simultaneous VoIP communications with an adequate perceived QoS and under diverse system configurations is evaluated by simulation. This choice is due to the notable organizational difficulty and the high costs of performing a complete proof-of-concept on the field, since it should have been necessary to involve numerous naval units.

The paper is organized as follows. An appropriate architecture for the marine emergency network scenario is defined in Section 2. Then we report the experimental performance evaluation of a WiMAX link in a marine environment (Section 3.1), and of the integrated WiMAX-satellite network (Section 3.2). The issues raising from the interference with devices that can be present in an emergency marine scenario are discussed in Section 4. Finally, the study on the VoIP capacity of the WiMAX system is described in Section 5. Section 6 draws the conclusions.

1.1. Related work

Performance measurements of real WiMAX test-bed are scarce, and in particular are almost absent in a marine scenario.

The general aspects of propagation models and path loss measurements are discussed in [4], for both large-scale path loss and small-scale multipath and fading. The recommendation number 1546 from the International Telecommunication Union (ITU) [2] provides some sea path measurements that show the maximum field-strength for several distances between the BS and the MS and for several transmitter antenna heights.

With regard to the few experimental performance studies of WiMAX networks available in the literature, we can cite [5], which presents throughput and received signal strength (RSSI) measurements for fixed WiMAX, [6], which reports some interesting results about QoS performance measurements for fixed WiMAX that go beyond the classical RSSI and throughput at IP layer, and [7], which describes the performance of a fixed Frequency Division Duplexing (FDD) WiMAX link under different loads and traffic conditions. Note that all measurement campaigns detailed in these papers refer to land test-beds.

As for WiMAX measurements in marine scenario, Joe et al. [8] present some RSSI measurements in a sea port scenario for a 5.8 GHz WiMAX network, whereas Shankar Pathmasuntharam et al. [9] describe a marine ship-to-ship/shore mesh network architecture for the same WiMAX system. With respect to these works, our study differs in terms of both system and scenario features, and of performance parameters. Specifically, the measurement campaign presented in this paper refers to a 2.5 GHz Mobile WiMAX system. Furthermore, the analysis is carried out taking into account parameters from the lowest layer (e.g. received signal strength) to the highest layer (e.g. perceptual quality of VoIP calls).

With reference to the use of a WiMAX-based architecture to share a satellite link towards the HQ, Bennett et al. [10] present a feasibility study for a tactical wireless extension of a satellite link by means of a traditional Point-Multi Point (P-MP) WiMAX architecture. With respect to that study, our work differs for the considered environment, i.e. the marine scenario instead of a land one, where the radio propagation is very different.

Finally, with regard to the study of the effects of interfering signals, previous works were mainly focused on the coexistence between WiMAX and other communication systems that operate in the same frequency band. In [11] and [12] the authors investigate, both analytically and experimentally, the interference that Ultra Wide Band (UWB) devices can introduce in a WiMAX system. Further studies on the degradation of WiMAX terminal performance due to the presence of UWB devices are presented in [13]. Detect And Avoid (DAA) procedures are presented in [14]. Such procedures consider the situation where a UWB device can detect