



Ph.D. in Electronic and Computer Engineering

Dept. of Electrical and Electronic Engineering

University of Cagliari



Communication technologies and data processing for safety

Ing. Mariella Sole

Advisor: Prof. Dr. D.D.Giusto

Curriculum: ING-INF/03 Telecommunications

XXVI Cycle

March 2014

To my parents

and

all important people in my life

Contents

- 1 Introduction** **1**

- 2 Radio network for public safety** **7**
 - 2.1 PMR Systems 7
 - 2.2 Digital PMR standards 10
 - 2.3 PMR systems in the European scenario 14
 - 2.4 DMR vs TETRA 15
 - 2.5 The DMR radio network 18
 - 2.6 Case study: DMR Networks for Health Emergency Management 19
 - 2.6.1 Description of the current SimulCAST network 19
 - 2.6.2 Health emergency requirements 21
 - 2.6.3 A DMR-based solution 22
 - 2.6.4 Radio network planning 24
 - 2.6.5 Results and discussion 28
 - 2.7 Case study: DMR Networks for Civil Protection Services 29
 - 2.7.1 National Program of radio networks for Civil Protection services 29
 - 2.7.2 The new radio network for Civil Protection in Sardinia 30
 - 2.7.3 General diagram of the radio network 34

2.7.4	Results and discussion	37
3	Control System for Workplace Safety in a Cargo Terminal	41
3.1	Scenario and technologies	42
3.1.1	Functional areas of terminal operations	42
3.1.2	Workplace safety requirements	43
3.1.3	Body Area Networks	44
3.2	Case study: Cagliari International Container Terminal	45
3.2.1	Description of current communication infrastructure	46
3.3	Design of the control system for workplace safety application	47
3.3.1	Requirements and constrains	47
3.3.2	Description of the control system	50
3.3.3	Use of sensors	50
3.3.4	Image data processing	52
3.3.5	A Use Case	53
3.3.6	Results and discussion	53
4	RFID Sensor Network for Workplace Safety Management	55
4.1	Technological Overview	56
4.2	Requirements and constrains	57
4.2.1	Requirements	57
4.2.2	RFID technologies	59
4.2.3	RFID reader constrains	60
4.3	System Architecture and Work in Progress	62
4.4	Conclusion and future work	64

5 Indoor Navigation Systems	65
5.1 Technologies overview	66
5.1.1 No infrastructured based solutions	66
5.1.2 Infrastructured based solutions	68
5.2 Application for Indoor Navigation Systems	70
5.3 Application for Indoor Navigation Systems	70
5.3.1 Functionality	71
5.3.2 Step detection	72
5.3.3 Gyroscope sensor	75
5.3.4 Route planning	77
5.4 Gyroscope calibration algorithm	79
5.4.1 Drift test	80
5.4.2 Rotation test	81
5.4.3 Gyroscope vs Digital Compass	84
5.4.4 Results and discussion	85
6 Concluding remarks	87
Bibliography	91

List of Figures

2.1 Cellular network	11
2.2 Trunked mode operation with dispatch	12
2.3 Repeater operation	12
2.4 Repeater DMO	12
2.5 Basic Direct Mode Operation (DMO)	13
2.6 Simulcast mode	13
2.7 Typical network architecture	13
2.8 DMR radio network	19
2.9 Simulcast network	21
2.10 Differences between analog, dual mode and DMR DIGITAL PMR system	23
2.11 The "north" and "south" DMR networks	26
2.12 Coverage maps	26
2.13 The logical network architecture	27
2.14 Provincial channels	33
2.15 Provincial radio network scheme	35
2.16 Link between main and remote sites	36
2.17 Master Station	36
2.18 Satellite Station	37

2.19 Regional Radio Network 38

2.20 Radio coverage in "Punta Minniminni" 39

2.21 Radio coverage in "Punta Sebera" 40

3.1 Process of unloading and loading of a ship 43

3.2 Network and communication 47

3.3 SAR (W/kg) versus radiated power (W) at distances of 10cm and 100cm of the
human body 49

3.4 Proposed control system 51

3.5 Integration of BAN and feature recognition for CCTV cameras 51

4.1 BAN sensor networks for workplace safety management 58

4.2 Example of a WISP tag 59

4.3 SAR (W/kg) vs. distance from the human body at varying reader powers 62

4.4 System architecture 63

5.1 User step detection 72

5.2 Estimate error in dead reckoning algorithm 73

5.3 Details of each step and of the error ellipse associated 74

5.4 Axes and /rotation of a smartphone: azimuth (z-axis), pitch (x axis) and roll (y
axis) parameter 76

5.5 Dijkstra algorithm description 77

5.6 Example of a building floor's graph 78

5.7 Test instruments 79

5.8 Acquired values from gyroscope without calibration - 1,000 readings 81

5.9	Calibrated values of the gyroscope computed by subtracting the Bias error from each reading (1.000 readings)	81
5.10	Gyroscope's average angular velocity for 1.000, 10.000 and 20.000 readings compared to the reference angular velocity of the Stepper Motor without calibration .	82
5.11	Gyroscope's average angular velocity for 1,000, 10,000 and 20,000 readings compared to the reference angular velocity of the Stepper Motor with calibration . . .	83
5.12	Paths inside a real indoor environment: each yellow triangle represents a check-point with a predefined orientation	84
5.13	Comparison between the absolute error of gyroscope and compass	86

List of Tables

2.1	Parameter settings for link budget simulation	25
3.1	RFID technology characteristics	48
4.1	Wireless Standards – Feature Chart	58
4.2	RFID technology characteristics	59
5.1	Specification equipment	80
5.2	Gyroscope's average angular speed in five session for 1.000 readings	80
5.3	Average error of the gyroscope compared to angular velocity of the stepper while the device is undergoing a rotation and without calibration	82
5.4	Average error of the gyroscope compared to angular velocity of the stepper while the stepper is undergoing a rotation and with calibration	83
5.5	Reference path	85

Chapter 1

Introduction

Emergency workers comprise large professional groups like volunteer fire-fighters, police officers, emergency medical staff and so on. Their professions have to deal frequently with a considerable number of a combination of health and safety risk factors, which are often unavoidable. For example, workplace scenes demanding the intervention of emergency workers may be located in remote, difficult to access areas (mountains, sea, caves), and sometimes in extremely difficult weather conditions. Moreover, emergency workers must arrive very rapidly at the disaster scene at any time of the day or night, and there is always the possibility of car crashes or other transportation accidents on the journey to the disaster scene or to hospitals. Others examples are the industrial workplaces, which are inherently places with a high concentration of heavy machinery, fast handling equipments, high heat and pressure pipes, polluted and explosive areas where people work in a relatively small area.

Therefore, in an environment where situational awareness and tactical decision making are critical elements to a successful operation, it is really important to have available efficient instruments to ensure the safety for all operators that work in the field.

Despite the fact that a lot sophisticated solutions have been used for increasing request

due to the growing need of safety concerns by the operators, the mission-critical environments are still considered high-risk environments with serious work safety related issues and higher accident rates than in other workplaces. This study focuses on the safety precautions in outdoor and indoor environments, safety communication and Personal Protective Equipment (PPE) and proposes solutions to ensure secure and reliable communications between forces deployed in the field and their dispatch center, which is often of decisive importance for the work of the emergency services, analyzing two different important case studies. Moreover, we have designed a control system intended as a platform for real-time information capable of monitoring, by means of camera and sensor data harvesting about people and vehicles movements. It provides automatic and semi-automatic risk prevention measures thanks to the work in progress on designing and implementing a first working prototype of sensor network based on RFID BAN. These capabilities are the topic of a larger research project that aims to find the optimal solution in terms of feasibility and practical implementation. To conclude our study, we have developed an indoor navigation system for mobile devices. The application is able to follow the user and it indicates the shortest path to achieve a specific destination. It uses only smartphone motion sensor and not requires the use of extra equipment. Moreover, thanks to an algorithm widely explained afterwards and the use of the gyroscope sensor rather than the compass, the mobile application ensures a very good orientation.

The thesis is organized as following:

- In the first chapter, to design a radio communication system both for health emergency services and Civil Protection services, different Professional Mobile Radio (PMR) standards were analyzed. PMR, also known as land mobile radio (LMR) in North Amer-

ica, are field radio communications systems which use portable, mobile, base station, and dispatch console radios. It has referred to a suite of radio mobile network technologies deployed for mission-critical users, which need high affordable communication system. In the specific, PMR networks provide radio services for closed user group, group call and push-to-talk, and call set-up times which are generally short compared with cellular system. In addition, they provide communications in extreme situations that might cause failures in other communications network, like 2G or 3G. As a result of the analysis of the main digital PMR standards (TETRA and DMR) used in European countries, we decided to use the DMR standard to design the radio network for 118 service in Sardinia and for Civil Protection service. DMR has been identified as the best solution, which grants cost saving, high coverage, spectral efficiency and simplicity in network configuration and it is well suitable in wide area with a low/medium density of traffic.

- The second and third chapter of the thesis are focused on improvement of the safety of operators in a maritime cargo terminal. Hence, a new infrastructure of a maritime cargo terminal has been defined, using a control system for monitoring workplace safety. By combining, in the control system, the inputs from a Body Area Network (BAN) integrated in the safety equipment and from CCTV cameras, a human supervisor is able to achieve an accurate overview of the entire situation in terms of work safety and act accordingly when needed. In addition, we focused even on the design and implementation of a working prototype of an RFID-based BAN sensor network for actively monitoring and preventing workplace safety risks in the same industrial area. This first conceptual and technological analysis, together with the test imple-

mentation, is the forerunner of a complex monitoring system in development to be implemented both for the specific case and for any industrial environment.

- The last chapter aims to describe an indoor navigation system developed for smartphone android. Specifically, it has been demonstrated how the use of a gyroscope sensor can bring more benefits respect to a compass sensor to get the best detected position. Nowadays, modern mobile devices, such as smartphones and PDAs in general, come to the market already equipped with sensors able to track them as they move, both in outdoor and indoor environment. The sensing technologies embedded in such devices make it ideal for a wide range of location-based services, such as navigation applications. An Inertial Navigation System (INS) uses motion and rotation sensors in order to determine the position, orientation, and velocity of a moving object/user without the need of external infrastructures. This is essential in an indoor environment where common localization systems, such as Global Positioning System (GPS), fail due to severe attenuation or obscuration of the satellite's signal. In inertial navigation systems, localization/orientation estimation is source-independent. The user's position is calculated in relation to a known starting position using a dead reckoning algorithm and the orientation is usually provided by a digital compass embedded in the smartphone. A digital compass sensor provides the orientation of the device relative to the magnetic north of the earth. However, when it is used in indoor environments, like any magnetic device, it is affected by significant error caused by nearby ferrous materials, as well as local electromagnetic fields. Such errors seriously affect the performance and the accuracy of the system, thus the need to investigate any alternative orientation technique. In the specific, we have developed an early prototype

of a pedestrian navigation system for indoor environments based on dead reckoning, 2D barcodes and data from accelerometers and magnetometers. All the sensing and computing technologies of our solution are available in common smartphones. The prototype has been further improved by a new algorithm described afterwards and now it is able to estimate the correct current position of the user, track him inside the building and provide the best path to achieve a specific destination.

Chapter 2

Radio network for public safety

2.1 PMR Systems

Professional Mobile Radio (PMR) refers to a suite of radio mobile network technologies which are deployed for mission-critical users like police forces, fire brigades and health emergency associations, which need high affordable communication systems. PMR networks provide radio services for closed user groups, group call and push-to-talk, and have call set-up times which are generally short compared with cellular systems. In addition they provide communications in extreme situations that may cause failing of other communications networks, like 2G/3G. A PMR network consists of one or more base stations and a number of mobile or vehicular terminals. Users manage radio communications directly, that is no intelligence in the network is needed. Implementation of PMR solutions relies on either analog or digital standards. Analog technology have had great success thanks to low implementation cost, long range coverage and ease of deployment. However, it has many limitations, such as the degradation of the audio quality for low distances, the overcrowding of the spectrum which may produce several interferences, and the battery life. Although they are still result widely diffused, emergency management networks are evolving towards advanced digital solutions

that allow operators to overcome the well-known and previously mentioned limitations of traditional analog networks. New digital solutions have been proposed and they are slowly replacing the traditional analog systems granting for larger coverage areas, higher security and wider range of services, either for voice or data/video transmission. A major advantage of digital systems is their ability to screen out noise and re-construct signals from degraded transmissions through coders that enable receiving radios to detect and automatically correct transmission errors, as long as the noise level is below a particular threshold. Additional advantages are related to the enhancement of spectral efficiency, as well as the implementation of powerful features like group calls, broadcast calls and the usage of a network backbone based on low cost TCP/IP solutions. The main research and standardization institutes are working on designing new digital Professional Mobile Radio (PMR) technologies to grant for larger coverage areas, higher security and wider range of services than traditional solutions, either for voice or data transmission. In addition, despite the PMR system has mainly used 25kHz wide channels, the Federal Communication Commission (FCC) mandated that all PMR communication systems operating in wide-band (25kHz) on VHF/UHF land mobile radio channels must migrate in narrowband (12.5kHz) by January 2013. This force to switch from analog to digital technology. PMR systems use two main different approaches:

- The first one relies on trunking or multiaccess technology [1]. Differently from conventional PMR standards, which allow communications on a single physical channel with the use of two frequencies for full-duplex communications, trunking provides for multiple FDMA or TDMA access on a single control channel allowing all users to share the same frequencies. The main trunking technology for PMR systems is the Terrestrial Trunked Radio (TETRA), an ETSI standard which grants fast one-to-one and one-to-

many voice and data radio communications [2].

- The second approach consists in simulcast network technology [3]. A simulcast network is a radio network in which all the repeaters transmit on the same frequency and at the same time, employing just a pair of frequencies for full-duplex communications as in analog networks. This solution allows for easy implementation although it is recommended for PMR networks with a medium/low traffic volume. The main PMR standard which implements digital simulcast is the Digital Mobile Radio (DMR) [4]. This one is an open standard which is able to work in dual mode, thus allowing the coexistence of analog and digital devices.

In the recent years, many public and private organizations, such as police forces, fire brigades and health emergency associations, have built their own trunking or simulcast digital radio solutions to replace analog radio networks. Trunking technologies became the good choice in the market of mission-critical public safety which requires higher bit-rate, reliability and security performance in areas with limited extension. In countries covered by ETSI, this market is mainly served by the TETRA standard, while in North America the Telecommunications Industry Association (TIA) has defined the Project 25 (P25) standard [5], that has similar capabilities with respect to TETRA. The DMR standard provides improved spectral efficiency, advanced voice control and integrated IP data services in licensed bands for high-power communications, which are suitable for mission/business-critical professional consumers. Many DMR radio networks have been realized in Europe, such as the emergency simulcast network for Fire Brigades into the Lötschberg railway tunnel (34km length, covered by 26 base stations interconnected by multiplex lines) or simulcast VHF network with UHF links for the Highway Police in the north-west of Italy. Next section describes the main PMR

standards and solutions with specific attention to the health emergency market.

2.2 Digital PMR standards

Digital PMR solutions rely on such standards as TETRAPOL [6], TETRA, P25 or DMR. TETRA and DMR are two open standards proposed by the European Telecommunications Standards Institute (ETSI) and are the most diffused digital technologies in Europe. In the USA, the Telecommunications Industry Association (TIA) defined P25, a standard that has capabilities similar to TETRA. In the following, we focus on the description of the main European standards. TETRA is based on trunking technology, that is the intelligence is in the network, not in the terminal user. It uses TDMA (Time Division Multiple Access) technology and provides 4 channels on a 25kHz bandwidth carrier, ensuring medium/high volume traffic. Higher data transfer rates up to 28.8kbit/s are implemented by reserving up to four channels for the same user connection. Bandwidth is allocated on demand. TETRA is a trunked system, which manages a number of calls through a Trunking Controller. It assigns the radio resource through one or more control channels. The control channel acts as a signaling communications link between the Trunking Controller and all mobile radio terminals operating on the system. The links between the radio base stations typically require 2Mb/s of bandwidth. Each repeater uses different frequencies thus the network is of "cellular type" (figure 2.1), providing a cell size smaller (usually well under 40km) than analogue network system.

TETRA allows either Trunking Mode Operation (TMO), as shows the Figure 2.2 and Figure 2.3, or Direct Mode Operation (DMO) as shows the Figure 2.4 and the Figure 2.5. TMO shares the radio resource, and the use of the radio channel is assigned only for the duration

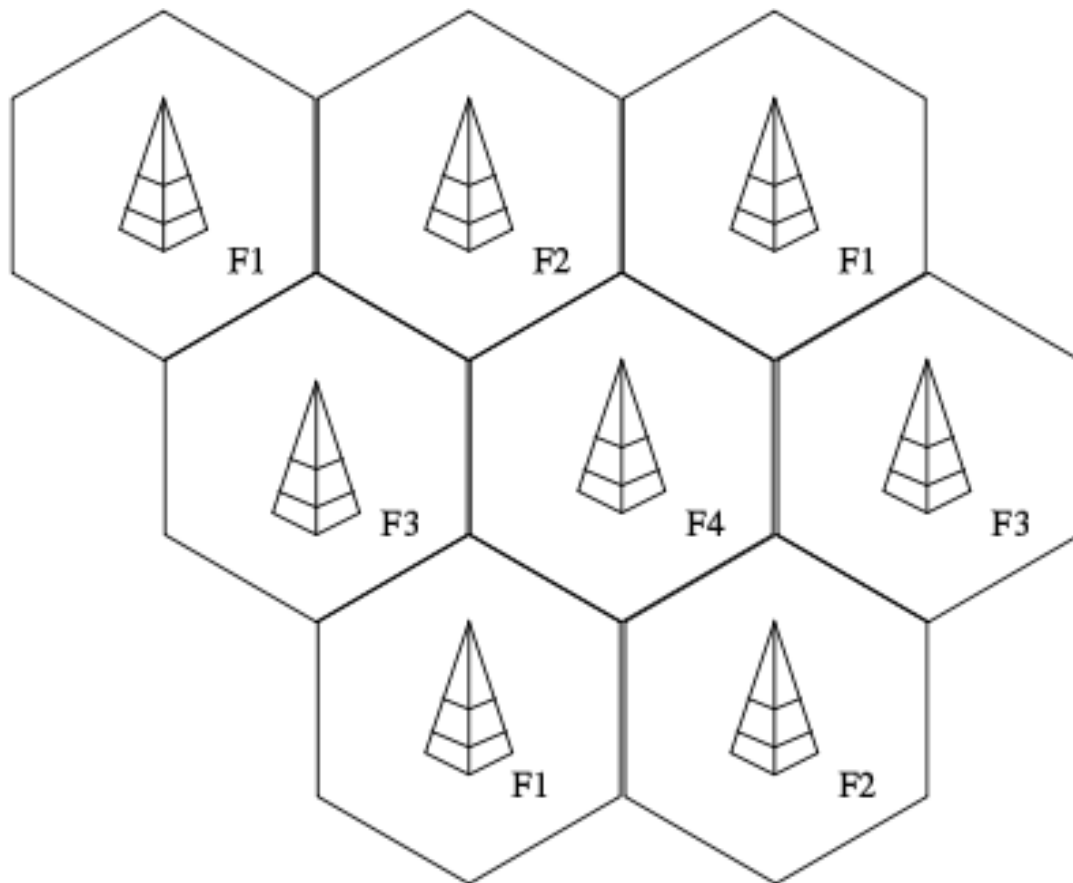


Figure 2.1: Cellular network

of the connection. DMO provides communications between terminals when they are out of the network coverage area.

As regard to DMR, this technology is more recent than TETRA and was developed by ETSI to grant gradual migration from the analogical conventional system to digital mode without new licenses and without changing the existing network architecture. DMR uses 2 time slots on a 12.5kHz bandwidth carrier, using TDMA and 4-FSK modulation; since the modulated signal has constant envelope, a transmitter can work in saturation (clipping) mode (C class or superior) with very low consumption (e.g., photovoltaic power sources can be used for base stations). DMR has a maximum bitrate of 9.6kbps, and can works in simulcast mode (figure 2.6), in star, linear, ring or tree configuration (figure 2.7) to provide a wider coverage area (until 80km), using a frequency pair only. Network and terminals can be dual mode,

thus granting the coexistence of analog and digital devices.

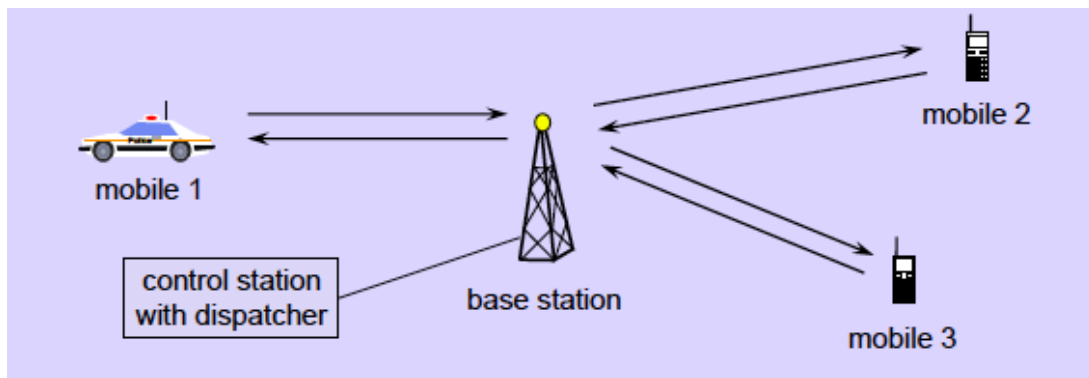


Figure 2.2: Trunked mode operation with dispatch

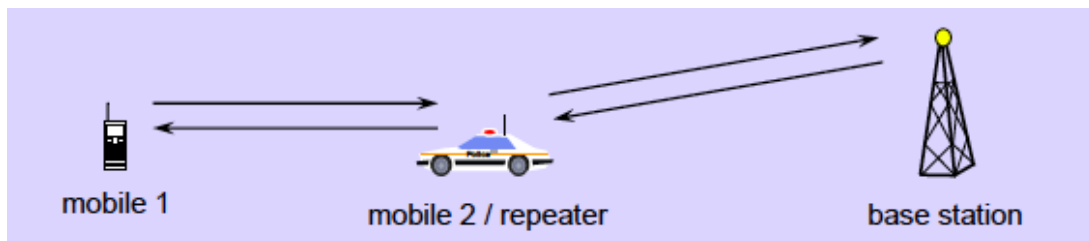


Figure 2.3: Repeater operation

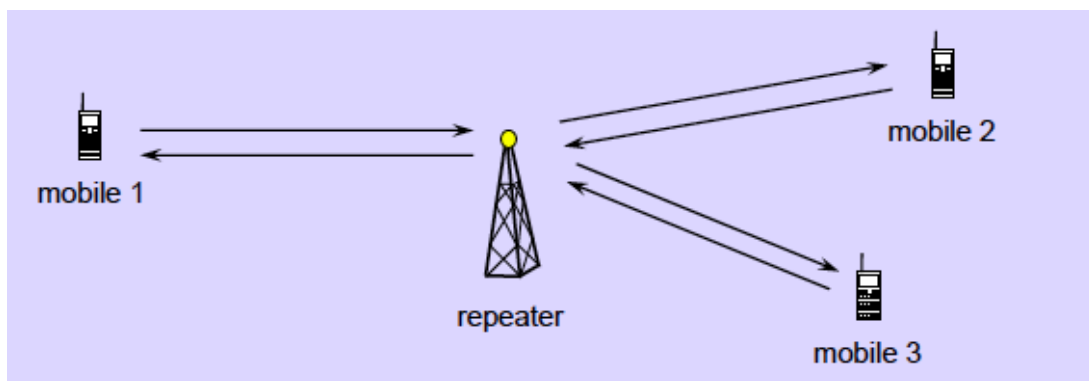


Figure 2.4: Repeater DMO

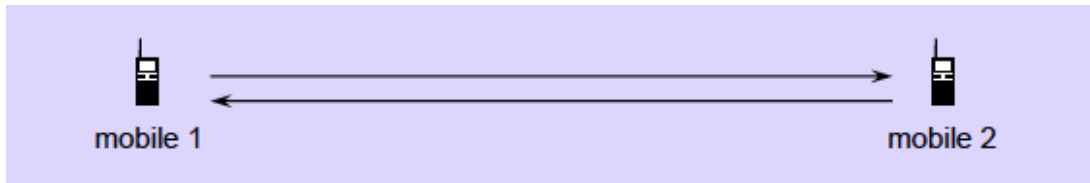


Figure 2.5: Basic Direct Mode Operation (DMO)

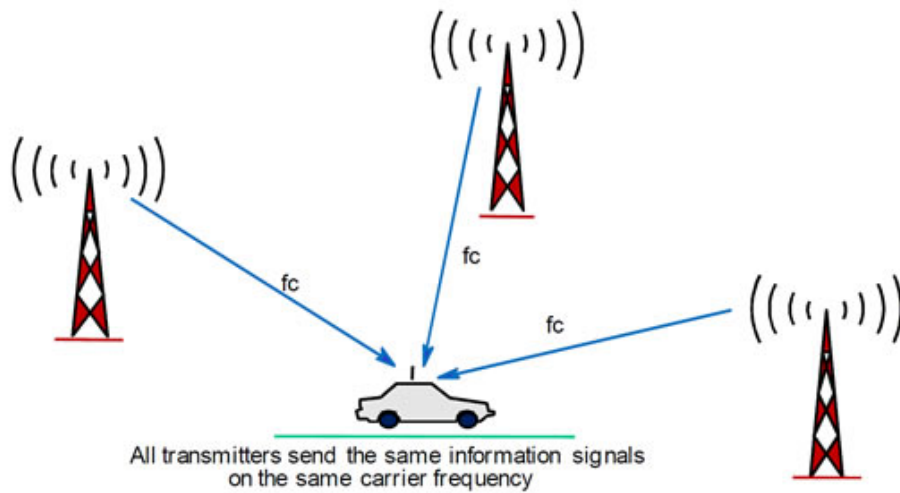


Figure 2.6: Simulcast mode

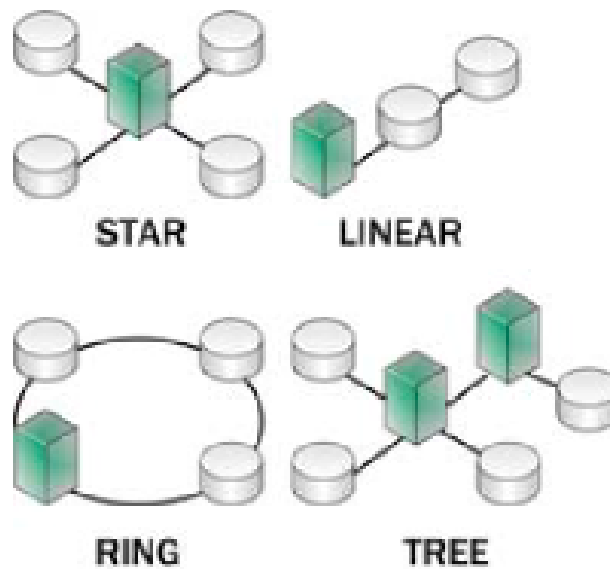


Figure 2.7: Typical network architecture

2.3 PMR systems in the European scenario

In Europe, either TETRA or DMR solutions have been deployed based on specific market requirements, existing technologies and orographical constraints. A wide number of European countries have adopted TETRA for public safety and security organizations. In 2004 in Netherlands, the C2000 project has provided implementation of a new digital TETRA radio communication network to organizations, like police, fire brigades, police, ambulance services and so on. Other European TETRA projects are Airwave in UK, RAKEL in Sweden, ASTRID in Belgium and VIRVE in Finland. In Italy, the Emilia-Romagna region opened the digital radio network named R3 for mobile communications professional. It was the first Italian region with self-designed TETRA radio network for health emergencies, civil protection and security. Regarding DMR networks, they are mainly suited for organizations which are not engaged in mission-critical work but which can still benefit from features usually associated with mission-critical systems, such as transportation, private security and small municipality users. DMR is also specifically targeted at systems where analog PMR is currently applied and to deliver digital voice, data and other supplementary services in a simple and low cost manner. A DMR system was built for the organization of the G8 meeting L'Aquila, Italy: that DMR network consisted of more than 70 base stations, organized into 7 simulcast networks and located in 30 geographically distinct areas of Central Italy, enabling radio communications between the DMR operational centre and more than 500 digital portable terminals of the Civil Protection and other institutional operators. As for health emergency service scenario, analog systems still result predominant, while both literature and market contexts lack of a clear choice of the digital PMR standard which may result most suitable to address the health emergency service requirements. If we refer to the Italian market, the

80% of solution for health emergency service implement analog technologies or 2G services, which are often used as backup due to the inefficiency of the analog coverage. Some regional authorities provided for migration to digital solutions building VPN-based TETRA networks for all public services, while in other case, DMR solutions were implemented to grant long range coverage.

2.4 DMR vs TETRA

In order to evaluate a PMR solution which results most suitable with respect to health emergency requirements, we carrier out a comparison between the main digital PMR standards that are used in European countries, that are DMR and TETRA. Different features have been taken into account:

- Coverage area: taking into account the same environment and morphological ground, the coverage area depends on the following factors:
 - dynamic sensitivity of the receiver, that shows the minimum signal to which the receiver begins to decode a transmission. It depends on both bit-rate and signal bandwidth and, typically, is equal to -110dBm for a DMR terminal, while is -105dBm for TETRA;
 - working frequency band: the area of coverage is inversely proportional to the frequency. Consequently, DMR standard may allows a coverage area greater than TETRA standard, because although both DMR and TETRA can work in VHF and UHF, TETRA is only used in the frequency band from 380MHz to 510MHz, while DMR may be used from 80MHz (low VHF) up to 470MHz;transmission power of

the mobile terminal: TETRA terminals are equipped with linear amplifiers, so that they transmit with power equal to 1W, while transmission power of DMR terminals is significantly higher (up to 5W).

Typically, the coverage area for a DMR radio system technology is twice that of TETRA technology. In other words, for the same coverage, TETRA requires twice as many base stations.

- Spectral efficiency: based on the available bandwidth for each channel, the frequency reuse factor (which is determined by the Carrier to Interference C/I), the cell size and the channel access technology. A TETRA base station offers 4 timeslots in 25kHz and a common signaling channel. DMR offers 2 timeslots, each one with 6.25 kHz of bandwidth, to transmit both voice and data. Then, the spectral efficiency of TETRA and DMR is equal to 4channels/25kHz. However, spectral efficiency of TETRA is reduced, due to difficulties in the reuse of frequencies between neighboring cells (it has to be noted that in practical situations, the distance between TETRA base stations is less than 10km).
- Green IT: DMR is the best solution with respect to the energy saving. TETRA must always consider both the linearization of the transmitter and the control channel. Therefore, a TETRA base station requires 8 to 15 times the power of DMR base station and thus higher energy consumption due to air conditioning systems. DMR base stations require 0.8~1.2kWh/day, as well as analog technology, and can be powered through the use of photovoltaic panels. This is not possible for existing TETRA base stations which require from 10 to 15kWh/day.

- Flexibility and Simplicity: TETRA network architecture is much more complex than a DMR one. It needs powerful nodes for switching, a broadband transport network and an accurate planning of both the reuse of frequencies and the coverage area. DMR, on the contrary, allows for implementation of different network configurations, the reuse of the same frequencies, and, through an IP backbone network, it can be easily upgraded with moderate costs.
- Lesser impact on existing systems and reusability of investments: DMR technology is an evolution of analog technology. Therefore, analog configuration could be retained, unless to integrate the number of satellite stations to optimize coverage; it is thus possible to reuse much of the sites with a significant cost savings. In addition, with dual mode terminals, it is possible to savings in migration costs and optimize the management of the migration.
- Easy implementation of the transport network: the transport network in a DMR system consists of the links between the base stations and between the base stations and the operative center. They can be implemented using mono-channel links in UHF band and their technology is built on special modules integrated in the same base stations. In the case of TETRA network, it is necessary to use broadband connections, such as radio links or optical fiber channels. When choosing DMR, simple construction of new sites or adaptation of the existing ones is possible with additional cost savings.
- Full-IP: this feature is currently available with either TETRA or DMR. Indeed, from January 2010 full-IP DMR solutions have been deployed by different vendors (Hytera, Radio Act ivity, Selex Communications).

2.5 The DMR radio network

The main components of a DMR network are the following (figure ??):

- User terminals (portable/vehicular): DMR terminals have to be dual mode to operate on both analog and digital system, according to the specifications described above. In addition, the terminals must enable the delivery of state change messages and GPS coordinates;
- Base transceiver station: a BTS is the interface between mobile terminals and DMR infrastructure; it is operating in the UHF band (450MHz). The base stations have to be distributed appropriately across the territory and it must be accessible for in situ management operations. DMR provides for three types of base stations, as analog systems: master, sub-master and satellite (or slave). The master chooses the best signal between the incoming ones from the slave stations, and sends it to all other stations. A particular BTS has to be installed in the Operative Center to allow network operators to access the radio resources.
- Central Office (CO): refers to the dispatcher workplaces, the server radio and the Network Management System (NMS).
- Transport Network: this may consist in mono-channel links (if a single pair of frequencies is configured) or additional infrastructures like PDH radio links or optical channels.

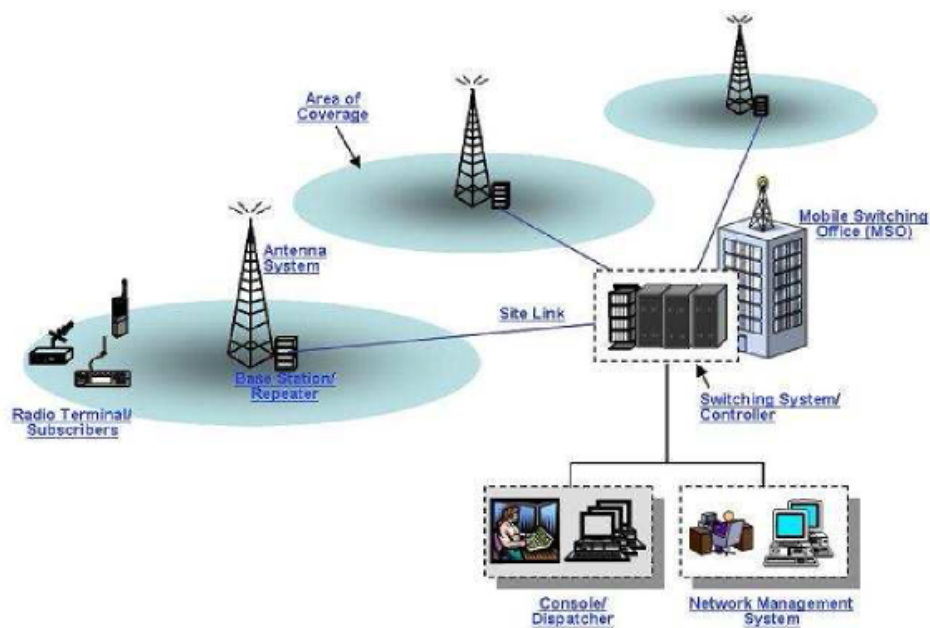


Figure 2.8: DMR radio network

2.6 Case study: DMR Networks for Health Emergency Management

The first case study describes the design of a practical DMR network, specifically the radio system for the health emergency service in Sardinia island (Italy). The objective is satisfy the requirements of the health emergency service, then to illustrate the advantages of migrating from analog to digital technology. Finally, we discuss the capabilities of DMR technology to provide the best solution for a wide regional emergency network with cost saving constraints.

2.6.1 Description of the current SimulCAST network

The current analog radio system is based on synchronous isofrequency technology, and uses Prod-El ECOS CTS (Coherent Simulcast Technology) modules manufactured by Selex Communications. In the CST network family, repeaters are interconnected through single-

channel UHF links, which are integrated with radio base stations. Synchronisation of all network repeaters is derived directly from the UHF radio carrier generated by the master station, with no effect on the 300 to 3000 Hz audio band. All repeaters in the network are synchronised in both frequency and phase: this allows all carriers to be broadcast coherently. This unique and patented system, called SDP (Sincronismo da Portante), together with the bi-directional signal equalisation carried out using DSP (Digital Signal Processing) techniques, permits mobile units to receive perfectly, even in equi-strength fields. Nowadays, this system allows partial coverage of the regional area. Voice communication are in half-duplex mode. Thanks to its flexibility, ECOS CST allows different network configurations (star, tree, linear), through the implementation of nested infrastructure levels, using master - submaster (or secondary master) - satellite station.

As shown in figure 2.9, a master station is the root of the tree; it takes the traffic from the leaf nodes (submaster and/or satellite), selects the better signal and sends it on to other BTS. It generates the criterion for synchronization of all network stations. The submaster station is a repeater station; it is connected to the master station and to one or more satellite stations. The submaster select the best signal among those from lower levels (submaster stations or other satellites) and forward to the next level, i.e. master or submaster. In addition, the submaster receives the selected signals by the master station and rebroadcast at the lower levels. The satellite station transmits to the upper level (master or submaster) the signal from a terminal and resend to terminal the best signal selected by the master. The interconnection between BTSs is made through a link in a single UHF 12.5kHz channel. The Central Office is connected to its master station through a single-channel UHF link. The network providing service to the Central Office for the north region consists of 15 base stations: 1 master, 3 submasters, 11 satellites. The network providing service to the Central Office of the south

region consists of 14 base station: 1 master, 3 submaster, 10 satellite.

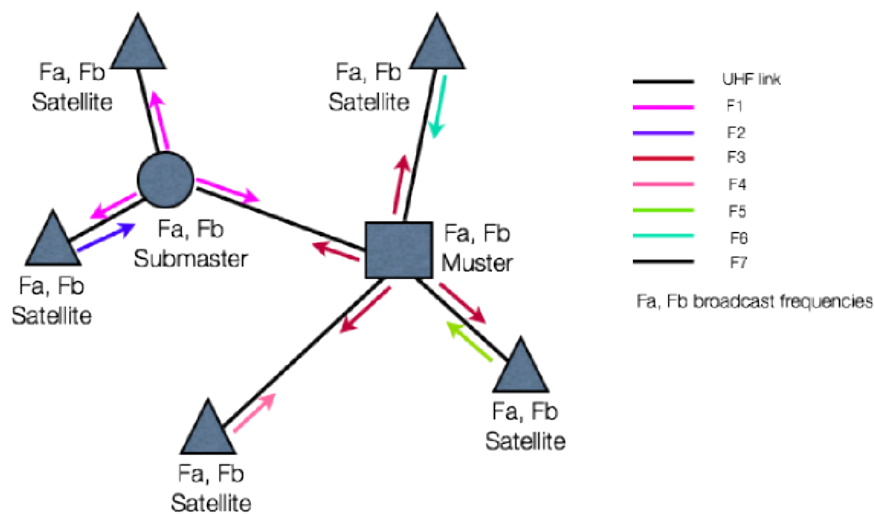


Figure 2.9: Simulcast network

2.6.2 Health emergency requirements

The main requirement of the radio network for Sardinia health emergency service is to provide full coverage of the whole region with specific regard to coast and valley regions that today result out of service. Data transmission is also a mandatory requirement due to the evolution of digital applications which will provide new opportunities in health services. In today scenarios, health emergency is mainly based on voice service, while data services are limited to information on ambulance status and geo-localization. However, in the next years the progress in the telemedicine market will require integration with health emergency service, by just upgrading digital infrastructures (for example, number of frequencies) to improve the available throughput. The system also requires flexibility and resilience so that it is recommended to be full-IP. This means higher efficiency and the ability to enable integration with other IP networks improving design, management functionalities, data center configuration and new services implementation. Finally, the new network has to be realized

by providing the highest cost saving through the re-use of existing sites and infrastructures.

2.6.3 A DMR-based solution

As a result of the analysis of TETRA and DMR features and performance, we decided to use DMR standard to implement the radio network for the 118 service in Sardinia. Indeed, DMR allows us a significant cost saving while providing all required functionalities. We can assure the coverage of the entire region with a fewer number of sites than TETRA and by reusing all existing sites and infrastructures. In a DMR network, the transport network requires less bandwidth than TETRA and can be realised in microwave links, fiber optic, copper pairs, generic TCP/IP connections, and unlike TETRA, even in mono-channel UHF. Further, since DMR is able to operate in dual mode (figure 2.10), it allows an easy management of the transitory and the re-use of analog terminals.

As regard to data transmission, both TETRA and DMR require to be configured with a higher number of channels to support data flow over dedicated or shared frequencies; in the case of DMR, upgrade of frequencies may be done by simply adding new modules on base stations. The biggest problem in the isofrequency networks concerns the effects on the receiver of the mobile terminal caused by the simultaneous reception of signals at the same frequency and with power levels that are different by 6 and 10 dB maximum. In this overlap area, the receiver could not catch the signal in any appreciable way. The size and shape of the overlap areas depend on the location and height of sites, from the lobes of the antennas, the power of the repeaters, and of course, orography. The phenomena that reduce the signal quality in overlap areas are due to both differences of $40\div 60 \mu\text{s}$ between propagation delays of signals redistributed, and degradations of the carrier synchronization. In network plan-

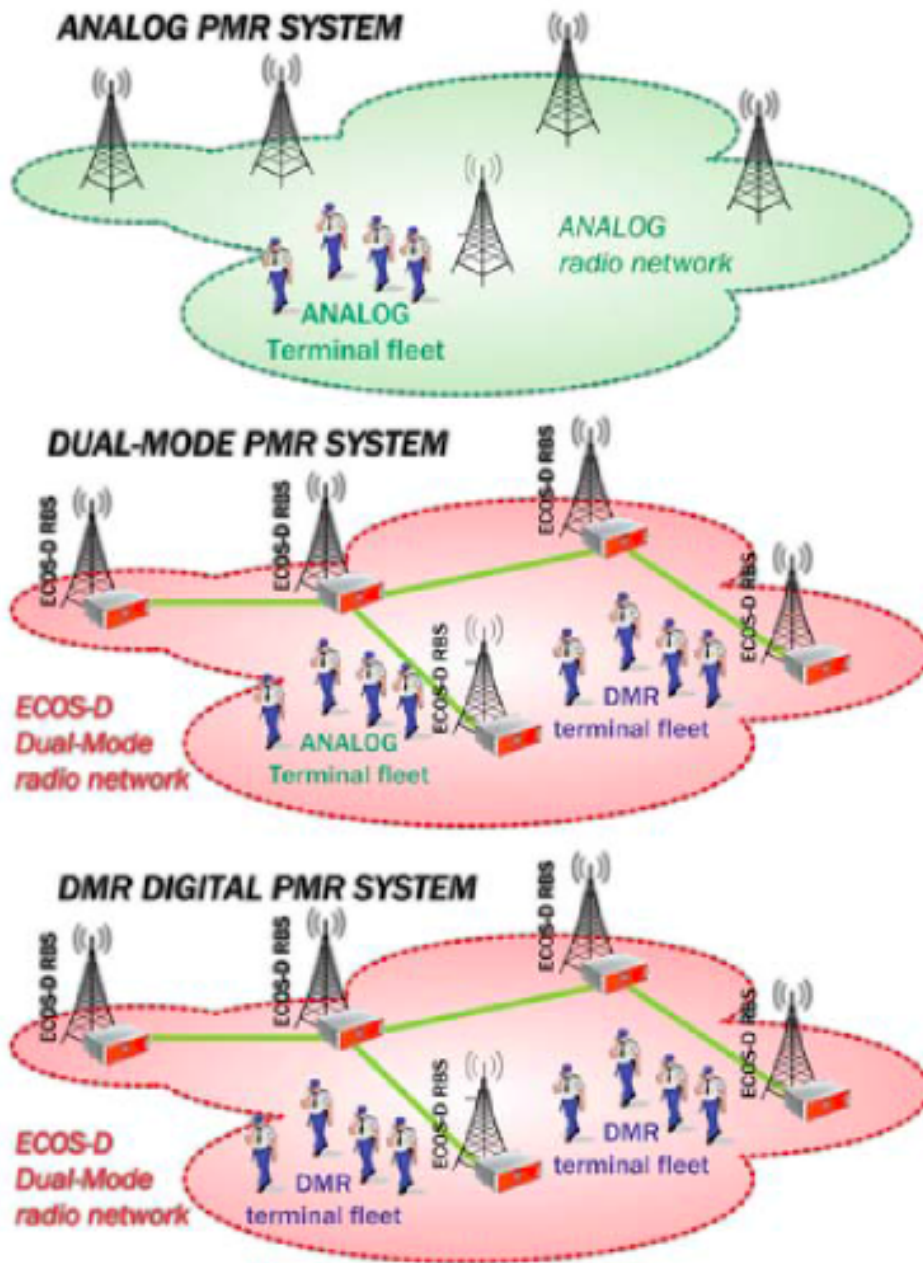


Figure 2.10: Differences between analog, dual mode and DMR DIGITAL PMR system

ning, to minimize overlapping areas, it is important to act on parameters of the transmitter. If such phenomena persist, a user may move away to find a place with better coverage. Anyway, these drawbacks on area overlapping are more easily solvable than problems arising with TETRA networks, such as interference between radio channels due to the cell topology.

2.6.4 Radio network planning

Planning the DMR network for 118 service in Sardinia involves the definition of the number and position of BTSs, configuration of the Operative Centre and topology and technology of the Transport Network. We chosen a DMR network operating in UHF band (450MHz) with a simulcast architecture based on a TCP-IP backbone, according to the specifications and requirements described previously. This is the best solution to ensure reliable data and voice communications over wide areas with a low/medium density of traffic. Simulcast networks also guarantee the following functionalities: configuration flexibility and expandability, easy traceability of users, continuity in communications, minimum call set-up time, dedicated channel access, automatic hand-over and roaming. For radio propagation simulation, we used a software package to provide an efficient and accurate estimation of the coverage area. In particular, we simulated the link budget in download and upload by settings the parameters as in Table 2.1, and using omnidirectional antennas (frequency range 430 ÷ 470MHz). The link budget shows a difference of 10dB in the path loss for the two directions (downstream and upstream). This is due to the fact that the base station transmission power is greater by a factor of 10 than terminals. The critical path loss is the one in uplink (150dB), due to limited power available for terminals. The signal threshold has been set through critical path loss and attenuation values simulated using the Okumura-Hata model [7].

	<i>Downlink</i>	<i>Uplink</i>
BS out Power (W)	20	10
BS out Power (dBm)	43	40
TX/RX Additional Loss (dB)	0	0
heightFeeder Loss (dB)	1	1
Combiner Loss (dB)	0	0
Duplexer Loss (dB)	1	1
Filter/Circulator Loss (dB)	0.5	0.5
Jumper-BS-side Loss (dB)	0.5	0.5
TOTAL Insertion Loss (dB)	3	3
Antenna Gain TX (dBi)	2	2
EiRP (dBm)	42	39
Body Loss (dB)	0	0
In Car Loss (dB)	0	0
Building Loss (dB)	0	0
TOTAL Loss Margin (dB)	0	0
Antenna Gain RX (dBi)	2	2
Sensitivity dynamic. RX (dBm)	-109	-109
Path Loss (dB)	153	150
Signal Threshold (dBm)		-106

Table 2.1: Parameter settings for link budget simulation

Figure 2.11 shows the resulting network architecture and the coverage area for the 118 service in Sardinia. A north and a south networks have been defined, according to the existing configuration. However, in order to provide a backup service, we provide for interconnecting each sub-network to each Central Office, as specified in the follows. The existing 30 base-station sites have been integrated which 29 new sites. In particular, the DMR north sub-network included 1 master, 5 sub-masters and 28 satellites, while DMR south sub-network is composed by 1 master, 4 sub-masters and 20 satellites. The 59 total sites are sufficient to ensure optimal coverage of the whole territory, as shown in the maps of network coverage (Figure 2.12).

Regarding the number of channels, we provide to configure the new DMR network to operate with a single channel (a pair of frequency), as the analog network. However, it is

DMR and South coverage.png

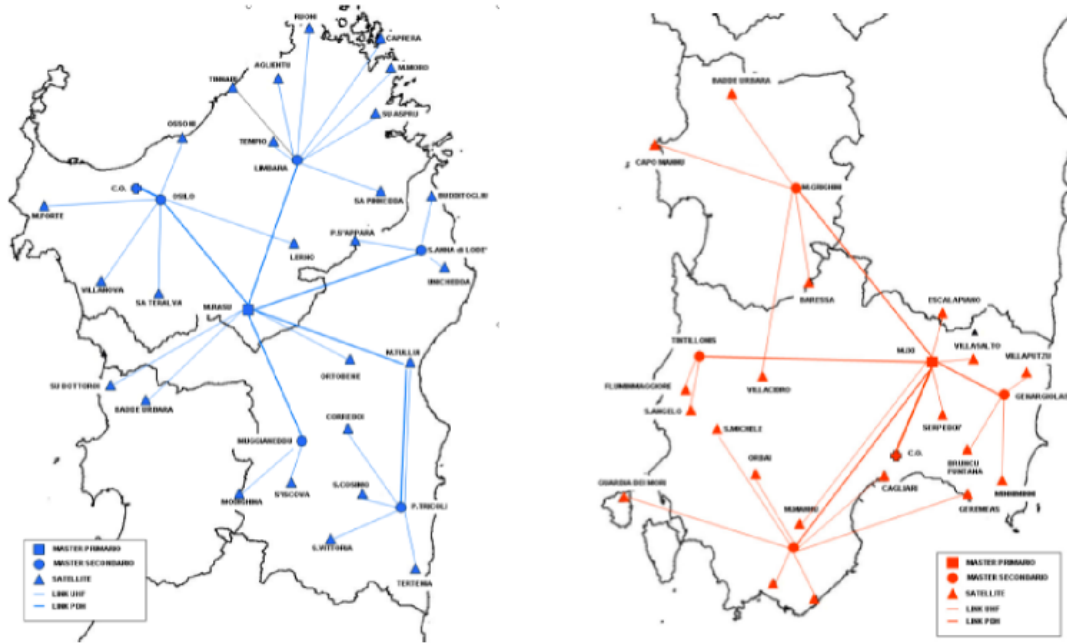


Figure 2.11: The "north" and "south" DMR networks

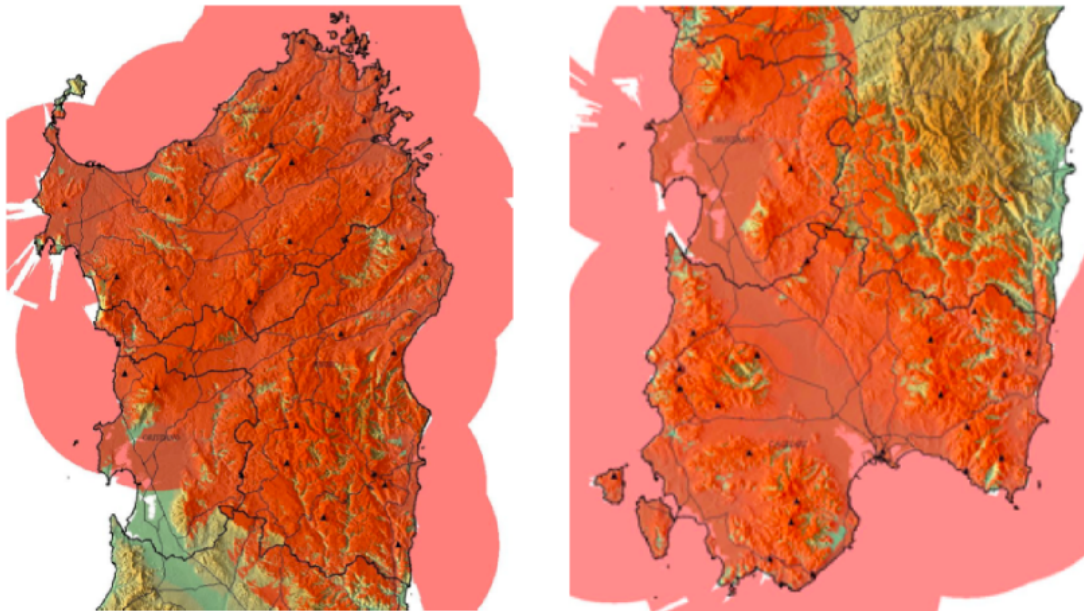


Figure 2.12: Coverage maps

possible to upgrade one or more additional channels to provide a configuration backup or to carry data traffic related to specific applications (i.e. telemedicine), while avoiding saturation in voice communication channels. Finally, in figure 2.13 the logical scheme of the Central Office and Transport Network is reported.

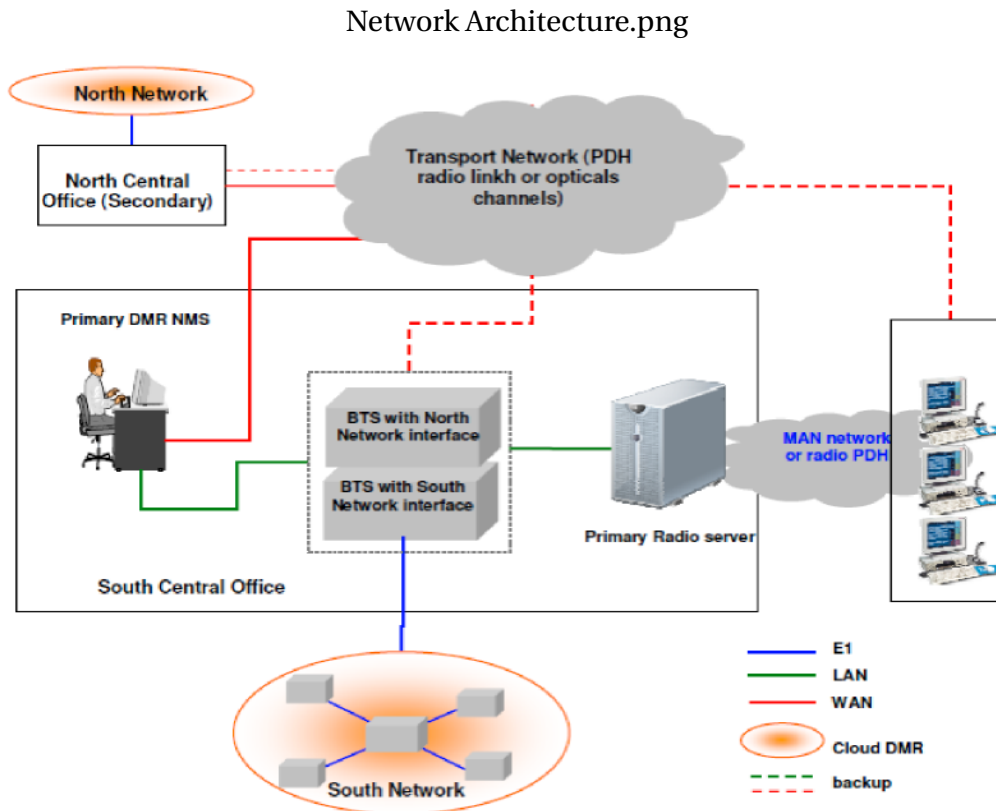


Figure 2.13: The logical network architecture

In order to improve availability and resilience of service, we provide for interconnecting both north and south networks to each Central Office, achieving interdependence between them. This may be implemented by installing into each Central Office two BTSs or BTS modules, one for each subnetwork. In particular, we elect the South Central Office as the primary one, while the North Central Office is the secondary one and become operative in case of fault of the primary CO. Note that this configuration replicates the one which is implemented for the current regional health services. In order to achieve redundancy and high availability,

we provide for interconnecting masters and COs either with PDH radio links or optical fiber channels.

2.6.5 Results and discussion

The main focus was to design of a radio network in the region of Sardinia in order to migrate health emergency service from analog to digital technology. We analyzed different PMR standards with specific attention to TETRA and DMR technologies. DMR has been identified as the best solution, which grants cost saving, high coverage, spectral efficiency and simplicity in network configuration and is well suitable in wide area with a low/medium density of traffic.

2.7 Case study: DMR Networks for Civil Protection Services

Radio network design for Civil Protection in Sardinia must to satisfy the technical specifications described by the Technical Group, as defined in Art.9 of the Understanding Agreement for the spectrum licensing, stipulated between the Minister of Economic Development and the Department of Civil Protection. These specification aim to realize an interoperable National Radio System, based on radio networks already realized from each region, which use common and free frequencies made available from the Department of Civil Protection.

2.7.1 National Program of radio networks for Civil Protection services

In the last years the Civil Protection Department has started a program for realaizing a radio communication system at the national level, based on homogenous regional and/or semi-regional networks, which aim to ensure a good radio-coverage on the whole Italian territory and reliable radio links for all forces deployed/intervening, included those coming from other regions to help and manage specific critical situations.

This needs derive from significative past experiences in emergency conditions, which required a specific professional radio system, different respect to the usually communications provided by commercial communication networks, with high-performance and high-reliability solutions to guarantee critical information security. Therefore, for dealing with emergency situations is indispensable planning a specific communication system for ensuring an efficient service of Civil Protection and in this specific case, the system have to be

based on dedicated radio network that provide to all users to have always an available radio channel. The channel is composed by a couple of reserved and free frequencies, ensured from the Understanding Agreement as previously mentioned. In the last years, the Italian regions had already realized own radio network in agreement with national program and other regions have just started the procedures to do it, for example Piemonte, Lombardia, Friuli–Venezia Giulia, Liguria, Marche, Lazio, Campania, Puglia, Calabria, etc. With evolution of radio networks from analog to digital technology, even the management of emergency is able to exploit new services, especially thanks to DMR radio networks, which are able to work in analog technology, to ensure the total interoperability of all analogical terminals just used from National System of Civil Protection, and to work in digital communication.

2.7.2 The new radio network for Civil Protection in Sardinia

The Civil Protection service of the Sardegna region, has not an own radio-mobile network yet, indispensable for the management of the critical situations, overall in case of natural disaster. Nowadays, each voluntary organization uses a own radio network or take advantages from other external infrastructures. The new radio network is based on the use of a couple of frequencies per semi-region and/or province, where, the last one can be interpreted as area territorially homogeneous. Specifically, the Understanding Agreement, as show the Figure 2.14, made available:

- a couple of frequencies for the realization of isofrequential channels radio called "Institutional", reserved for institutional structures involved in the management of emergencies;

- a couple of frequencies for the realization of isofrequential channels radio called "Voluntary" used by voluntary associations.

In view of the orography of the territory, to ensure a high degree of resilience, and in view of a increase in emergency operations during natural disasters or other emergency events in the Region of Sardinia, we have planned the realization of two radio networks for each province and, for each one, it will be allocated a channel (two frequencies). In particular, for each province will have:

- a radio network "Institutional" which will allow communication in the DMR mode;
- a radio network "Voluntary" which will allow the communication in ANALOG or DMR mode.

The proposed solution allows to obtain optimum coverage of the Region of Sardinia. New radio system implementation for the Civil Protection of Regione Sardegna, needs the following:

- provincial networks described above;
- central office of Civil Defense, located in Cagliari;
- portable terminals, vehicular and for fixed places.

The management system of the radio network and resources related to it, the centralization and coordination of all communications and then all the resources available to deal with emergency situations, are going to be located within the Regional Operational Centre of Cagliari. The operators of the Central are going to have an equipment suitable for communications (voice and data) and monitoring, for having the opportunity to interact with

the Central Office of the National CPD (Civil Protection Department). This interconnection will ensure to the staff of the ISS (Italy Situation Room) the operativity on the radio networks present in the damaged area due to calamitous event, through access to radio channels of the radio network of the Region of Sardinia, even on multiple channels simultaneously.

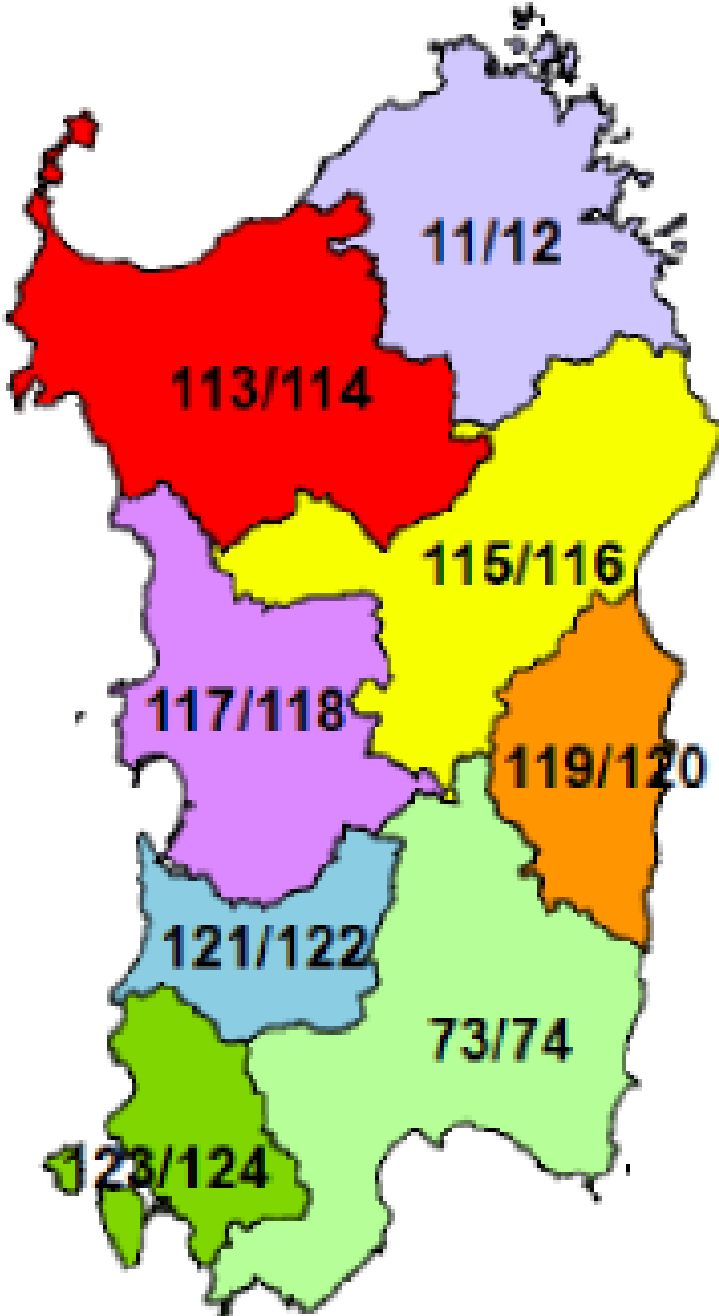


Figure 2.14: Provincial channels

2.7.3 General diagram of the radio network

The radio network infrastructure is going to be isofrequential, based on Simulcast synchronous solutions and it is going to allow to the radio network for Civil Protection services to work in FM analogic mode or "dual mode" analog FM/digital DMR, to consent a natural migration toward technologically advanced systems, even ensuring the total interoperability for all analogical terminals already used by the National System of Civil Protection. The radio network is composed by broadcasting equipment to provide an efficient and affective service of radiomobile communication respect to operative needs of the National System of Civil Protection of the Sardinia region, and to ensure high degree of resilience. As stated previously, the architecture of the new radio network will be simulcast type. In general, this architecture can provide two types, the first one characterized by connections with single-channel UHF system designed and introduced on the market in the '80s by Philips Radiocommunications for simulcasts of analogue networks; the second one characterized with connections via cable or microwave radio system created by the German company AEG in the late 70s. However, nowadays, it is possible the design and the set up of the radio network with configuration "mixed". Respect to the orography of the territory to ensure a high degree of resilience and to deal with possible growth of emergency activities, the radio system for the Civil Protection is going to consist of two radio networks for each province, each of which will be allocated a channel (two frequencies). Ultimately, the project provides 16 radio network realization with the use of 16 channels (8 pronvinces):

- 1 channel in DMR mode for each province for institutional actions;
- 1 channel in DMR or ANALOG mode for voluntary actions.

Therefore, for each province (Cagliari, Carbonia / Iglesias, Medio Campidano, Oristano, Sassari, Olbia / Temple, Nuoro, Ogliastra), the whole network will be composed by (figure 2.15):

- an "Institutional" radio network for DMR communications;
- a "Voluntary" radio network for dual-mode communications whit automatic switching between ANALOG and DIGITAL mode;

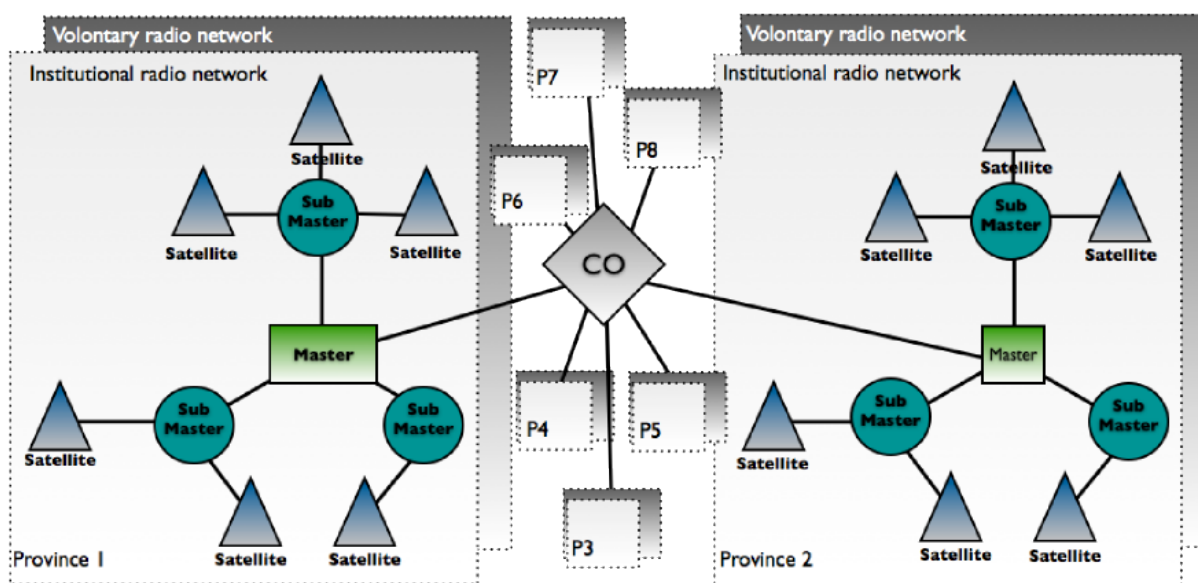


Figure 2.15: Provincial radio network scheme

The BTS (base transceiver station) can be Master (figure 2.17), Submaster and Satellite type (figure 2.18). Each BTS will take place on each site of RRN network (figure 2.19). For the connections between the base radio stations, the new radio communication system will use a multi-channel radio system, with digital microwave radio link available thanks to Regional Administration (Regional Radio Network), which are be able to transmit both voice and data communication of the DMR network, and other different services which need connections in regional level. For coordinating and the management of all activities applicable to the Civil Protection services, the CO will be allocated in Cagliari.

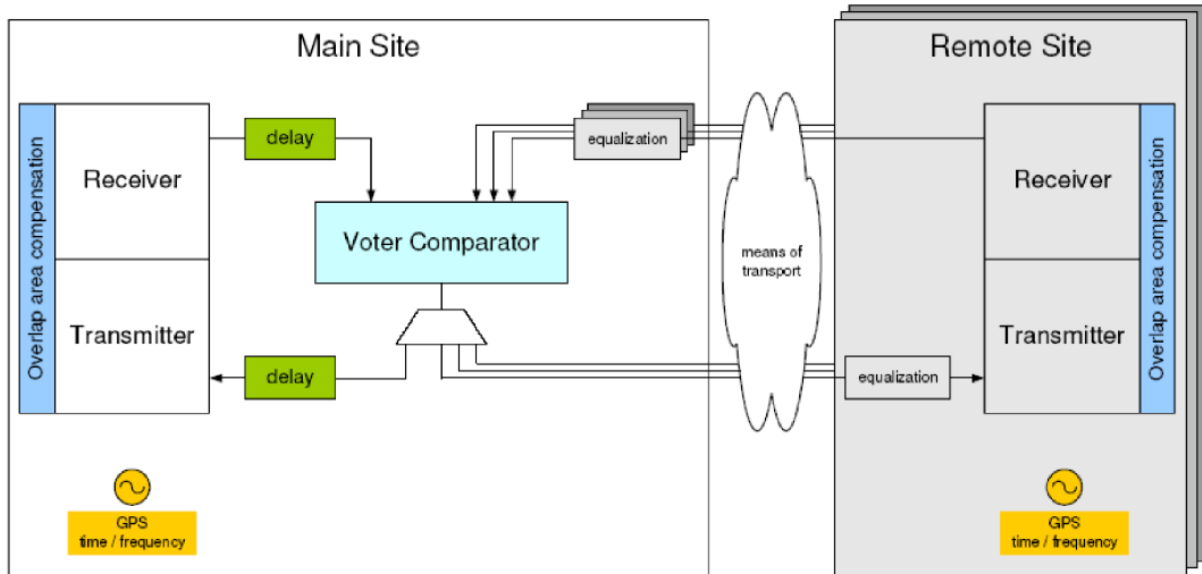


Figure 2.16: Link between main and remote sites

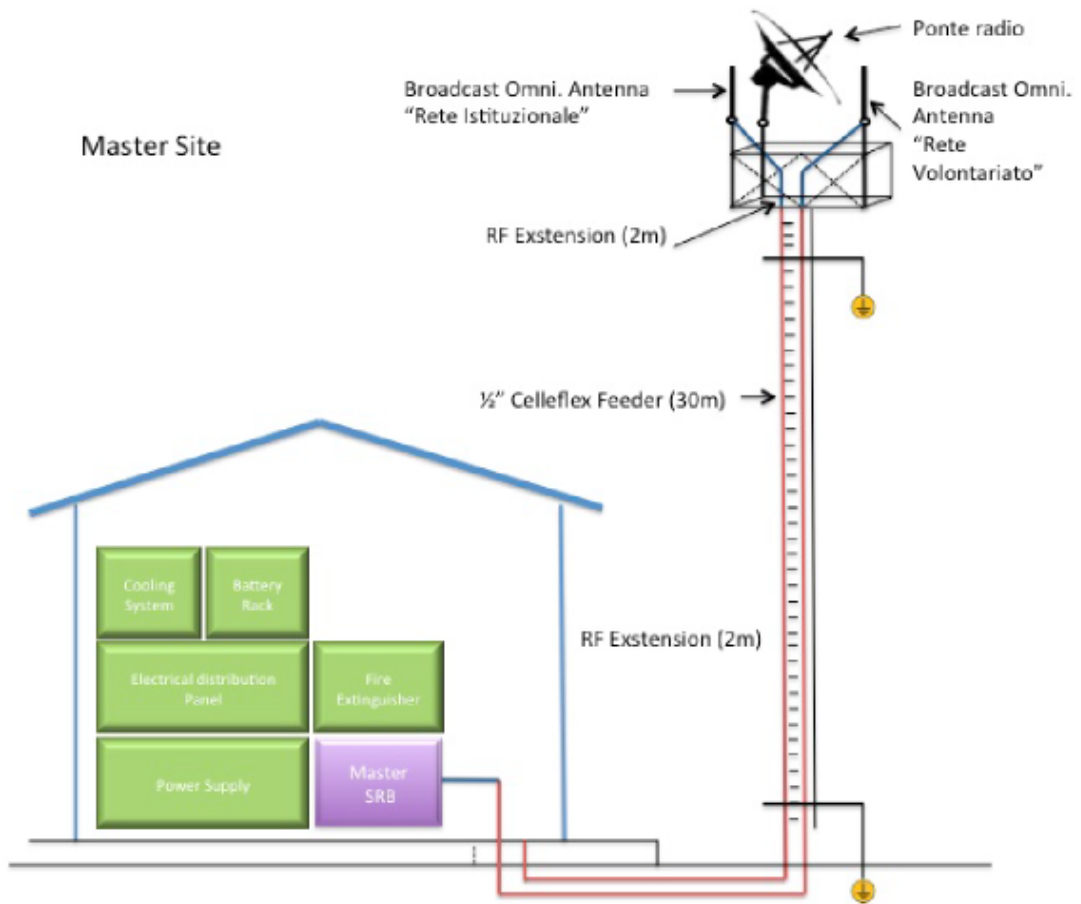


Figure 2.17: Master Station

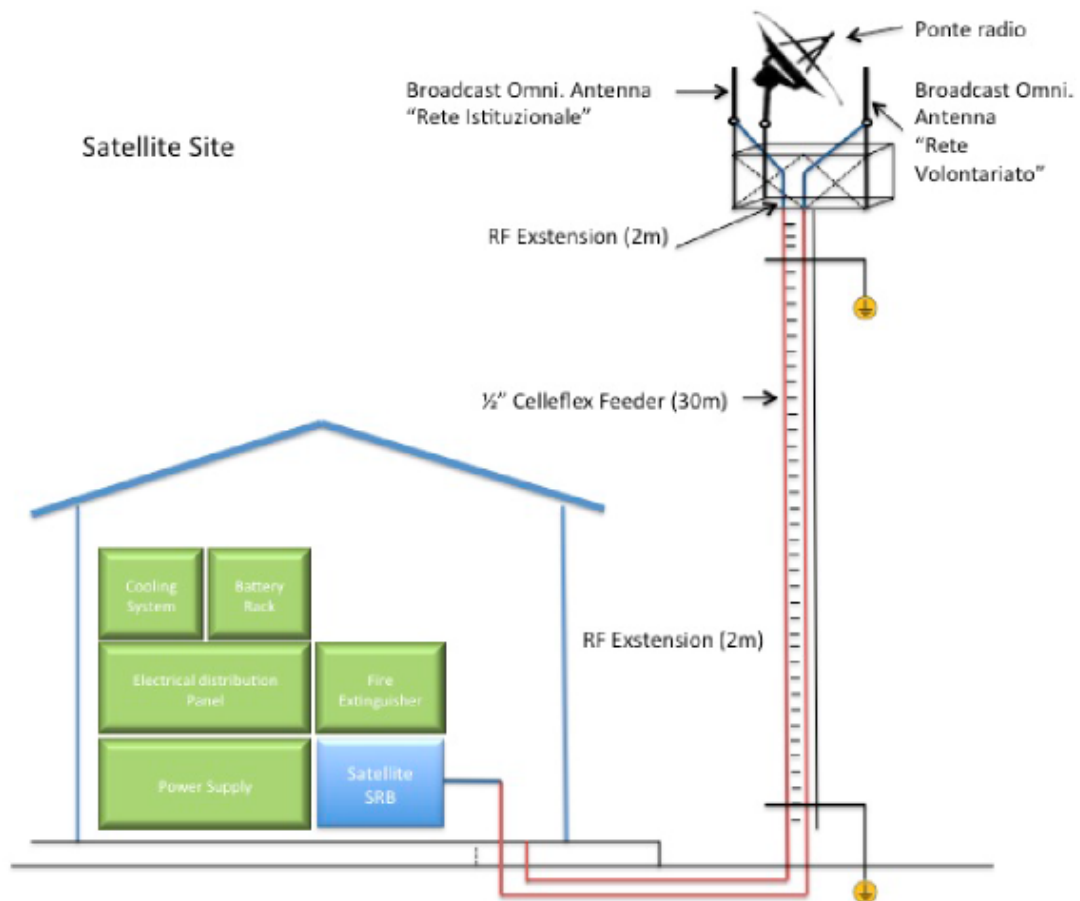


Figure 2.18: Satellite Station

2.7.4 Results and discussion

Each BTS will be placed on the Regional Radio Network. It is composed by 30 sites and 4 Regional Operative Central which are managed from the Department of Defense of the Environment, and moreover it will be added four sites to guarantee a total coverage in the following zones: urban and suburban area of Olbia, Bosa, the islands of S. Antioco and S. Pietro, urban and suburban area of Cagliari (for the latter we have used the Belvedere site in Cagliari). We had used omnidirectional antennas (frequency range 136 ÷ 174MHz) with an Effective Radiated Power (E.I.R.P) of 10W. Each site is hosting at least an synchronous isofrequential repeater to ensure a global coverage specially in the risk areas, urban and suburban areas. For radio propagation simulation, we used a software package to provide an efficient

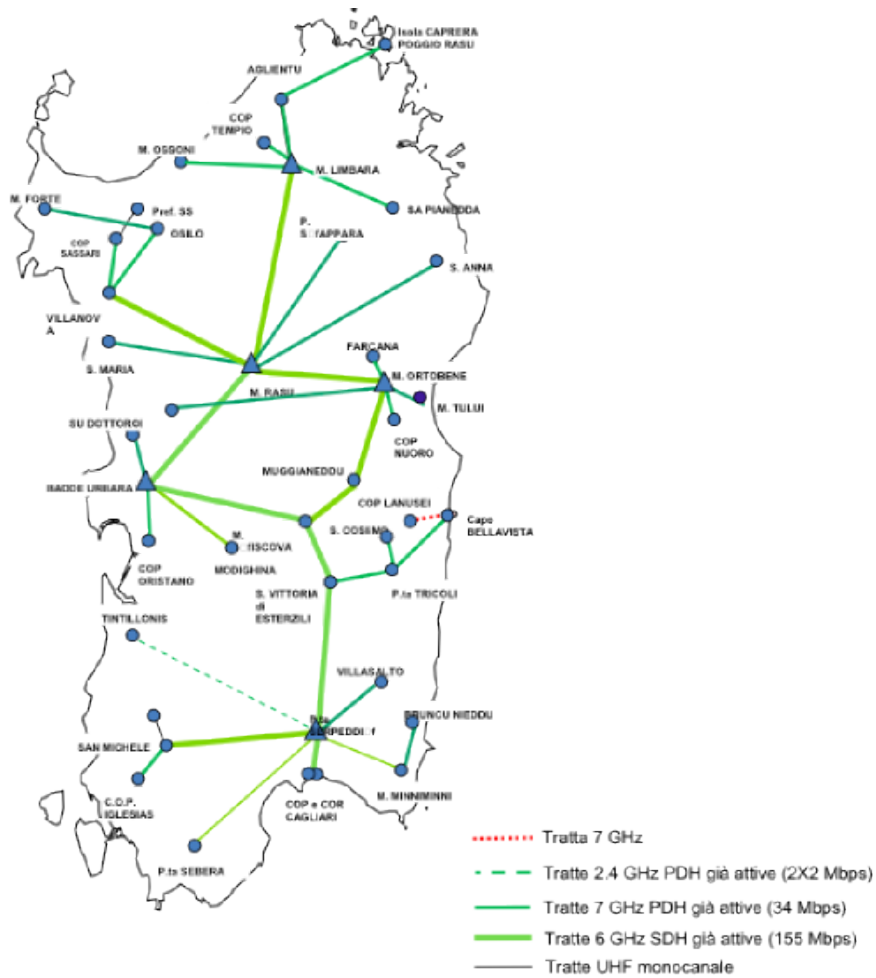


Figure 2.19: Regional Radio Network

and accurate estimation of the coverage area. The following images shows some example of radio coverage.

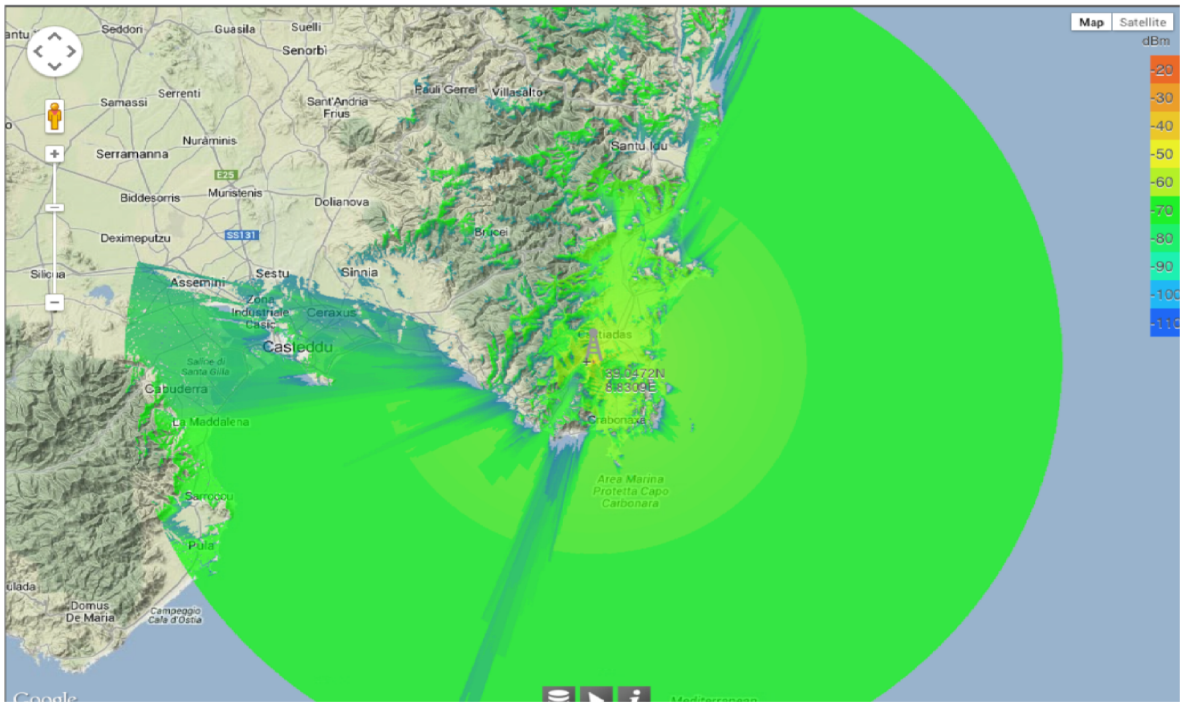


Figure 2.20: Radio coverage in "Punta Minniminni"

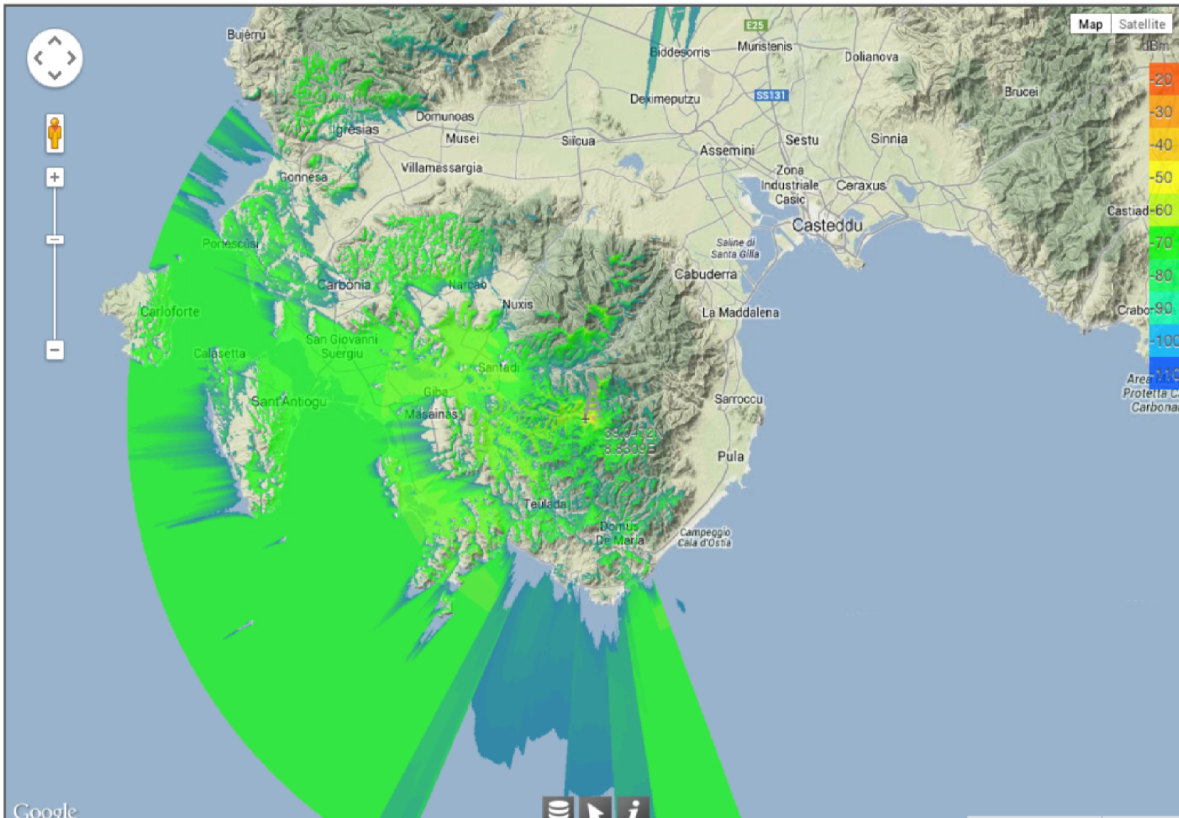


Figure 2.21: Radio coverage in "Punta Sebera"

Chapter 3

Control System for Workplace

Safety in a Cargo Terminal

Maritime ports are busy commercial, industrial and transport nodes playing a key role in regional economic growth. However, the concentration of shipping and land transport, port operation and people movements in a relatively small area can present serious work safety related issues. Despite the fact that sophisticated innovations in cargo handling equipment and methods, port work is still considered as one of the most dangerous land-based occupations with higher accident rates than other high risk industries. The underlying causes are the inherent danger of port work, the often inadequate management control, training and risk assessments combined by the increasing commercial pressure on ports and terminals for a quick turnaround of vessels. The shipping and port industries have started applying ICT technologies for increasing profitability and responding to the growing need of safety concerns of their clients and the operators. In this context, an application of particular importance is the design of an intelligent system for monitoring, reporting and preventing risks through the use of sensors, actuators and heterogeneous communication channels that are

able to interoperate both in terms of technology and system design. This intelligent control system is intended as a platform for real-time information capable of: video monitoring; sensor data harvesting; people and vehicles movement monitoring; automatic and semi-automatic risk prevention measures implementation; and systems implementation for augmented reality visualization of critical situations. These capabilities are the topic of a larger research project that aims to find the optimal solution in terms of feasibility and practical implementation.

3.1 Scenario and technologies

In the context of maritime transport, the container traffic plays a dominant role. This huge volume of traffic requires a continuous adaptation of port infrastructures, in order to make sorting of containers more efficient. Within a container terminal, for moving containers from ships to barges, trucks and trains and vice versa, different kinds of material handling equipment are used such as quay cranes, stacking vehicles, lorries, etc.

3.1.1 Functional areas of terminal operations

Usually, a terminal container is composed of four main parts: landside and quayside, storage system and cargo handling system (including gate, parking, office buildings, customs facilities, container freight station with an area for stuffing and stripping, empty container storage, container maintenance and repair area, etc.). As every other terminal, a container terminal is a complex system that functions efficiently only when its layout is designed in such a way that the loading and discharging process of vessels runs smoothly. The loading and unloading process is described in [8]. When a ship arrives at the port, the import con-

tainers have to be taken off the ship by Quay Cranes (QCs), which takes the containers off the ships hold or off the deck. Next, the containers are transferred from the QCs to vehicles that travel between the ship and the stack. This stack consists of a number of lanes, where containers can be stored for a certain period of time. The lanes are served by cranes and straddle carriers (SCs). A straddle carrier can both transport containers and store them in the stack. It is also possible to use dedicated vehicles to transport containers. The vehicle arrives at the stack and a crane takes the container off the vehicle and stores it in the stack. After a certain period the reverse process carries the containers to barges, deep sea ships, trucks or trains. This process, illustrated in Figure 3.1, can also be executed in reverse order, to load export containers onto a ship.

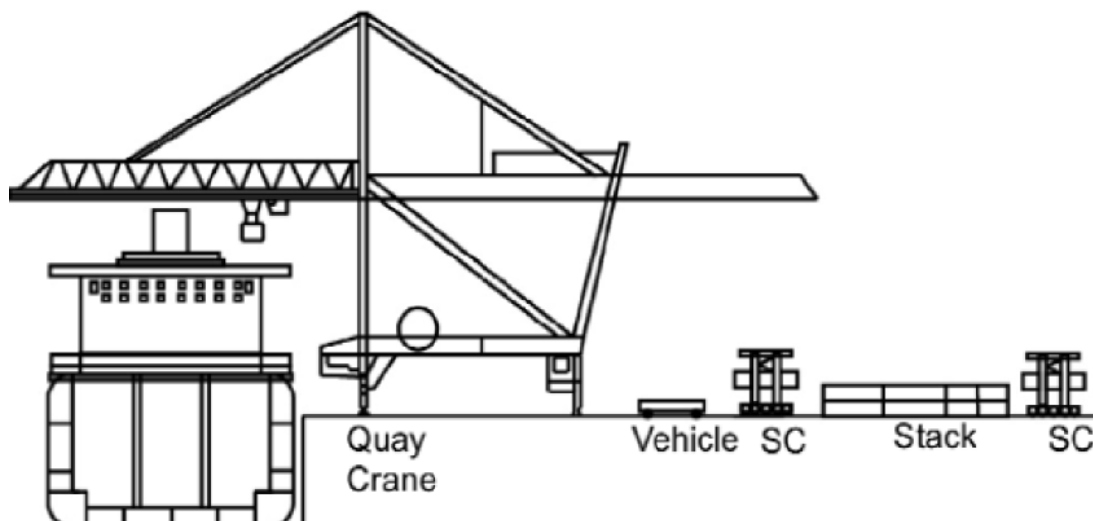


Figure 3.1: Process of unloading and loading of a ship

3.1.2 Workplace safety requirements

The concept of safety is one of the predominant concerns in various industrial fields, and in particular in the shipping industry. In this context, peculiar safety measures have to be

taken while handling, stowing and shipping containers. The Maritime Safety Committee (MSC) of International Maritime Organization (IMO) and also the Port Equipment Manufacturers Association (PEMA) announced in June 2011 new industry recommendations [9] regarding safety standards for quay cranes as a joint initiative with the TT Club [10] and ICHCA (International Cargo Handling Coordination Association). For the specific context of a maritime cargo terminal, the cause of damage to personnel or property may be of various nature: exposure to chemical carcinogens and mutagens, physical or biological agents, air or noise emissions, vibration, and ultrasonic radiation; accidents caused by contact with a mobile structure or moving vehicle. Therefore, personal protective equipment, like clothing, helmets, goggles, or other garment designed to protect the wearer's body from injury should be worn appropriate.

3.1.3 Body Area Networks

The use of sensors, actuators and heterogeneous communication channels can be used for minimizing the injury risks to personnel and damages to vehicles. In order to find the best solution, which can be used to suit the safety requirements, this paper proposes an infrastructure of BANs. A BAN is formally defined by IEEE 802.15 as, "*communication standard optimized for low power devices and operation on, in or around the human body to serve a variety of applications including medical, consumer electronics/personal entertainment and others*" [11]. Some of the more common use cases of BAN technology are: Body Sensor Networks (BSN), Monitoring, Mobile Device Integration, Personal Video Devices [12]. Sensors and actuators are the key components of a BAN used to describe wearable computing devices able to transfer data to a central unit through wireless links. A BSN is formed by a vari-

able number of sensors, called Body Sensor Units (BSU), all connected to the Body Central Unit (BCU). The BSUs acquire and collect specific data (e.g., body temperature, vital signs, distance from some reference sensors, etc.), processes them if necessary, and transmits the data via wireless links to a BCU. The sensor device design is usually composed by the sensor itself, a radio module, a micro-processor and an energy source.

3.2 Case study: Cagliari International Container Terminal

Cagliari International Container Terminal (CICT) is the fourth most important commercial port of Italy, handling yearly 708,000 TEUs (Twenty-foot equivalent unit) from over 900 ships. The terminal is composed by 400 thousand square meters of storage, 1.520 meters of quay with seven gantry cranes and one mobile crane, an yard capacity equal to 24.000 TEU with four reach stackers and eight front loaders. The wireless data infrastructure is constituted by thirteen 802.11 Access Point (AP) mounted on 6 poles of 23 meters height connected to the control center via optic fiber (62.5/125 multi modal), on two poles of 14 meters height in MESH mode (frequency 5 GHz) and on five quay cranes. Each pole has also a perimeter video surveillance system installed. The time-critic voice communications are based on the TETRA trunking standard [2] [13]. At present, it is possible to locate the position of the vehicles authorized to operate in the area thanks to the built-in GPS sensors of the vehicular terminal. Each vehicle is in fact equipped with a radio that uses TETRA standard. Currently, there is no dedicated system to locate the workers and to constantly verify the presence of all necessary protection equipment.

3.2.1 Description of current communication infrastructure

The Figure 3.4 describes the current network configuration in the Cagliari International Container Terminal. 13 Access Point (AP) are managed by a Controller placed in the Control Room. The Controller provides:

- the account management;
- Channel Fly: an new approach to optimizing RF channel selection based on capacity averages across all channels. Specialized algorithms select the best channel based on historical values;
- Background scanning: with background scanning, the AP hops off of the channel and checks every other possible channel for potential interference. However, a significant problem with background scanning is so-called "dead time." Dead time occurs when the AP is not on the same channel as its associated clients. If a client wants to transmit while an AP is performing a background scan it will have to wait.

On 13 AP, 6 AP in Root mode are located on poles height 23m, which are connected to the Control Room by means multimodal optical fiber 62.5/125. In case of fiber fault, they could be able to work in mesh mode. A IP video surveillance system is installed at the mid of each pole. 7 AP PoE (Power over Ethernet) in Mesh mode are located on poles height 14m, to transfer data signal at 5GHz to the previously mentioned 6AP. PoE technology enables an access point to receive electrical power and data over the same cable. A software component handles the sending of the operating instructions via telnet protocol to the various devices installed on all operating vehicles and terminals.

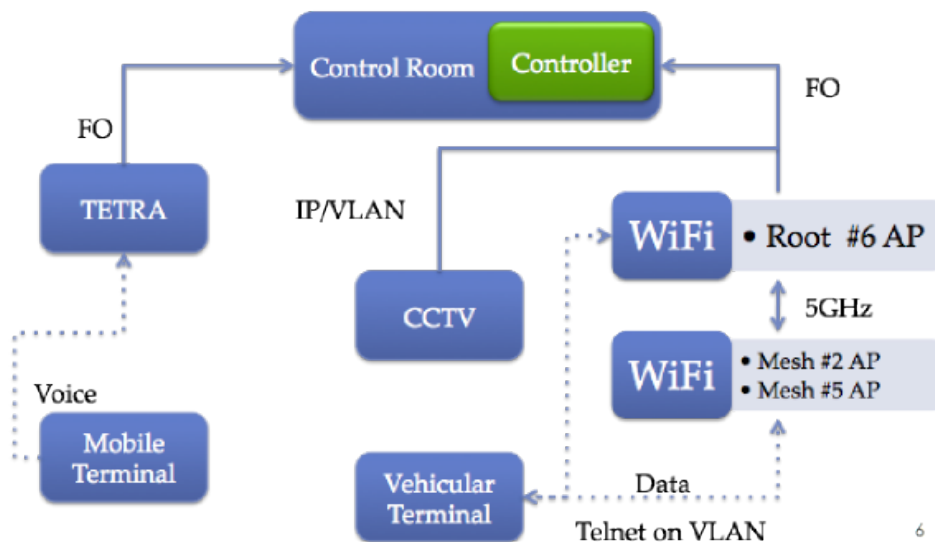


Figure 3.2: Network and communication

3.3 Design of the control system for workplace safety application

As mentioned in the introduction, the main purpose of this work is to improve the safety of operators in an industrial environment such as a cargo terminal. Personal protective equipment, like clothing, helmets, goggles, or other garments designed to protect the wearer's body from injury should be worn appropriately, according to strict specific regulations. The aim to have an overview on the current usage of protective equipment can be achieved through the design of a Control System.

3.3.1 Requirements and constrains

When speaking of work safety issues, even with strict regulations and risk assessment studies, the human error plays a major role in generating potentially dangerous situations. Most of these accidents can be avoided or limit the damage when using proper protective equipment. For the specific case of a maritime cargo terminal the operators have to wear appro-

appropriate helmet, jacket and shoes. Real-time monitoring independently of the location of the correct use of these personal safety items is a challenging issue requiring advanced sensor and communication techniques. The main requirement when monitoring personnel is the wearability of the sensors attached to the previously mentioned protective equipment. After taking into consideration various wireless standards such as Bluetooth, Zigbee and WLAN, we considered RFID technology with passive sensor tags [14],[15] as the most viable alternative. This choice was due mainly to the fact that RFID does not require a power source for the sensors themselves, but only for the central unit. RFID technology is standardized for four frequency ranges, as presented in Table 4.2:

<i>Frequency</i>	<i>Typical Operation Range</i>	<i>Typical Max. Range in Open Space</i>
LF 135 kHz (W)	Near Field	50 cm
HF 13.56 MHz	Near Field	3m
UHF 869 MHz	Near / Far Field	9m
MW 2.4 GHz	Far Field	15m
MW 5.8 GHz	Far Field	20m

Table 3.1: RFID technology characteristics

The wavelengths in the microwave (MW) range are absorbed by the human body, introducing severe limitations for the usage specific to a BAN. This made us take into consideration only the lower frequencies for the purpose of the Control System. Among these, we opted for the UHF systems, taking into consideration the low data rate provided by the LF systems and the limited range of both LF and HF systems [16]. The UHF RFID reader systems may create RF energy absorption, that can represent a significant impact to the human body when present in high densities and/or close proximities. Therefore, international regulations make use of the specific absorption rate (SAR) parameter to induce constraints on the radiated electromagnetic fields in the proximity of the human body. SAR is the rate at which

the body or tissues absorb RF energy when exposed to an electromagnetic field. A dosimetric measure that has been widely adopted for SAR calculations is the time derivative of the incremental energy (dW) absorbed by, or dissipated in an incremental mass (dm) contained in a volume element (dV) of a given density ρ , which is expanded in the following equation [17].

$$SAR = \frac{d}{dt} \left(\frac{dW}{dm} \right) = \frac{d}{dt} \left[\frac{dW}{\rho(dV)} \right] = \frac{\rho}{2\rho} |E|^2 \quad (3.1)$$

The most restrictive international limits for the SAR are the ones imposed by the FCC in the US, which state a limit value of SAR = 1,6 W/kg. Using the equation for the trend-line as depicted in Figure 3.3, it can be seen that the FCC limit is reached for a 1W of radiated power, at 10 cm away from the human body, using a 7.4 dB gain reader antenna [17].

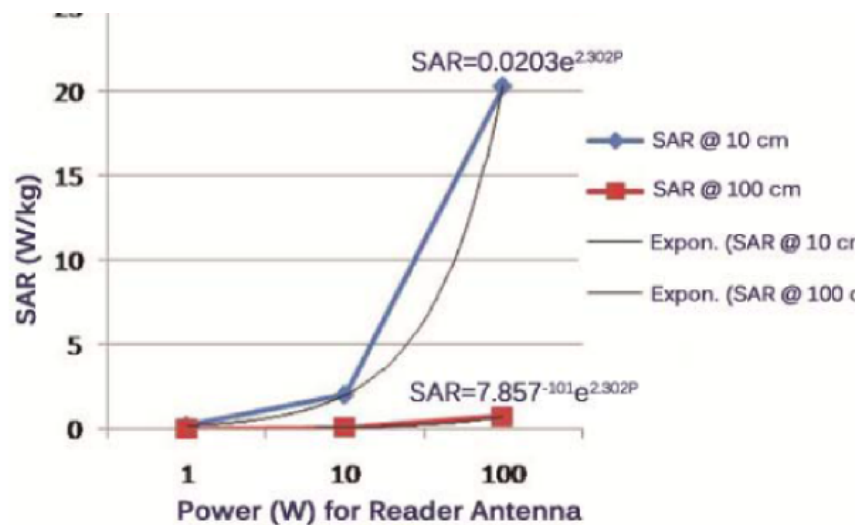


Figure 3.3: SAR (W/kg) versus radiated power (W) at distances of 10cm and 100cm of the human body

These figures highlight some limitations on the number of readers to be used and their distance from the human body. A further constraint to be taken into consideration before designing the Control System is to consider the radio technology to be used by the sensor's main unit for communicating with the Control System. Albeit an extended WLAN cover-

age at our case study site, we opted for the TETRA standard currently used on-site for voice communication. The ability of TETRA to convey also a reasonable amount of data (up to 7,2 kbps) and its low power consumption were the main reasons for choosing TETRA as the radio interface between BCU and the Control System. Also, by using the TETRA system, we are able to implement the design of the BCU as an add-on to the workers' TETRA personal radio.

3.3.2 Description of the control system

The proposed control system consists of seven main components, presented in Figure ??:

- A BAN composed of a set of sensors (BSN) and a central unit (BCU). The BCU is able to forward the data via radio using TETRA;
- Personal Radio interface for data and voice connections with the operators;
- Closed Circuit Television (CCTV) installed on the port's perimeter, able to provide a feedback in front of detected problem from BAN and to validate actions through real-time monitoring combined with image processing, pattern and feature recognition;
- Interface with the terminal operators and with other port companies or operators;
- Control System and Coordination Console, the main block, an aggregator of the previously mentioned building blocks, providing decision facilities and user interfaces;

3.3.3 Use of sensors

The operators have to wear inside the port area appropriate equipment such as helmet, jacket and shoes. Each garment has an integrated RFID tag with an unique identification

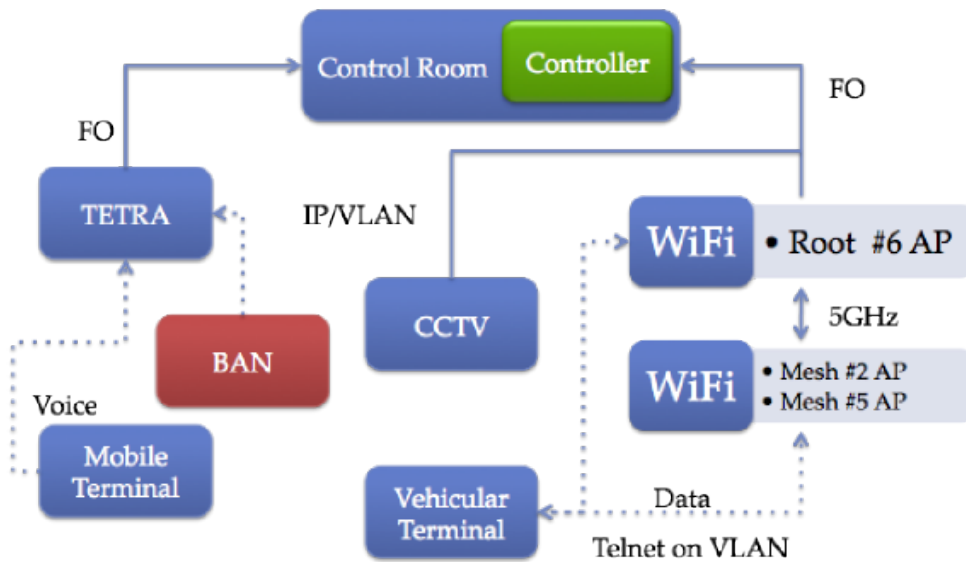


Figure 3.4: Proposed control system

code. Specific items such as helmets and shoes contain also a sensor unit besides the RFID tag, used to collect sensing information [?]. In the specific case of workplace safety applications, as shown in Figure 3.5, two pressure sensor-tag are placed in the shoes, a temperature sensor together with a photocell are placed in the helmet for sensing the body heat and the presence of light inside the helmet.

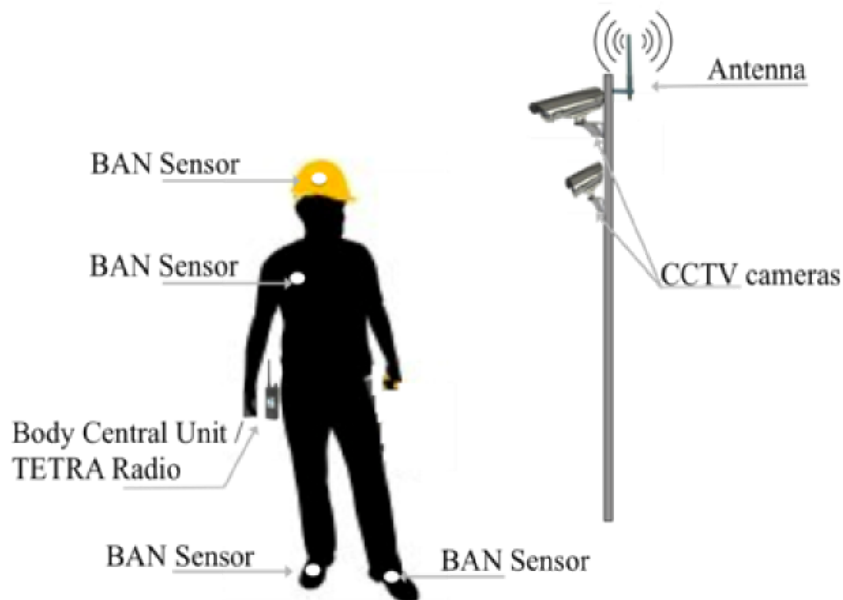


Figure 3.5: Integration of BAN and feature recognition for CCTV cameras

Each sensor-tag is read by an RFID reader (BCU) placed in the operator's belt, forwarding the read data via radio to the Control System. In this way, by receiving periodic information or by polling requests, the Control System is able to identify and localize in real-time alterations of the safety procedures. The RFID design proposed in this paper, uses passive sensor tags. They offer several advantages such as smaller size, lower cost, no power supply needed and inherently longer life cycles than other solutions. To avoid possible false alarms generated by the BAN and/or to ensure that the equipment is worn in appropriate way, an active use of CCTV video cameras using algorithms for feature recognition is used [22], as described in the next section.

3.3.4 Image data processing

As mentioned in the Control Systems description, the images delivered by the CCTV cameras in the port perimeter are analyzed with image processing methods in order to extract in real time the typical features (shape, size, color) of the used safety equipment. Among various image processing and feature detection methods, based also on previous experiences, we chose the Speeded Up Robust Features (SURF) method, a highly robust image processing method, scale and rotation invariant, based on interest point detector and descriptor. It can extract unique keypoints and descriptors from an image even with different image transformations like rotation, scale illumination and viewpoint changes [18]. In this particular application case, the keypoints of the incoming images are compared with a set of training images that contain the typical elements for a work safety environment, such as silhouettes of workers wearing helmet, safety vests and also these elements on their own.

3.3.5 A Use Case

In this context we are going to analyze the systems behavior and performance in a specific use case. As analyzed before, a regular worker in the maritime terminal wears usually three pieces of protection equipment: helmet, jacket and shoes. The most difficult safety risk to be monitored is the position of the helmet with respect to the operator's body. Often during summertime the temperatures can be significantly high, leading the operators not to wear their helmets. To monitor the correct position of the helmet, the sensors placed inside the helmet will transmit the data to the BCU (positioned in the belt) to check if the helmet is present on the operator's head or not. Every T seconds (with $T = 5 - 8$ seconds), the BCU polls the sensors to verify the position of the helmet. Alarms will not be sent immediately whenever the BCU verifies that a helmet is not worn correctly, but the alarms will be summed for a number of polling cycles. The alarm will trigger automatically a verification step based on the CCTV cameras and the pattern recognition algorithms. The Coordination Console will then report in a graphic representation the alarms status and history, leaving the human operator with enough data to make the proper disciplinary decision.

3.3.6 Results and discussion

The research in this paper is aimed to improve the existing infrastructure of a maritime cargo terminal using a control system for monitoring workplace safety. By combining in the control system, the inputs from a BAN integrated in the safety equipment and from CCTV cameras, a human supervisor is able to have an accurate overview of the entire situation in terms of work safety and act accordingly when needed. This first conceptual and technological analysis is the forerunner of a complex monitoring system in development to be

implemented for the specific case of a maritime cargo terminal.

Chapter 4

RFID Sensor Network for Workplace Safety Management

Industrial workplaces are inherently places with a high concentration of heavy machinery, fast moving handling equipments, high heat and pressure pipes, polluted and explosive areas, high working elevations, people movements and more in a relatively small area. Despite sophisticated innovations, industrial environments are still considered high-risk environments with serious work safety related issues and higher accident rates than other workplaces. Industries have started applying Information and Communication Technologies (ICT) for increasing profitability and responding to the growing need of safety concerns of the clients and operators. In this context, an application of particular importance is the design of an intelligent system for monitoring and preventing risks through the centralized use of sensor techniques and communication technologies. The examples for personal protective equipment (PPE) management found in the literature generally include a portal with fixed antennas for environment management or recording and monitoring the inspection of safety items [19], or handheld equipment to track, read and manage performance pro-

cedures of workers PPE in a semi automatic manner [20]; in some cases the development includes also the working garments management besides the PPEs [21]. The management related actions include alarm systems when the requirements of the safety management systems are not covered [22] or when the semantic information included in the location data indicates an uncovered risk in different applications [[23]-[24]. The objective is to present the work in progress on designing and implementing a first working prototype of an RFID based BAN sensor network for actively monitoring and preventing workplace safety risks in an industrial area. This study aims to investigate the real-time monitoring of the correct use of personal safety equipment by means of advanced sensor and communication techniques.

4.1 Technological Overview

The concept of safety is one of the predominant concerns in various industrial fields. In this particular context, specific safety measures have to be taken while handling and storing materials and during workers transit. The cause of personnel injuries or property damage may be of various nature: exposure to chemical carcinogens and mutagens, physical or biological agents, air or noise emissions, vibration, and ultrasonic radiation; accidents caused by contact with a mobile structure or moving vehicle. Therefore, personal protective equipment, such as clothing, helmets, goggles, or other garments designed to protect the wearer's body from injury should be worn appropriately. Risk assessment in the workplace includes procedures designed to determine the quantitative or qualitative value of risk related to a specific situation and a foreseen hazard. This may include the characterization of different parameters as the worker and/or machinery location, work equipment monitoring and several parameters regarding the specific risks such as concentration, temperature, posture,

effort, work rhythm. Several of these values can be detected, measured and assessed using ICT solutions. When speaking of work safety issues, even with strict regulations and risk assessment studies, the human error plays a major role in generating potentially dangerous situations. Most of these accidents can be avoided or limited in damage when using personal protective equipment. For the case of a typical industrial environment the operators have to wear appropriate helmets, jackets and shoes.

4.2 Requirements and constrains

As mentioned in the introduction, the main purpose of this work is to improve the safety of operators in an industrial environment such as a cargo terminal. Personal protective equipment, like clothing, helmets, goggles, or other garments designed to protect the wearer's body from injury should be worn appropriately, according to specific regulations. For these specific needs we chose an infrastructure of Body Area Networks.

4.2.1 Requirements

The main protective items in most industrial environments consist of helmet, protective jacket and shoes, which is why we considered a BAN with sensors added or included in the protective equipment, as depicted in Figure 4.1. The sensors have to be able to signalize the presence of the personal protective equipment on the worker's body and also to have the capability to send some other useful data such as temperature and orientation. The main requirement when monitoring protective equipment and inherently the personnel, is the wearability of the sensors attached to the protective equipment, hence size and battery life are the most important parameters. Our study took in consideration various wireless stan-

standards such as Bluetooth Low Energy (BLE), Zigbee, ANT, NFC and RFID (passive). Table 4.1 presents a comparison of the wireless standard initially considered for the purpose of the current research.

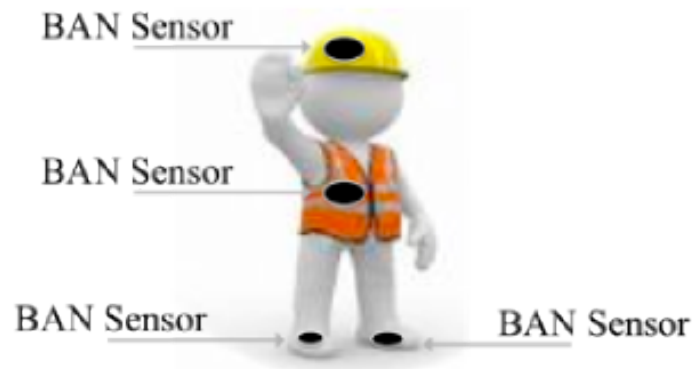


Figure 4.1: BAN sensor networks for workplace safety management

<i>Features</i>	<i>BLE</i>	<i>ZigBee</i>	<i>ANT</i>	<i>NFC</i>	<i>RFID (passive)</i>
Power Profile	up to years	years	months	months	infinite
Nodes	n.d	64000	infinite	n.d	infinite
Range	50m	100m	7/30m	<0.2m	4/10m
Data rate	1Mbps	250kbps	1Mbps	424kbps	1000kbps
Current	<15mA	35mA	n.d	<15mA	>20mA
Battery	yes	yes	yes	yes/no	no

Table 4.1: Wireless Standards – Feature Chart

Based on this comparison of these main wireless standards, we considered NFC technologies and RFID with passive sensor tags [14], as the most viable alternatives, due to the fact that they do not require a power source for the sensors themselves, but only for the central unit. The final choice to use RFID over NFC was motivated by the reduced range of the latter technology, unsuitable for an industrial environment. The main counter candidate from the battery-operated standards are ZigBee and BLE both low-cost and low-power technologies, flexible and small enough to meet the constraints but discarded for the necessity of having a power source.

4.2.2 RFID technologies

RFID technology is standardized for four frequency ranges, as presented in Table ???. The wavelengths in the microwave (MW) range are largely absorbed by the human body, introducing severe limitations for the usage specific to a BAN. This made us take into consideration only the lower frequencies for the purpose of the present research activities. Among these frequencies, we opted for the UHF systems, taking into consideration the low data rate provided by the LF systems and the limited range of both LF and HF systems [25] and the fact that the system will be operated mainly outdoors.

<i>Frequency</i>	<i>Typical Operation Range</i>	<i>Typical Max.Rrange in Open Space</i>
LF 135 kHz (W)	Near Field	50 cm
HF 13.56 MHz	Near Field	3m
UHF 869 MHz	Near / Far Field	9m
MW 2.4 GHz	Far Field	15m
MW 5.8 GHz	Far Field	20m

Table 4.2: RFID technology characteristics

Among various commercially available RFID systems, a very interesting alternative is the platform called WISP (Wireless Identification and Sensing Platform) [26]. WISP (figure 4.2) is RFID technology combined with a series of sensors that are can be powered and read by UHF RFID readers.

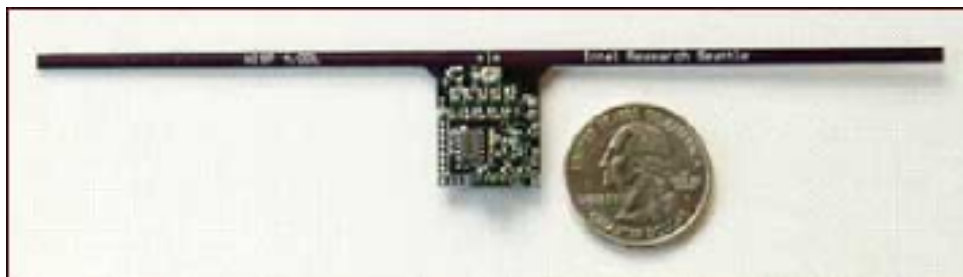


Figure 4.2: Example of a WISP tag

To a RFID reader, a WISP is just a regular Electronic Product Code (EPC) tag; but inside

the WISP, the harvested energy is used for operating a 16-bit microcontroller. The microcontroller can, among others, sample sensors and report the data back to the RFID reader. WISPs are built with light sensors, temperature sensors, and strain gauges and WISPs do not require batteries since they harvest their power from the RF signal generated by the reader. The WISPs consist of a board with power harvesting circuits, demodulator, modulator, microcontroller and external sensors [15] and have been successfully tested also in industrial environments.

4.2.3 RFID reader constrains

The UHF RFID reader systems may create RF energy absorption, that can represent a significant impact to the human body when present in high densities and/or close proximities. Therefore, international regulations make use of the Specific Absorption Rate (SAR) parameter to induce constraints on the radiated electromagnetic fields in the proximity of the human body. SAR is the rate at which the body or tissues absorb RF energy when exposed to an electromagnetic field. A dosimetric measure that has been widely adopted for SAR calculations is the time derivative of the incremental energy (dW) absorbed by, or dissipated in an incremental mass (dm) contained in a volume element (dV) of a given density (ρ), which is expanded in (1) [27]

$$SAR = \frac{d}{dt} \left(\frac{dW}{dm} \right) = \frac{d}{dt} \left[\frac{dW}{\rho(dV)} \right] = \frac{\rho}{2\rho} |E|^2 \quad (4.1)$$

where E is the peak value of the magnetic field measured in V/m and σ the electrical

conductivity of the biological tissue. Both σ and ρ depend on the type of the analyzed tissue.

For the current study, the body is relevant as a whole, taking into consideration that the RFID tags are distributed all over the body. Therefore, the performed computations took into account the Whole Body SAR, where the human body is approximated by a cylinder composed by the skull together with two types of tissues (muscular and soft) with a high amount of water. The SAR simulations were done considering a reader working at 869 MHz with a circular antenna polarization having a 6 dBi gain. The values for the density and the electrical conductivity were chosen as $\sigma = 0,65$ S/m and $\rho = 1306$ kg/m³ and the SAR was calculated as a function of the reader's distance from the human body. Three different transmitting powers were taken into consideration, from a minimum of 0.2 W typical for portable readers, up to 1 W, the output power level of stand-alone RFID installations. The tag had a gain of 1 dB and a backscattering efficiency of -20 dB. The results of the numeric simulation are presented in figure 4.3. The most restrictive international limits for the SAR are the ones imposed by the FCC in the US, which state a limit value of SAR = 1,6 W/kg. The IEC (International Electrotechnical Commission) recommends a slightly higher value of 2 W/kg, valid for the EU, South Korea and Japan.

Using the graph in Figure 4.3, it can observe that the FCC limit can be reached for a value of 0.6 W of radiated power only at a distance of 10 cm from the human body. For the 0.2 W the FCC limit is not a problem, which is not the case for 1 W of radiated power where the SAR limit is reached at around 20 cm. These figures highlight the main limitations on the number of readers or antennas to be used and their distance from the human body.

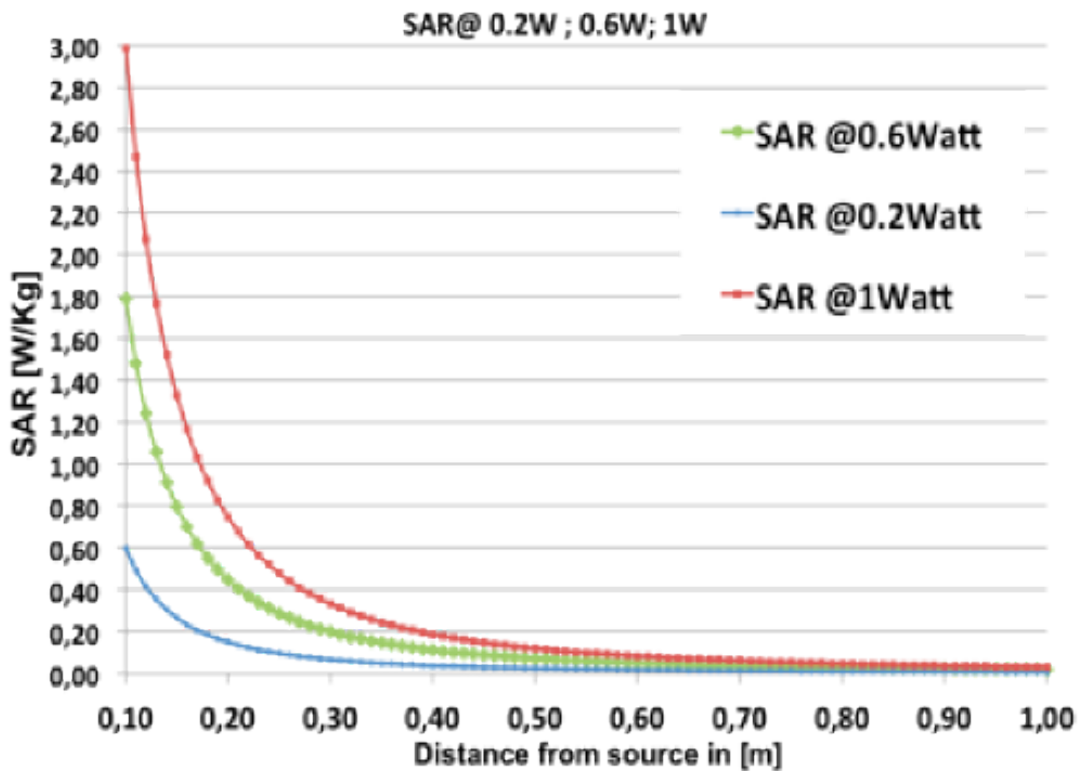


Figure 4.3: SAR (W/kg) vs. distance from the human body at varying reader powers

4.3 System Architecture and Work in Progress

Inside the industrial environment the operators must wear the appropriate protective equipment such as helmet, jacket and shoes. The equipment forms a BAN, each item having an integrated RFID tag with a unique identification code. Specific items such as the helmet and the jacket also contain a sensor unit besides the RFID tag, used to collect sensing information. As shown figure 4.1, two RFID tags are placed in the shoes, a WISP tag with temperature sensor together with a photocell are placed in the helmet for sensing the body heat and the presence of light inside the helmet. The jacket includes a WISP tag with a temperature sensor and an accelerometer. The BCU in charge for collecting the data from the BAN is represented by fixed RFID readers placed in strategic check points of the industrial environment, for example on the bus carrying the workers to specific places and at the access points to cranes

and heavy machinery, sensing tags at a distance of 1 m. All readers are connected through an Ethernet port to a local LAN through which the status of the tags and the information returned by the various sensors can be read and stored in a database. A schematic diagram of this architecture is presented in figure 4.4.

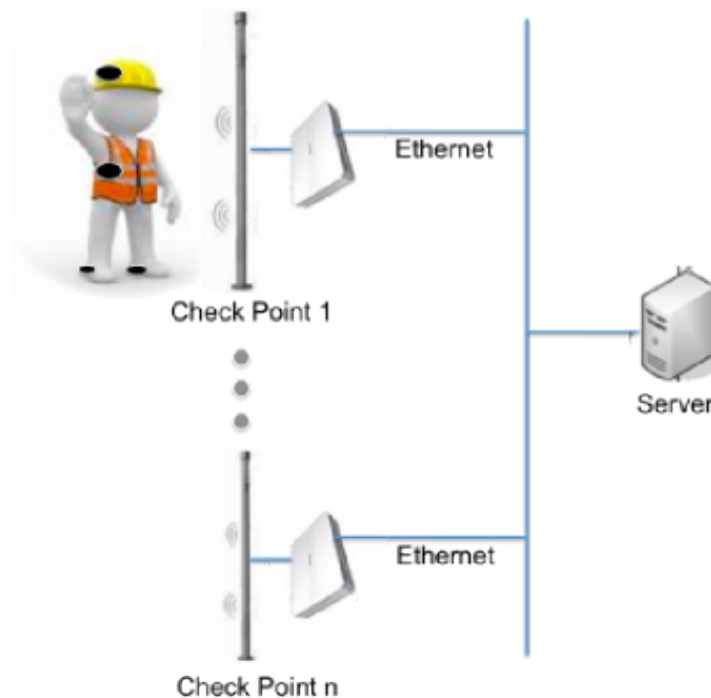


Figure 4.4: System architecture

By constantly monitoring the check points for several times a minute, a human operator or a software can notice missing protective equipment and/or out-of-range output values of the sensors. Based on this basic architecture for monitoring the use of personal protection equipment, we intend to develop a more complex system involving also active RFID tags placed on the transport means of the industrial environment and at the limits of hazardous areas. The work in progress includes building up risk-reducing policies based on the positions of the workers relatively to the transport means and the hazardous areas. Furthermore, in progress is also the development of mechanisms for preventing roll-over and crushing incidents with acoustic and visual warning systems. Another direction of development, cur-

rently under preliminary evaluation, is the use of portable RFID readers as a BCU within the BAN to monitor on a perpetual time basis, polling every 10 - 15 seconds the presence of the protection equipment and forwarding the received data via radio to a central unit. The current tests evaluate the feasibility of the portable reader in terms of battery life, deployment costs and reliability.

4.4 Conclusion and future work

This part of the thesis presents the work in progress on the design and implementation of a working prototype of an RFID-based BAN sensor network for actively monitoring and preventing workplace safety risks in an industrial area. This first conceptual and technological analysis, together with the test implementation is the forerunner of a complex monitoring system in development to be implemented for the specific case of an industrial environment.

Immediate steps will consist in considering extended use cases, limiting false alarms, testing feasibility and technological limitations. Further development will consider also the social relationships among the distributed sensors. This approach is expected to guarantee a higher scalability and a better reaction to frequent state, is typical for the SIoT (Social Internet of Thing) paradigm [14-15].

Chapter 5

Indoor Navigation Systems

Nowadays, modern mobile devices, such as smartphones and Personal Digital Assistant (PDA) in general, come to the market already equipped with sensors able to track them as they move, both in outdoor and in indoor environment. The sensing technologies embedded in such devices make it ideal for a wide range of location-based services, such as navigation applications. An Inertial Navigation System (INS) uses motion and rotation sensors in order to determine the position, orientation, and velocity of a moving object/user without the need of external infrastructures [28]. This is essential in an indoor environment where common localization systems, such as Global Positioning System (GPS), fail due to severe attenuation or obscuration of the satellite's signal. In inertial navigation systems, localization/orientation estimation is source-independent. The user's position is calculated in relation to a known starting position using a dead reckoning algorithm and the orientation is usually provided by a digital compass embedded in the smartphone. A digital compass sensor provides the orientation of the device relative to the magnetic north of the earth. However, when used in indoor environments, like any magnetic device, it is affected by significant error caused by nearby ferrous materials, as well as local electromagnetic fields. Such errors seriously affect

the performance and the accuracy of the system, thus the need to investigate any alternative orientation technique. The present work focuses on this problem by investigating the use of a gyroscope for navigation in indoor environment.

5.1 Technologies overview

In the last two decades many efforts have been carried out in the domain of indoor navigation by the research community but positioning and navigating in indoor building (in order to find the path to unknown locations) are still a primary challenges. Many solutions have been proposed in the field of mobile applications, so in the following a review of the state-of-the-art will be presented in order to classified the solutions as belonging to infra structured based approach or not.

5.1.1 No infrastructured based solutions

Inertial Navigation System (INS) only relies on the use of motion and rotation sensors, such accelerometer and gyroscope, to determine position, orientation, and velocity of moving objects and/or users within indoor environment, no external infrastructures are needed to calculate their motion and position. To this category belongs the solution presented in [29] by Ladetto and Merminod. In their work the authors developed a Pedestrian Navigation System based mainly on a digital magnetic compass. They showed how coupling a magnetic compass with a low-cost gyroscope in a decentralized Kalman filter configuration the errors in the determination of the azimuth of walk can be limited. In non-magnetically disturbed areas, they registered a position error below 10 meters while with the additional use of the gyroscope this error is around few meters. Another solution, based on Augmented Reality

(AR), is proposed in [30]. In this system, users are equipped with a communication device with built-in sensors, a wearable camera, an inertial head tracker and display. The method is based on sensor fusion of estimates for relative displacement caused by human walking locomotion and estimates for absolute position and orientation within a Kalman filtering framework. In order to detect and measure a unit cycle of walking locomotion and direction achieved they analyzed the outputs from self-contained sensors (acceleration vector, angular velocity and magnetic vector). The absolute positioning is obtained using image matching of video frames from the wearable camera with an image database that was prepared beforehand. The indoor positioning and localization system proposed in [31] can provide 3D positioning and orientation data without the use of any additional infrastructure in the environment. Their prototype, called TrackSense, can deliver up to 4 cm accuracy with 3 cm precision in rooms up to five meters squared, as well as 2 degree accuracy and 1 degree precision on orientation. The mentioned solution is based on the use of a camera to locate and track a grid pattern projected onto surfaces in the camera's field of view. In this way they are able to determine its distance and orientation and use that information to calculate its 3D position and pose in the room. A solution that uses geo-coded QR Codes which embed the coordinate (x, y, floor) and social computing for individuals with cognitive impairments is presented in [32]. QR Codes are posted at selected positions on routes. Only using the camera embedded in his PDA (Personal Digital Assistant), the user can take photos of his surrounding during his planned trip. The navigational photos are served on demand to the user by shooting the QR Code when it is in eyesight range. A tracking function is also integrated in the system in order to increase workplace and life independence for cognitive-impaired users, avoiding deviation from the preset route to and from the work and also, in case of anomalies, to support them with opportune procedures. A low-cost indoor naviga-

tion system running on off-the-shelf camera phones is presented in [33]. The user location is calculated in real time by detecting strategically placed unobtrusive fiducial markers with the built-in camera of the phone. The approach allows the continuous scanning of an environment in real time (15 Hz or more) in search of navigation hints. No external infrastructure is required and the only requirements are paper markers (square markers or frame markers) and static digital maps. In [34] the authors proposed an infrastructure free indoor navigation system for humans in *extreme* environments. The solution only rely on the use of the integrated accelerometer (used as a pedometer) of the mobile device is used and the built-in compass: the pedometer enables dead reckoning, where the current position estimation is based upon a previously determined position. To make the picture of the indoor map usable for navigation, a reference-sequence is needed to adopt it to the users physiognomy (i.e. the length of legs and size of foot). They do not estimate a step length, but simply assume that user keeps the same step length most of the time. The reference points in the indoor scenario have to be identified by the user on the YAH-map. In [35], the authors proposed a novel solution to provide reliable orientation information for mobile devices, called *Polaris*. The presented solution works in indoor environments and is not affected by magnetic interferences. Pictures of the ceiling of indoor environment are aggregated and computer vision based pattern matching techniques are applied in order to utilize them as orientation references for correcting digital compass readings.

5.1.2 Infrastructured based solutions

Any kind of solution that uses wireless technologies, such as Wi-Fi, radio-frequency identification (RFID), Ultra-wideband (UWB) and Bluetooth can be catalogued as belonging to

this class. The mentioned solutions can provide fairly accurate results but at the same time are affected by high costs and are strongly dependent on fixed-position beacons. Among this category, RADAR is an indoor localization and tracking system that uses radio-frequency and provides the user's location with an error of few meters. It operates by recording and processing signal strength information at different location inside the area of interest [36]. Another system, which provides context-aware navigation services is percept [37]. The system uses Braille fitted RFID tags corresponding to key locations in the building such as entrances, exits, elevators etc. The user wears a glove able to scan the destination encoded in the tag and is able to send the information to the smart phone via the Bluetooth module fitted on the glove. The server is then contacted in order to obtain the desired navigation information. A Wi-Fi based solution is presented in [38]. The authors investigated the use of trilateration technique in order to calculate the user's position by analyzing Wi-Fi signal strengths with IEEE 802.11g networking standard from a minimum of 3 access points (AP) within an indoor area. Wi-Fi is also used for the implementation of WifiSLAM's software [39]. Specifically, WifiSLAM's technology triangulates Wi-Fi signals to enable precise location tracking in indoor environments using ambient Wi-Fi signals from routers that are already present inside the building, providing accuracy of around eight feet. A Bluetooth-based micro-locations system, called iBeacons by Apple, is described in [40]. It works by monitoring and triangulating signals from Bluetooth Low Energy (BLE) beacons. With BLE, a phone can announce its presence to other devices in range in an extremely power-efficient way. It's used by retailers, museums and businesses of all kinds to find out exactly where people are, so they can automatically serve up highly relevant interactions to customers' phones.

5.2 Application for Indoor Navigation Systems

In the context of Indoor Navigation System, we have developed an early prototype of a pedestrian navigation system for indoor environments based on dead reckoning, 2D barcodes and data from accelerometers and magnetometers. All the sensing and computing technologies of our solution are available in common smartphones [41]. The prototype has been further improved by a new algorithm described afterwards and now it is able to estimate the correct current position of the user, track him inside the building and provide the best path to achieve a specific destination [42]. The application does not need to connect to any external or pre-installed positioning system such as GPS or Radio Frequency Identification (RFID), or to use Wireless Fidelity (Wi-Fi) trilateration. The prototype of the proposed system uses just the data from the motion sensors embedded in the smartphone to compute the correct position of the user based on a known initial location, combined with a reference map of the building.

5.3 Application for Indoor Navigation Systems

The initial position of the user, the only certain information on which the system relies on for further calculation, is retrieved by scanning and decoding a georeferenced datamatrix (2D barcode), placed inside the building, using the built-in camera of the smartphone. Based on the URL encoded in the datamatrix, the application downloads from a dedicated server the indoor vector map for the specific floor, the initial position of the user on the map (corresponding to the point where the user stands when scanning the datamatrix) and a database that stores information about the setup of the building. When the user starts walking, the application draws step by step his position over the downloaded map of the building floor.

The user's position is calculated in relation to a known starting position using a dead reckoning algorithm. In the specific, the application tracks the number of steps taken by the user based on the linear numerical values returned by the smartphone's accelerometers. The acceleration value is the modulus of the accelerations registered in the x, y and z axes. One step is detected when this module is above a high threshold (Th_{high}) and successively is below a Th_{low} value. To determine the orientation, only the gyroscope is used thanks to an algorithm of calibration widely described next.

5.3.1 Functionality

The initial position of the user, the only certain information on which the system relies on for further calculation, is retrieved by scanning and decoding a georeferenced datamatrix (2D barcode), placed inside the building, using the built-in camera of the smartphone. Based on the URL encoded in the datamatrix, the application downloads from a dedicated server the indoor vector map for the specific floor, the initial position of the user on the map (corresponding to the point where the user stands when scanning the datamatrix) and a database that stores information about the setup of the building. When the user starts walking, the application draws step by step his position over the downloaded map of the building floor. The user's position is calculated in relation to a known starting position using a dead reckoning algorithm. In the specific, the application tracks the number of steps taken by the user based on the linear numerical values returned by the smartphone's accelerometers. The acceleration value is the modulus of the accelerations registered in the x, y and z axes. One step is detected when this module is above a high threshold (Th_{high}) and successively is below a Th_{low} value. To determine the orientation, only the gyroscope is used

thanks to an algorithm of calibration widely described next.

5.3.2 Step detection

The user step is detected by means of the accelerometer sensor, which provides three values, one for each of the x, y and z-axes. In order to obtain a more realistic value of acceleration for any possible position, all three acceleration values are used. Each step is detected when the value of the module (1) is above a high threshold (Th_{high}) and successively is below a low threshold (Th_{low}).

$$\sqrt{x^2 + y^2 + z^2} \quad (5.1)$$

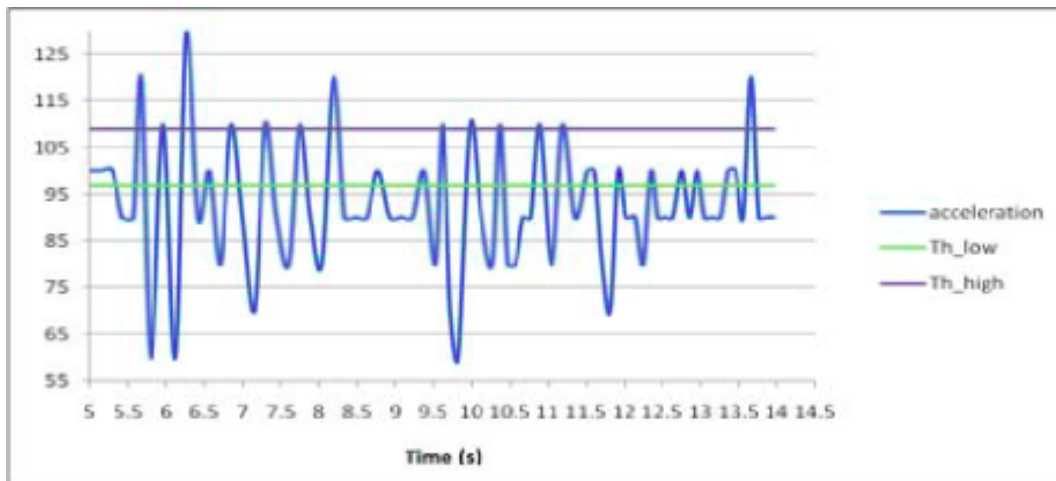


Figure 5.1: User step detection

The Figure 5.1 is an example graph of the accelerometer's measurement for a step length of 70cm, having the absolute values Th_{high}= 109 and h_{low}= 97.

The current orientation of the user is measured by the smartphone's digital gyroscope described in the next section. Gyroscope and Accelerometer's output data are used such as input data to the dead reckoning algorithm, which provides the current user position respect to the previously memorized user position. Although the algorithm gives initially good results, the main problems occurs with the time, due to of the errors introduced from accelerometer and gyroscope sensor. Accordingly, even the next calculated position is characterized by an amplified error how shown in the following Figure 5.2.

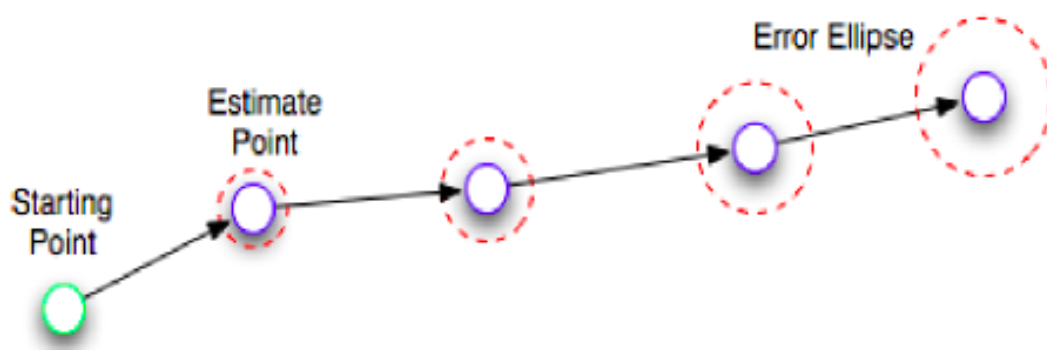


Figure 5.2: Estimate error in dead reckoning algorithm

In the Figure 5.2, the starting point with a null positioning error is represented in green. In the next positions, the ellipse in dashed red indicates the error, and it grows due to of the dependence with the previous position. This error ellipse represents the estimated position and size increases step by step. In the Figure 5.3 the single step and the ellipse corresponding is been represented

The v_1 movement vector represents the position change from P_0 to P_1 . The ellipse represents the accuracy estimated. The axes of the ellipse are determined by the accuracy of the direction estimated and by the speed measured. In the specific, the ab -axis identifies the accuracy of the sensor direction, while the cd -axis determines the accuracy of speed calculation. For multiple steps, the current position P_n , where n is the number of dead reckoning

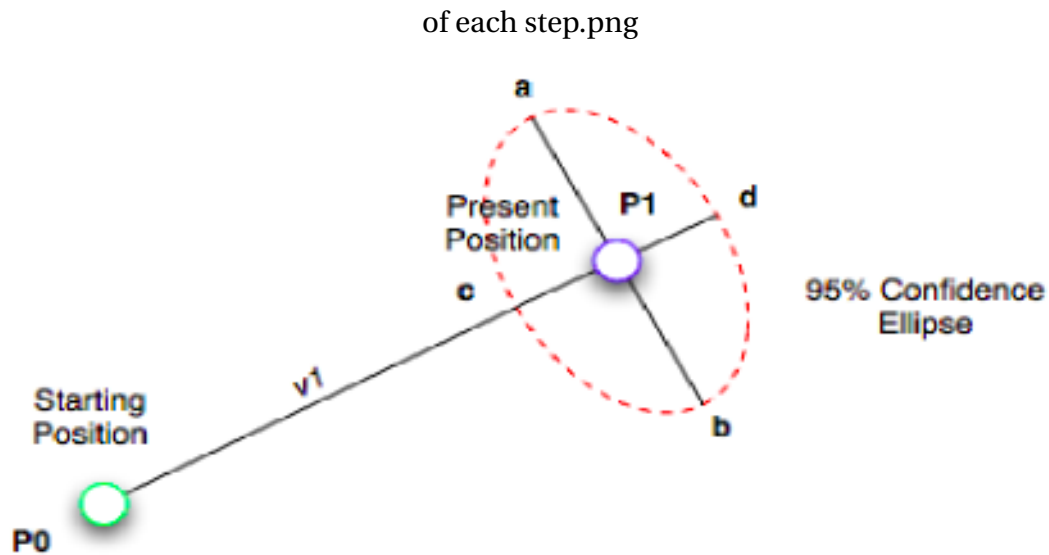


Figure 5.3: Details of each step and of the error ellipse associated

calculations from the point P_0 , is described by the following formula:

$$P_n = P_0 + \sum_{i=1}^n (v_i + v_e) \quad (5.2)$$

Reading dirty, due to the poor quality of the sensors positioning, hampers the implementation of dead reckoning algorithm on mobile devices. The sensor noise could corrupt the signal and increase the potential error. Therefore, it is imperative an accurate reading of value, and where possible, the use of techniques for the correction of the data or recalibration of the system.

5.3.3 Gyroscope sensor

To improve the path precision and decrease the error position, the calibration algorithm has been applied on the gyroscope sensor. A gyroscope is a device for measuring or maintaining orientation, based on the principles of conservation of angular momentum. It's used primarily for navigation and measurement of angular velocity up to 3 directions: 3-axis gyroscopes are often implemented with a 3-axis accelerometer to provide a full 6 degree-of-freedom (DoF) motion tracking system. Some basic specifications of a gyroscope sensor are [1]:

- Measurement range: specifies the maximum angular speed that can be measured by the sensor. It is typically expressed in degrees per second [deg/sec];
- Number of sensing axes: to measure angular rotation, the gyroscope can use one, two, or three axes. The spatial orientation of a rigid body is thus based on three parameters: azimuth, rotation around the z axis; pitch, rotation around the x axis; roll, rotation around the y axis, as shown in Figure 5.4;
- Working temperature range: from -40°C to between 70°C and 200°C;
- Shock survivability: specifies how much force the gyroscope can withstand before failing. Fortunately, gyroscopes are very robust, and can withstand a very large shock (over a very short duration) without breaking. Generally, this is measured in [g] (1g is the earth's acceleration due to gravity), occasionally is also given the time with which the maximum g-force can be applied before the unit fails;
- Bandwidth: the bandwidth of a gyroscope typically indicates how many measurements can be made per second, thus the gyroscope bandwidth is usually intended in [Hz];

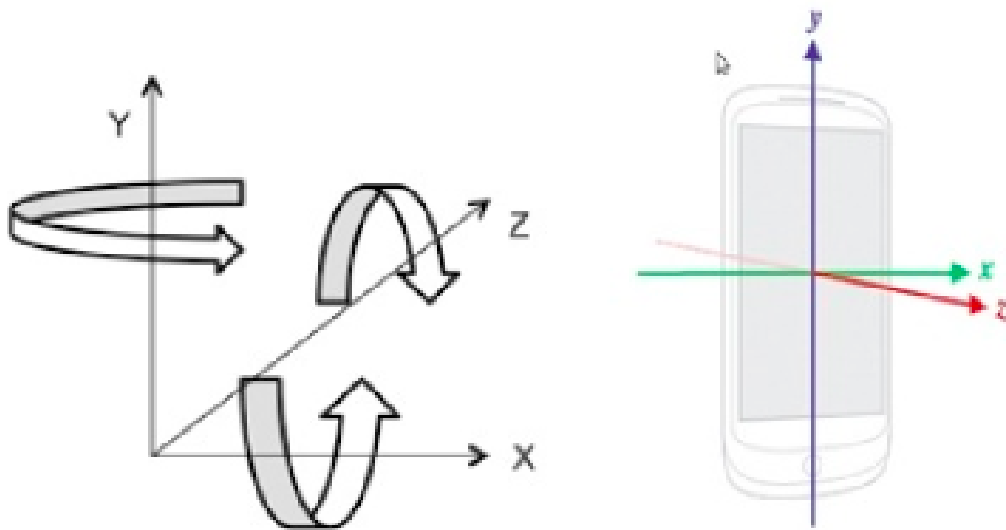


Figure 5.4: Axes and /rotation of a smartphone: azimuth (z-axis), pitch (x axis) and roll (y axis) parameter

- Angular Random Walk (ARW): this is a measure of gyroscope noise [deg/ sec];
- Bias: the Bias of a gyroscope sensor is the signal output when it is not experiencing any rotation. The Bias error can be expressed in [deg/sec].

$$\theta(t) = \epsilon * t \quad (5.3)$$

A constant Bias error of ϵ , when integrated, causes an angular error which grows linearly with time;

To improve the gyroscope's accuracy, the calibration algorithm has been elaborated. It is based on subtraction of the Bias error from each gyroscope's reading in two cases. The algorithm will be widely described in the next section.

5.3.4 Route planning

The indoor application provides to the user the best route from a start position to a specific destination. The application uses the Dijkstra algorithm. It is a graph search algorithm that solves the single-source shortest path problem for a graph with non-negative link path costs, producing a shortest path tree. This algorithm is often used in routing and as a subroutine in other graph algorithms. Given initial graph $G=(N, L)$ with N nodes and L links, the algorithm finds the path with lowest cost (i.e. the shortest path) between the start node and single destination nodes. For instance, the Figure 5.5 shows the shortest path between the "Node 2" and "Node 5" composed by three edge with lowest cost.

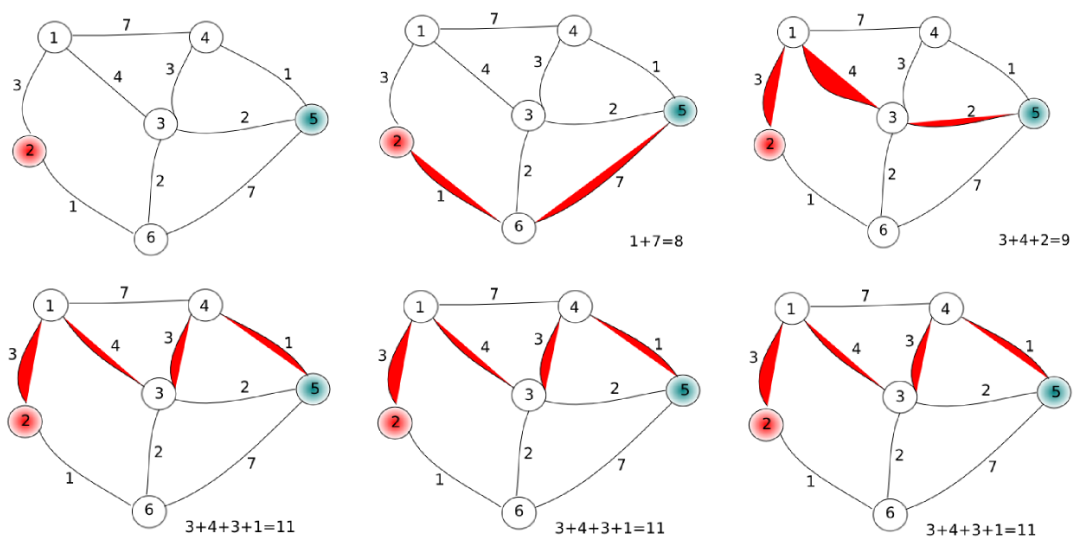


Figure 5.5: Dijkstra algorithm description

In our indoor navigation application, the same principle is been used. Specifically, a venue it is represented from a number N of rooms and a number L of links (or path) to achieve a determinate destination. A super-graph $SG=(N,L)$ is been created to represent entire venue. It is made up from each graphs drawn for every floor. The Figure 5.6 shows the graph $G=(23,22)$. Each node is labeled with the specific room number except the border nodes (H2_A2 and AB_B2). Indeed, the border node represents the connection between two

5.4 Gyroscope calibration algorithm

To improve the gyroscope's accuracy we created an algorithm for both still and rotating devices:

- The first part is related to the Bias error when the device is not undergoing rotation. In this case, the constant Bias error of a gyroscope can be estimated by taking a long-term average of the gyroscope's output, which it would be null. Once the Bias is known, it will be subtracted from each value of the gyroscope's output. For this kind of test we have not used any particular equipment, but only the smartphone Figure 5.7 on the level;
- The second part is related to the Bias error when the device is moving.

The equipment used to calculate the real Bias error, when the device is undergoing rotation, is a Stepper Motor Figure 5.7, which converts electrical pulses into discrete mechanical movements. The tests were carried out with a smartphone Samsung Nexus S Figure 5.5.

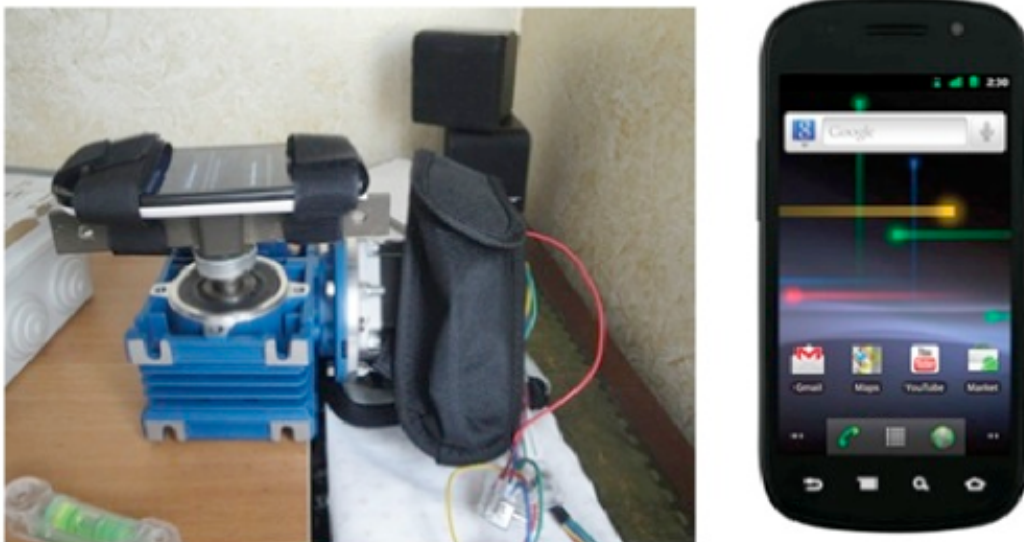


Figure 5.7: Test instruments

Embedded sensors in mobile smartphone Samsung Nexus S			
Sensor type		Manufacturer	Quantity Measured
Accelerometer	KR3DM	STMicroelectronics	Acceleration
Gyroscope	K3G	STMicroelectronics	velocity
Magnetic Field	AK8973	Asahi-Kasei	Magnetic Field
Stepper Motor			
Angular Velocity [rad/s]		0.307876080	

Table 5.1: Specification equipment

5.4.1 Drift test

The goal is to find a calibration method for the gyroscope, when the device is not undergoing rotations. In this case, the angular velocity along the three axis should be zero. We calculate the average error of the gyroscope's output along z axis. We have made 4 tests on 1.000, 5.000, 10.000 and 100.000 readings, each composed by 5 sessions (S). This way, we can evaluate how the gyroscope's output changes over time with a constant number of readings.

Table 5.2 shows that the average error of the angular velocity is similar for each test and it is independent from the number of readings.

Session	Test 1 $\mu(z)$	Test 2 $\mu(z)$	Test 3 $\mu(z)$	Test 4 $\mu(z)$
1	-0.00344	-0.00310	-0.00317	-0.00337
2	-0.00321	-0.00329	-0.00328	-0.00361
3	-0.00331	-0.00330	-0,00341	-0.00359
4	-0.00344	-0.00374	-0.00373	-0.00375
5	-0.00290	-0.00288	-0.00291	-0.00319
$\mu/5$	-0.00326	-0.00326	-0.00330	-0.00350

Table 5.2: Gyroscope's average angular speed in five session for 1.000 readings

The gyroscope's error is completely random and it does not follow a specific error model. For this reason we assume that the Bias is equal to the average error on 1.000 readings. Figure 5.8 and figure 5.9 show how the calibration algorithm improves the accuracy of the output of the gyroscope by subtracting the Bias from each reading.

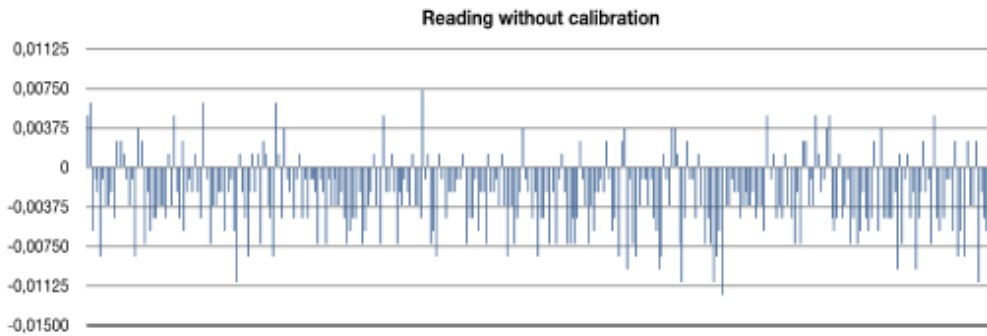


Figure 5.8: Acquired values from gyroscope without calibration - 1,000 readings

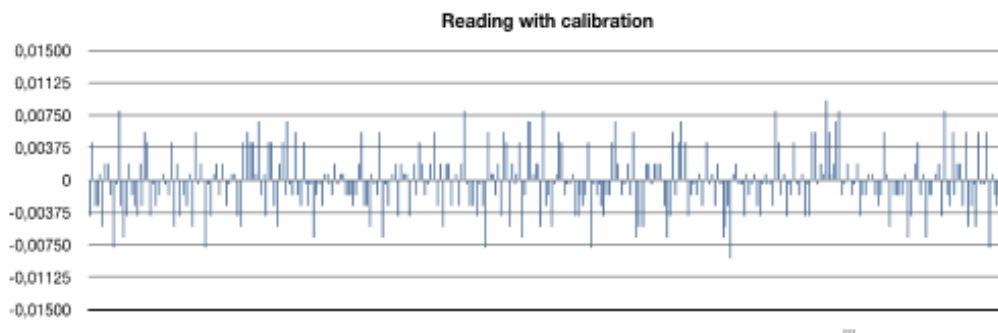


Figure 5.9: Calibrated values of the gyroscope computed by subtracting the Bias error from each reading (1.000 readings)

5.4.2 Rotation test

To evaluate the error of the gyroscope when the device is undergoing a rotation, a stepper motor is used. It has a constant angular velocity of 0.307876080 [rad/s]. We fixed the device on the stepper motor thus the gyroscope starts reading the angular velocity when the stepper starts moving. We have made three tests with different number of readings (1,000, 10,000, and 20,000). Each test has been done for 10 times as shown in the following Table 5.3.

As shown in figure 5.10, the trend of the blue line, which refers to the 1.000 readings, shows how the average angular velocity acquired by the sensor is significantly different from the trend representing the reference angular velocity.

Increasing the number of readings, the red and green line show a more regular trend

Session	Test 1 $\mu(z)$	Test 2 $\mu(z)$	Test 3 $\mu(z)$	Stepper $\mu(z)$
1	0.310910783	0.310656723	0.311009743	0.30787608
2	0.308800393	0.311028093	0.311249073	0.30787608
3	0.310697943	0.310950093	0.311037773	0.30787608
4	0.310861703	0.310756913	0.311065993	0.30787608
5	0.310462643	0.310637243	0.310994773	0.30787608
6	0.309352843	0.310583343	0.311551243	0.30787608
7	0.308340043	0.311504683	0.311021863	0.30787608
8	0.308239443	0.310784043	0.311163783	0.30787608
9	0.310514923	0.310720443	0.310731343	0.30787608
10	0.307767003	0.311079643	0.311277343	0.30787608

Table 5.3: Average error of the gyroscope compared to angular velocity of the stepper while the device is undergoing a rotation and without calibration

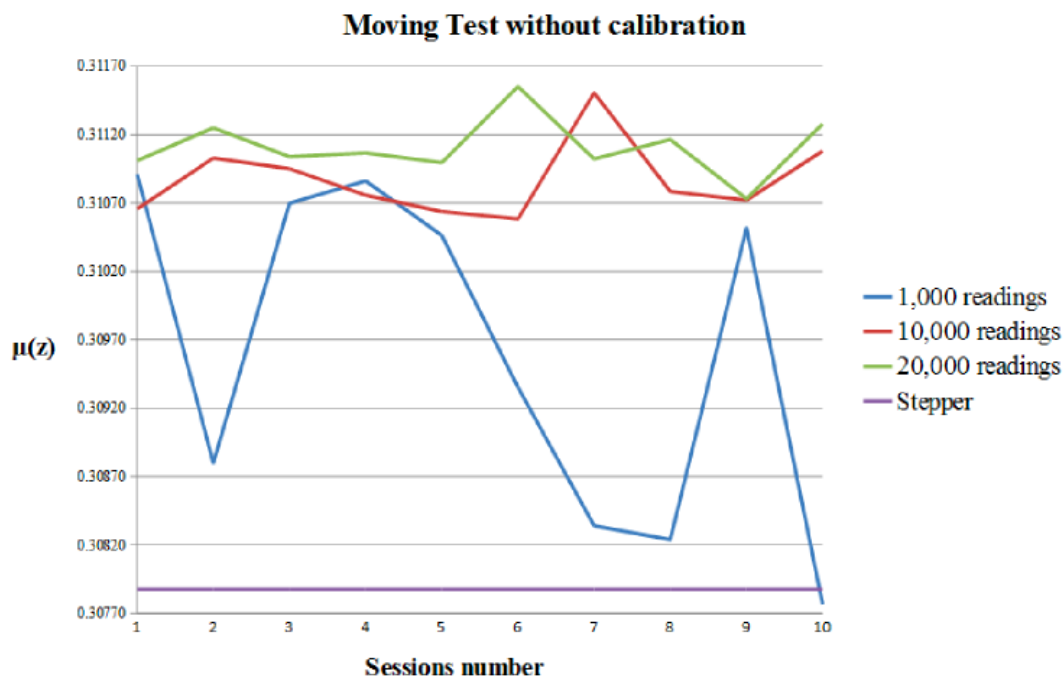


Figure 5.10: Gyroscope's average angular velocity for 1,000, 10,000 and 20,000 readings compared to the reference angular velocity of the Stepper Motor without calibration

compared to the blue line, even if they are more shifted upwards than the last one. The calibration is based on subtracting the Bias error from the average of the number of readings.

The following Table 5.4 shows how the averages have changed. Figure 5.11 highlights how the lines are closer to the reference angular velocity, and this one illustrates and demonstrates the correct algorithm functioning.

Session	Test 1 $\mu(z)$	Test 2 $\mu(z)$	Test 3 $\mu(z)$	Stepper $\mu(z)$
1	0.30778804	0.30753398	0.307887	0.30787608
2	0.30567765	0.30790535	0.30812633	0.30787608
3	0.3075752	0.30782735	0.30791503	0.30787608
4	0.30773896	0.30763417	0.30794325	0.30787608
5	0.3073399	0.3075145	0.30787203	0.30787608
6	0.3074606	0.3074606	0.3084285	0.30787608
7	0.3052173	0.30838194	0.30789912	0.30787608
8	0.3051167	0.3076613	0.30804104	0.30787608
9	0.30739218	0.3075977	0.3076086	0.30787608
10	0.30464426	0.3079569	0.3081546	0.30787608

Table 5.4: Average error of the gyroscope compared to angular velocity of the stepper while the stepper is undergoing a rotation and with calibration

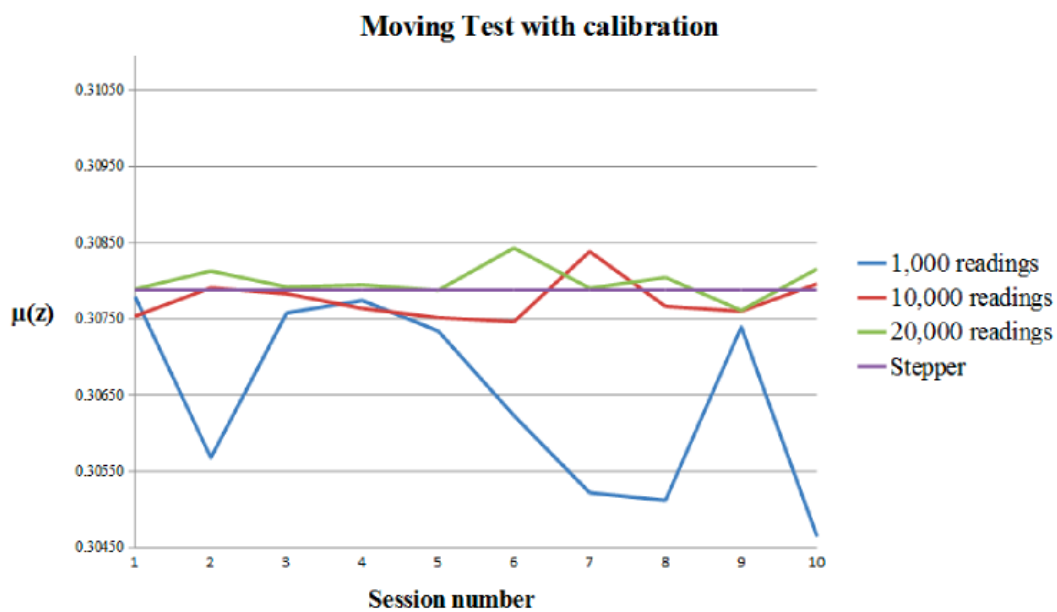


Figure 5.11: Gyroscope's average angular velocity for 1,000, 10,000 and 20,000 readings compared to the reference angular velocity of the Stepper Motor with calibration

The calibration algorithm has been applied for improving the prototype's functionality of a pedestrian navigation system described previously; in this case, is enough to activate the calibration just once at the application's start.

5.4.3 Gyroscope vs Digital Compass

Some other tests have been carried out in order to understand if the compass and the gyroscope's error are affected by larger errors in relation to longer paths and if it is possible to find a breakpoint, at which the two errors are comparable. Figure 5.12 shows the paths inside the building along six different blocks not subjected to electromagnetic pollution, otherwise the compass's output would be negatively affected.

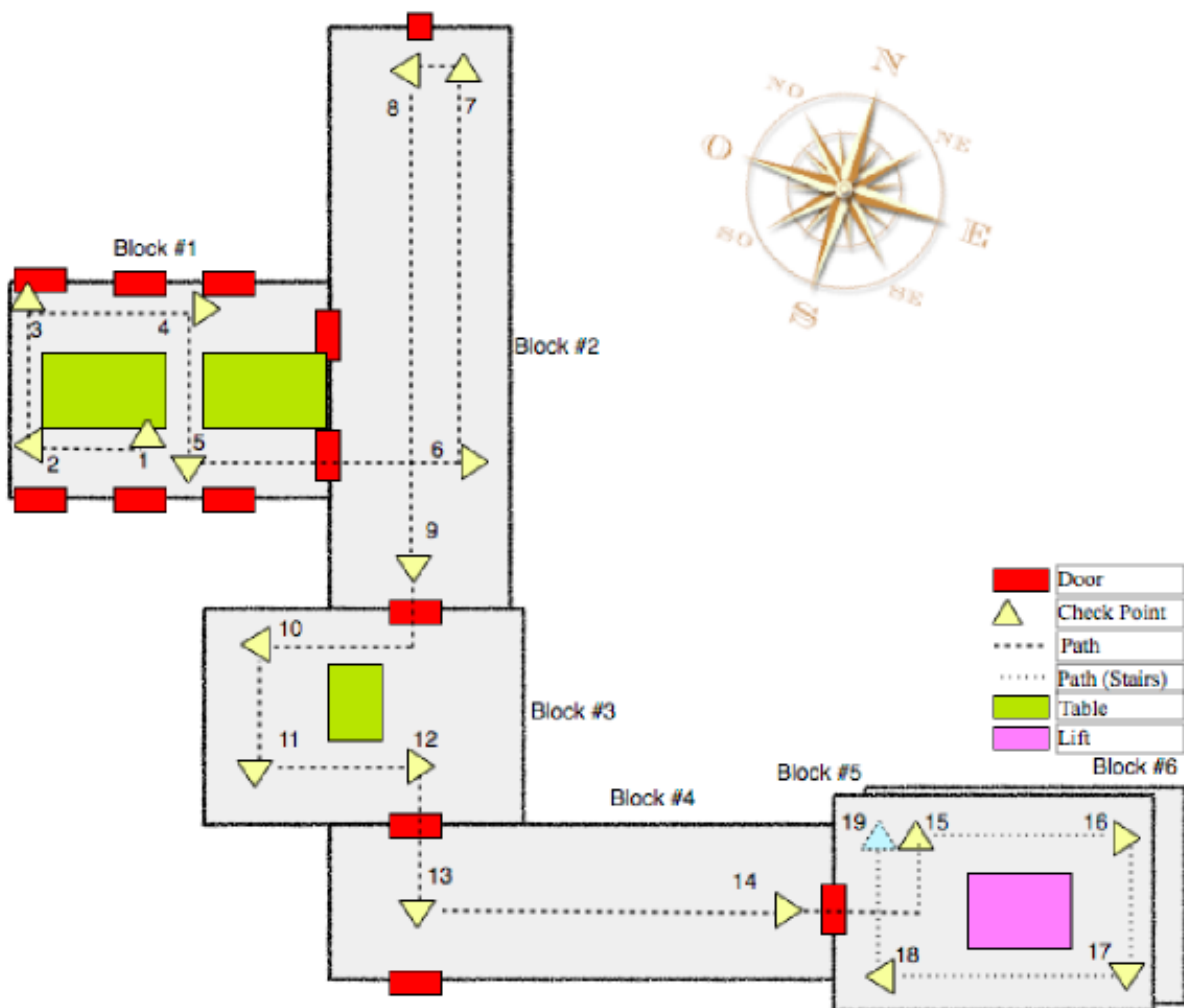


Figure 5.12: Paths inside a real indoor environment: each yellow triangle represents a check-point with a predefined orientation

In each check point (described by a numerated triangle), we read the angle rotation of the compass and the gyroscope. The objective is to analyse the absolute error of each sensor as

subtracting between the acquired and attempted value. About the gyroscope, the attempted value is a rotation angle composed by a multiple of 90 degrees, while the angle provided by the compass is acquired compared to the real reference system (magnetic north). In 5 paths of different length, starting with the shortest path made of 5 points, and finishing with the longest one made of 19 points, as shown in Table 5.5, the experimental results have shown how, compared to the gyroscope's absolute error, the compass's absolute error is random and independent from the length of the path.

Path	Block1	Block2	Block3	Block4	Block5	Block6
1	X					
2	X	X				
3	X	X	X	X	X	
4	X	X	X	X	X	X

Table 5.5: Reference path

The gyroscope accumulates some errors for rotations in the same verse, while the error decreases for rotation in the opposite verse, resulting in a very small error lying between -4 and 10 degree. The compass's absolute error instead lies between -58 and 132 degrees (figure 5.13).

5.4.4 Results and discussion

The main objective of this research was to examine the accuracy level that can be achieved in indoor navigation, specifically for the developed prototype, using exclusively the gyroscope sensor for the orientation. In order to reach the objective, the output from the gyroscope sensor has been analyzed with the device in static position and throughout a rotation. In both cases, the calibration algorithm satisfies the requirement and ensures a better orientation of the used device in indoor environment. Besides, we have compared the behavior of compass

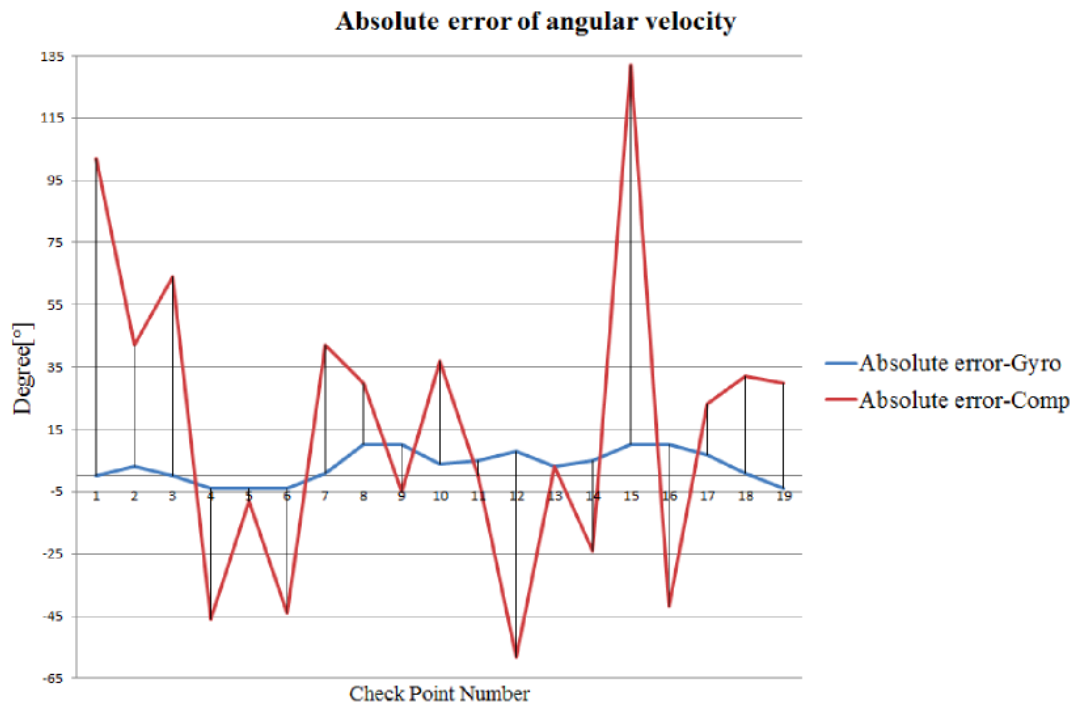


Figure 5.13: Comparison between the absolute error of gyroscope and compass

and gyroscope over time and for different paths. In conclusion, we have established how the gyroscope sensor is better than the compass for indoor navigation, specifically for our mobile application, and how is possible to correct the error introduced from the gyroscope in static position and undergoing rotation.

Chapter 6

Concluding remarks

The concept of safety is one of the predominant concerns in various fields. Major disasters require coordination with good communications and exchange of information among different authorities and different occupational groups. Therefore, developing a digital communication system for disaster management is essential for all stakeholders actively involved in disaster control to ensure their safety.

On the one hand, in this thesis we designed a digital communication radio system both for health emergency services and Civil Protection services. In the first case, the objective was to migrate health emergency service from analog to digital technology. In the second case, the radio network design for Civil Protection in Sardinia had to satisfy the technical specifications described by the Technical Group, as defined in Art.9 of the Understanding Agreement for the spectrum licensing, stipulated between the Minister of Economic Development and the Department of Civil Protection. These specification aim to realize an interoperable National Radio System, based on radio networks already realized from each region, which use common and free frequencies made available from the Department of Civil Protection. In both case, DMR has been identified as the best solution, which grants cost saving,

high coverage, spectral efficiency and simplicity in network configuration and is well suitable in wide area with a low/medium density of traffic.

On the other hand, our interest was to investigate and develop a control system in industrial workplaces, still considered high-risk environments with serious work safety related issues and higher accident rates than other workplaces. In the specific, we considered the Cagliari International Container Terminal, which represents the fourth most important commercial port of Italy.

When speaking of work safety issues, even with strict regulations and risk assessment studies, the human error plays a major role in generating potentially dangerous situations. Most of these accidents can be avoided or limit the damage when using proper protective equipment. For the specific case of a maritime cargo terminal the operators have to wear appropriate helmet, jacket and shoes. Real-time monitoring independently of the location of the correct use of these personal safety items is a challenging issue requiring advanced sensor and communication techniques. We considered a BAN (Body Area Network) with sensors added or included in the personal protective equipment, like clothing, helmets, goggles, or other garments designed to protect the wearer's body from injury, which should be worn appropriately, according to specific regulations. The sensors have to be able to signalize the presence of the personal protective equipment on the worker's body and also to have the capability to send some other useful data such as temperature and orientation. The final choice to use RFID over other technologies, was motivated by the reduced range of the latter technology, unsuitable for an industrial environment. Among various commercially available RFID systems, a very interesting alternative is the platform called WISP (Wireless Identification and Sensing Platform). To conclude, inside the industrial environment the operators must wear the appropriate protective equipment, which forms a BAN. In fact, two

RFID tags are placed in the shoes, a WISP tag with temperature sensor together with a photocell are placed in the helmet for sensing the body heat and the presence of light inside the helmet. The jacket includes a WISP tag with a temperature sensor and an accelerometer. The BCU in charge for collecting the data from the BAN is represented by fixed RFID readers placed in strategic check points of the industrial environment, for example on the bus carrying the workers to specific places and at the access points to cranes and heavy machinery, sensing tags at a distance of 1 m. All readers are connected through an Ethernet port to a local LAN through which the status of the tags and the information returned by the various sensors can be read and stored in a database. By combining in the control system, the inputs from a BAN integrated in the safety equipment and from CCTV cameras, a human supervisor is able to have an accurate overview of the entire situation in terms of work safety and act accordingly when needed.

We analyzed another aspect about developing an early prototype of a pedestrian navigation system for indoor environments based on smartphone's self-contained sensors. The main objective of this research was to examine the accuracy level that can be achieved in indoor navigation, specifically for the developed prototype, using exclusively the gyroscope sensor for the orientation. In order to reach the objective, the output from the gyroscope sensor has been analyzed with the device in static position and throughout a rotation. In both cases, the calibration algorithm satisfies the requirement and ensures a better orientation of the used device in indoor environment. Besides, we have compared the behavior of compass and gyroscope over time and for different paths. In conclusion, we have established how the gyroscope sensor is better than the compass for indoor navigation, specifically for our mobile application, and how is possible to correct the error introduced from the gyroscope in static position and undergoing rotation.

Bibliography

- [1] J.E.Flood. *Telecommunications Switching, Traffic and Networks*. Prentice-Hall, New York, NY, USA, 1998.
- [2] EN-300-392 ETSI. *Terrestrial Trunked Radio (TETRA)*. 2009.
- [3] D.Dernikas and J.G.Gardiner. Modelling the simulcast radio transmission. *IEE National Conference on Antennas and Propagation*, pages 307–311, August 1999.
- [4] TS-102-361 ETSI. *Electromagnetic compatibility and Radio spectrum Matters (ERM): Digital Mobile Radio (DMR) Systems*. 2007.
- [5] TIA. Tia-102:project p.25. 2004.
- [6] TETRAPOL Factsheet. Tetrapol factsheet, ofcom. 2005.
- [7] M.Hata. Empirical formula for propagation loss in land mobile radio services. *IEE Trans. Vehicular Technology*, pages 317–325, 1980.
- [8] I.F.A. Vis and R. de Koster. Transshipment of containers at a container terminal: An overview. *European Journal of Operational Research*, Volume 147, Issue 1, May 2003.
- [9] TT Club, ICHCA International, and Port Equipment Manufacturers Association. Recommended minimum safety specifications for quay container cranes. 2011.

- [10] TTCLUB Mutual insurance limeted. Ttclub mutual insurance limeted @ONLINE.
- [11] EN-300-392 ETSI. *Terrestrial Trunked Radio (TETRA)*. 2009.
- [12] Ryuji Kohno Huan-Bang Li. Body area network and its standardization at ieee 802.15.ban. advances in mobile and wireless communications. *Lecture Notes Volume 16*, pages 223–238, 2008.
- [13] M. Fadda, M. Murrioni, C. Perra, and V. Popescu. Tv white spaces exploitation for multimedia signal distribution. signal processing: Image communication. *IEE Trans. Vehicular Technology*, pages 893–899, September 2012.
- [14] M. Buettner and D Wetherall. Ban empirical study of uhf rfid performance. *MobiCom*, 2008.
- [15] D. J. Yeager, A. P. Sample, and J. R. Smith. Wisp: A passively powered uhf rfid tag with sensing and computation. *RFID Handbook:Applications, Technology, Security Privacy*, March 2008.
- [16] L. Sandip. *RFID Handbook*, 2006.
- [17] D.D. Arumugam and D.W. Engels. Impacts of rf radiation on the human body in a passive rfid environment. *Antennas and Propagation Society International Symposium*, pages 1,4,5–11, July 2008.
- [18] L. Atzori, T. Dessi, and V. Popescu. Indoor navigation system using image and sensor data processing on a smartphone. *Optimization of Electrical and Electronic Equipment (OPTIM)*.

- [19] Grumett S. Recording and monitoring the inspection of safety items. *In Proceedings of the Second international conference on Ambient Intelligence (AmI'11)*, 2009.
- [20] Ramirez Chaidez L. V. Farioli L. D. Method for tracking procedures performed on personal protection equipment (ppe) and actions of individuals. 2008.
- [21] Berendsen S. AB, Andreasen P, and Eriksson J. A system for dispensing of garments. 2006.
- [22] IND TECH RES INST. Equipment management methods and systems. 2006.
- [23] Heo J M. Admission control system for reinforcing safety in dangerous zone through dual check of safety helmet equipment of user by using rfid tags. 2006.
- [24] Nakanishi Metal Works Co. System for monitoring and alerting use condition of safety belt. 2009.
- [25] L. Sandip. *RFID Sourcebook*, 2006.
- [26] Wikipedia.
- [27] D.D. Arumugam and D.W. Engels. Impacts of rf radiation on the human body in a passive rfid environment. *Antennas and Propagation Society International Symposium*, July 2008.
- [28] A. D. King. Inertial navigation - forty years of evolution. *Handbook of Engineering Fundamentals By Ovid W. Eshbach*, pages 140–149, 1998.
- [29] Q. Ladetto. Digital magnetic compass and gyroscope integration for pedestrian navigation. *9th Saint Petersburg International Conference on Integrated Navigation Systems*, 2002.

- [30] Kougori M. and Kurata. Personal positioning based on walking locomotion analysis with self-contained sensor and a wearable camera. *In Proceedings of ISMAR 2003*, pages 103–102.
- [31] M. Kohler et al. Tracksense: Infrastructure free precise indoor positioning using projected patterns. *Pervasive Computing, LNCS 4480*, pages 334–350, 2007.
- [32] Chang Y.J., Tsai S. K., Wang T. Y, and Chou L. D. A novel wayfinding system based on geocoded qr codes for individuals with cognitive impairments. *In Proceedings of the 9th international ACM SIGACCESS conference on Computers and accessibility*, pages 231–232, 2007.
- [33] Mulloni A., Wagner D., Barakonyi I., and Schmalstieg D. Indoor positioning and navigation with camera phones. *IEEE Pervasive Computing*, pages 22–31, 2009.
- [34] Gehring S.and Löchtefeld M.and Schöning J. and KrügerA. Exploring the usage of an electronic compass for human navigation in extreme environments. *Haptimap 2010: Multimodal Location Based Techniques for Extreme Navigation, in conjunction with Pervasive 2010*, 2010.
- [35] Z. Sun, A. Purohit, S. Pan, F. Mokaya, R. Bose, and P. Zhang.
- [36] Bahl P. and Padmanabhan V.N.
- [37] Gandhi Siddhesh Rajan, Ganz Aura, Mullett Gary, Puleo Elaine, and Wilson Carole Schafer James, Singh Tushar.
- [38] Nor Aida Mahiddin, Noaizan Safie, Elissa Nadia, Suhailan Safei, and Engku Fadzli.
- [39] WiFi Slam. Wifi slam indoor gps @ONLINE.

- [40] Apple. ibeacon.
- [41] A. Serra, V. Marotto, and D. Carboni. Indoor pedestrian navigation system using a modern smartphone. *12th international conference on Human Computer Interaction with mobile devices and services (MobileHCI 2010)*, pages 397–398, 2010.
- [42] A. Serra, T. Dessì, D. Carboni, V. Popescu, , and L. Atzori. Inertial navigation systems for user-centric indoor applications. *NEM Summit - Towards Future Media Internet*, 2010.

List of Publications Related to the Thesis

Published papers

Submitted papers

- T. Onali, M. Sole, D.D. Giusto, *DMR Networks for Health Emergency Management: A Case Study*, IWCMC201
- M. Sole, C. Musu, F.Boi, V. Popescu, D.D. Giusto, *Control System for Workplace Safety in a Cargo*, IWCMC 2013
- M. Sole, C. Musu, F.Boi, V. Popescu, D.D. Giusto, *RFID Sensor Network fo workplace Safety Management*, ETFA 2013
- M. Sole, V. Marotto, A. Serra, D. Carboni, T. Dessi, A. Manchinu, *Orientation Analysis through a Gyroscope Sensor fo Indoor Navigation System*, CENICS 2013

Conference papers

- T. Onali, M. Sole, D.D. Giusto, *DMR Networks for Health Emergency Management: A Case Study*, IWCMC201

- M. Sole, V. Marotto, A. Serra, D. Carboni, T. Dessi, A. Manchinu, *Orientation Analysis through a Gyroscope Sensor for Indoor Navigation System*, CENICS 2013