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Report on Considered Scenarios for Performance Validation and Field Trials

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Abstract:
This deliverable describes the selected scenarios and the technical setups for performance evaluation, validation and field trials. Based on the summarized RESCUE use cases two corresponding scenarios have been selected. For the *public safety operations* an indoor validation as field trial and demonstration will be performed and in contrast to this the *vehicle-to-vehicle (V2V)* use case will be considered by a broadband channel sounding campaign. Whereby the results of the V2V channel sounding campaign will be subsequent analysed and used for extended channel modelling and for practical validation within the OTA facility. All practical validation steps are based on a software defined radio (SDR) testbed where the new physical and protocol layer are integrated. The document provides an overview on the realistic validation and evaluation approaches within RESCUE.

Keyword list: validation, verification, SDR, channel sounding, channel modelling, OTA, demonstration, V2V, VANET, public safety operations, lossy links, multi-hop communication, wireless networks

Disclaimer:

Executive Summary

The aim of the RESCUE project – "Links-on-the-fly Technology for Robust, Efficient, and Smart Communication in Unpredictable Environments"- is to investigate new approaches and concepts to introduce distributed turbo codes into wireless systems. The focus will be on multi-hop communication in mesh networks whereby the topology of the network is dynamically changing.

This deliverable summarizes the discussion within the WP4 – "Validation, Integration and Field Trials" on the selected scenarios derived on the defined RESCUE use cases within deliverable D1.1. In RESCUE different stages on performance evaluation have been established, while mainly model based software simulations are considered for intensive studies in the individual WP's, the hardware based validation is in cooperated to study the application of the new concepts within real-world conditions. Software-defined-radio (SDR) devices are employed to integrate the new algorithms and to create a multi node test platform. A frequency licence and weather condition independent practical validation will be done within the Over-The-Air (OTA) facility and – for a proof-of-concept – field trials as well as a final demonstration will be done.

The RESCUE project addresses two important use cases: public safety operations in situations where due to disasters the communication infrastructure is partially inoperable, and vehicular-to-vehicular communications where due to moving cars the communication links will undergo constant changes. Both cases have in common that safety-critical information must be reliable and efficiently transferred.

To cover both RESCUE use cases and not to neglect one of them during the validation phase it has been discussed and decided to perform the field trial and the final demonstration in a sub-scenario of the public safety use case: an indoor public safety operation. Typical rescue - public safety - situations will be handled equally indoors as well as outdoors. Because of easy access to power supply and the required connectivity between an SDR device and a control laptop it will be simpler to deploy the mesh network indoors. However from propagation and communication point of view an indoor situation is not easier compared to a comparable outdoor case.

The second use case - V2V – will be used for validation at different levels. In focus will be a channel sounding campaign for 2 sub-scenarios employing dedicated antenna arrays. These sub-scenarios will be a street crossing and a street with passing and upcoming vehicles. By means of high resolution multipath parameter estimation the directional characteristic of the propagation channel will be analysed and modelled. The extended WINNER like channel models are considered for software simulation as well as for the OTA test method. In the latter a virtual electromagnetic environment will be create within an anechoic chamber whereby a SDR device will be deployed in side this environment. This method allows for tests of one network node under realistic but also fast changing wireless propagation conditions.

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List of Acronyms and Abbreviations

Term	Description
AWGN	Additive White Gaussian Noise
BFT	Blue Force Tracking
CUDA	Compute Unified Device Architecture
DMO	Direct Mode Operation
LOS	Line Of Sight
MIMO	Multiple Input Multiple Output
NLOS	Non Line Of Sight
OTA	Over-The-Air testing method
PPDR	Public Protection and Disaster Relief
PTT	Push-To-Talk
SDR	Software Defined Radio
TETRA	Terrestrial Trunked Radio
UCA	Uniform Circular Array
VANETs	Vehicular Ad-Hoc Networks
V2V	Vehicle-To-Vehicle

1. Introduction

The basis of the RESCUE project is in the design and research of a novel communication concept called "links-on-the-fly". This technology is targeted for largely unplanned multi-hop or mesh wireless networks that are further subject to dynamic topology changes. Firstly, the design takes advantage of the inherent broadcast nature of the radio channel, and the multi-route diversity of the mesh network so that the communication *reliability* increases, and the outage probability reduces. Secondly, the overall *spectral efficiency* and *communication range* are enhanced by the fact that even the erroneously decoded data packet transmissions are utilized, as the relay nodes may re-encode and re-transmit them towards the destination. The underlying idea is that the different transmitting nodes in the network form together a distributed turbo code that the destination can iteratively decode even if the channel (link) conditions between different nodes are mainly unknown. One of the main challenges of the RESCUE project is to discover efficient "soft" routing protocols that support distributed turbo coding under topology changes, and can facilitate a variety of unicast and multicast services.

One potential practical framework for the links-on-the-fly concept is *public safety* operations that take place in areas where the communication infrastructure is partially inoperable due to a disaster such as earthquake. In a fast emergency network roll-out, the destinations may be multiple wireless hops away from the originating transmitters. Furthermore, the nodes may be moving, which results in changing or unpredictable channel conditions, and – in larger scale – network topology changes. The traditional public safety applications to be supported are push-to-talk (PTT) and blue force tracking (BFT), but more advanced services such as video streaming are highly valuable for public safety operations as well. Another potential framework is *vehicle-to-vehicle* (V2V) communication. Here, cars and other vehicles share, for example, safety-critical information about the road and traffic conditions with each other. The vehicles form a mesh network where the node distances and the channel conditions may vary greatly. The network is also subject to constant high-speed node movements and topology changes. Thus, the main challenge is the routing protocol that will be active virtually at all times. The general use case scenarios and the requirements for the RESCUE system design are described in another deliverable [D11].

One of the objectives of the RESCUE project is to show the validity of the links-on-the-fly technology via various means: information theoretic analyses, model-based numerical simulations, over-the-air (OTA) testing, and – for a proof-of-concept – field trials and demonstrations employing programmable software-defined-radio (SDR) platform devices.

Furthermore, a channel measurement campaign will be carried out to characterize the properties of typical V2V channels. The campaign has two goals: to utilize the measurement results for OTA testing, and to construct a measurement-based parametric V2V channel model that enables workstation simulations. The simulations will provide realistic performance figures to quantify the gains of the links-on-the-fly technology.

The final test for the technology developed within the project is the field trial employing SDR platform devices. For practical reasons, the most likely scenario for the field test will emulate a public safety operation that takes place in indoor facilities. It models rescuers that need to maintain communication also when entering indoor facilities such as factories, warehouses, or residential buildings, for example in order to carry out search and rescue operations. In this case, the communication channels between the rescue personnel and towards the control unit suffer from attenuations caused by heavy walls or floors instead of large distances. Furthermore, the movements of the personnel inside buildings will result in significant dynamic changes in the connectivity and the network topology.

2. Minimum technical setup and overview on RESCUE use cases

Within the [D1.1] the RESUCE use cases have been introduced and deeply discussed from different technical perspectives. This chapter summarize these findings in terms of the *system topology*, *communication case* and the expected *propagation channel*. Furthermore the minimum technical setup for practical validation based on hardware devices will be highlighted.

2.1 Summary of RESCUE use cases

Disaster such as natural cataclysm, fires and terroristic attacks in public places such as airports, shopping malls or underground stations could possibly lead to catastrophic consequences. In this situation it can be expected that the available communication infrastructure will be at least partially inoperable. However it is commonly agreed that support and rescue units need to be in permanent communication to others as a command and control unit and even within their individual units. This use case is called public safety operations.

The second RESCUE use case is the V2V communication scenario, where cars and other vehicles share, and actively distribute safety critical information. These can be road and traffic information however such a use case can be further explored towards high automated driving of vehicles at public roads.

In the RESCUE project these two different use cases will be researched, evaluated and tested w.r.t. their communication requirements within their specific application scenario.

Public safety operations use case

Public safety operations usually take place in outdoor circumstances. It requires dedicated networks that ensure specific services as shown in Fig. 2.1 (for more details the reader is referred to Section 2.1 of D1.1) [D1.1].

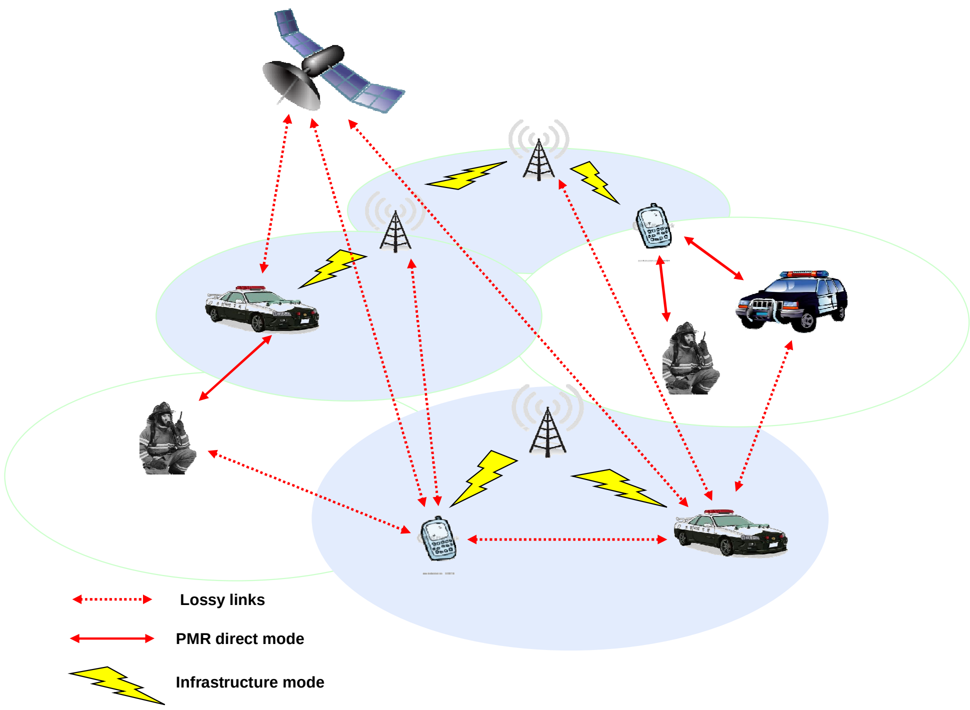


Fig. 2.1 Public safety scenario based on the RESCUE concept.

Indoor emergencies due to fires, mining accidents, terrorist attacks, and toxic releases are one of the major types of emergencies that have resulted in high civilian deaths and injuries.

Furthermore indoor localization is critical in emergency response operations inside buildings, because building occupants need to be located for rapid rescue, rescuers will need to maintain a collaborative and reliable communication also when entering indoor facilities such as factories, warehouses, or residential buildings in order to carry out search and rescue operation minimizing the risk of injury and delay in the operations.
In order to be able to evaluate the RESCUE impact in the industry we will evaluate and simulate an indoor emergency situation which may occur due to a fire inside a building. Let's assume the scenario where a group of fire rescue people need to enter a burning house in order to locate and save people which are stuck inside the building without knowing how to escape. The rescue team will be divided in different groups in order to be able to cover more rooms in the shortest possible time without losing communication signal between rescuer or the command center.
The first scenario will be a single-hop connection with devices connected to an access point (base station). The second one will be a multi-hop scenario where relay link will transmit copy of the message to the destinations node according with the new links-on-the-fly model (this is also explained in more details in sections 3.3 and 3.4).

System topology

Public safety operators rely on dedicated network concepts, as sketched in Fig. 2.1. These infrastructure elements have strong similarities with the civil/commercial cellular/wireless communication networks. However to fulfil specific requirements arising from the coordination and control of the rescue operation specific differences are introduced, whereby a summary can be found in [D1.1, chapter 2.1]. The so called Public Protection and Disaster Relief (PPDR) is deployed by the TETRA system and in future by the LTE technology. Typical relief services are Push-To-Talk (PTT), Blue Force Tracking (BFT) as well as Direct Mode Operation (DMO). Besides the cellular topology of TETRA or LTE also single-hop and a broadcast mode are considered and under discussion. For the new RESCUE design multi-hop concepts will be one of the key elements. It is important to note that the topology of the network will change while the rescue units are moving.

Communication case

Different service applications have been established in the past for the relief communication in disaster scenarios. Based on these approaches certain assumptions on the expected communication has been made, however these will evolve already with new standards and possibilities provided by LTE and by the advances of the technical equipment used by the rescue units.
Besides the wide coverage of wireless channel characteristics, which will be discussed below, the node density, the node mobility and with it the traffic pattern of such public safety operations will change. New communication applications as live video streaming or 3D building/environmental map interaction are just few examples of the new possibilities but also of the new demands.

Propagation channel

Depending on the underlying disaster environment the propagation channel will change. In [D1.1] channel models from WINNER 2 [WIN2D112] have been chosen for software based performance evaluations. To reduce the simulation effort propagation scenarios have been selected which match the introduced use case - the urban micro cell models B1 and B2. Due to the moving of people within the rescue units and of the units itself the multiple links and hence the wireless channels are changing constantly. So the topology as well as the propagation conditions as line-of-sight (LOS) and non-line-of-sight (NLOS) is changing.
However as detailed above also public safety operations quite often happen inside of buildings or constructions. In this case, the communication channels between the rescue personnel and the control unit suffer from attenuations caused by heavy walls or floors instead of large distances. Furthermore, the movements of the personnel inside buildings will result in significant dynamic changes in the connectivity and the network topology will change quickly due to the mobility of rescuers.

Vehicle-to-vehicle/ use case

The second potential scenario will be the vehicle-to-vehicle (V2V) communications also known as VANET. In this scenario vehicles as cars, trucks and others as emergency vehicles exchange and share safety-critical information about traffic, situation (even rescue operations) and road conditions in order to efficiently collaborate among themselves and with civilians. Another very demanding future application will be high automated driving of vehicles at public roads. Compared to the public safety operations scenario described above VANETs will change very quickly their location, topology and undergo different propagation conditions due to their high mobility. Note here that in an urban rescue operation with a partially destroyed infrastructure, communication ranges tend to increase, favouring additional device to device (D2D) information exchange.

System topology

The standardisation path for VANETs is very complex and it is still under development even though standard protocols have been introduced. Recently a new protocol standard for vehicular communications has been introduced and adopted. The IEEE 1609 protocol stack known as Wireless Access in Vehicular Environment (WAVE) defines the protocol used for the Dedicated Short-Range Communications (DSRC) as well as the specification for the technical requirements. This new protocol standard includes several technical issues and limitations, such as multi-channel organisation, spectrum allocation, networking and transport design, access layer specifications, network topology, spectrum-bandwidth allocation and applications' requirements specifications.
Vehicle-to-Vehicle communications (V2V) bring the promise to improve road safety and optimise road traffic through co-operative system applications especially for the emergency communication scenario addressed by the RESCUE project.
The vehicular environment has some unique characteristics, such as the variable and unstable nature of wireless links, the lack of central coordination, the short-lived intermittent connectivity and the dynamic topology that lead to a very challenging multichannel coordination, access and synchronisation.
The VANETs topology is dynamic due to the network's nature. The vehicles move with high speed so the topology is always changing. This is caused by the high mobility of the nodes that form the vehicular network. Moreover, the topology changes may occur when the distance between nodes increases, so no link or only a lossy link can be established. Moving vehicle, periodic connectivity, and mobility in the network nodes make the adoption and roll-out of future V2V networks challenging. Another reason for topology change can occur when there is need of dropping the original link because another more important link needs to use the wireless resources (prioritization).

VANETs consist of particular technical features, such as:

- Distributed processing and organized networking,
- Highly variable and constrained topology,
- Large number of nodes including their speed and their geographical distribution,
- Frequent partition because of the high level of mobility,
- Communication conditions and mobility patterns and low power constraints.

Communication in VANET network raises several challenges in order to ensure a reliable end-to-end connectivity between nodes (users). RESCUE will design a new concept of communication to be deployed reliably in this dynamic and unpredictable network environment.

Communication case

We consider in our RESCUE VANETs scenario vehicles equipped with radio-enabled devices, which act not only as mobile nodes but as routers for other nodes too. The portable devices are IP-based as well as having both ad-hoc and infrastructure modes IEEE 802.11 and IEEE 1609 connection capabilities. In the considered V2V wireless multi-hop scenario the network will be composed by multiple devices. In this context, the objective is to establish point-to-point communications (voice/video) between two cars (Fig. 2.2) as well as distributing road specific information for traffic prediction and road safety.
In addition to classical point-to-point communications between vehicles, we consider in our V2V scenarios some specific VANET applications as the Point to Multi-hop application below.

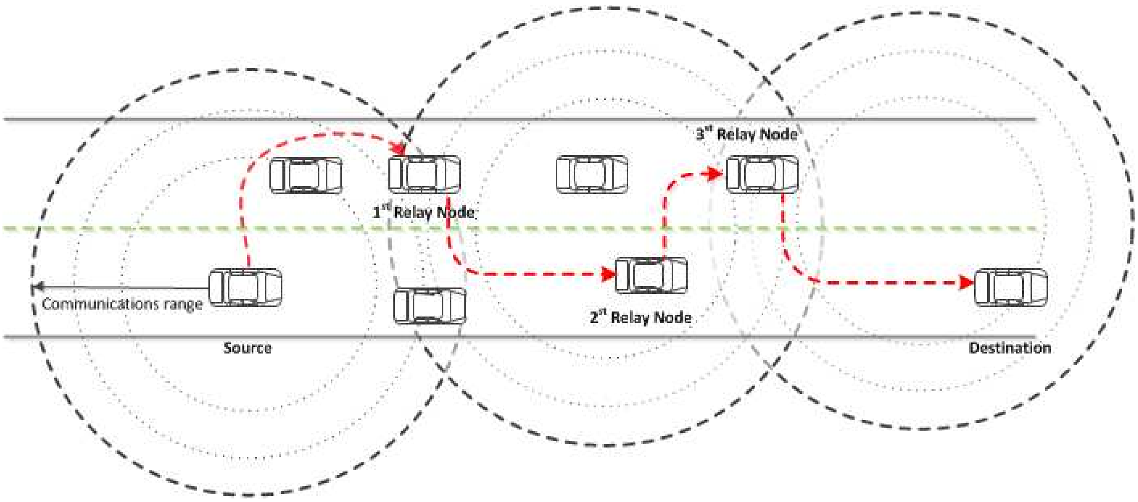


Figure 2.2: Point to multi-hop message propagation in VANETs.

Fig. 2.2 shows that each one of the vehicles (nodes) has a certain transmission range. Hence, to disseminate the information to each one of the nodes, the message has to be transmitted to a node which is within the sender's transmission range (first hop), then the node that received the message has to send it to the next node (second hop) and so on.

In V2V communication scenarios due to possible high speed of the terminals a fast changing environment must be assumed. Indeed, this mobility is the main difference between the public safety scenarios and the considered V2V environment. Some of the main aspects of VANET communications are listed below:

- **Topology and its' dynamics change**: Due to the fact that the vehicles move with high speed, the VANETs topology is not stable, but always changing. This will make the measurement process more challenging in terms of performance evaluation because the connectivity between nodes can change frequently particularly in area with low density of vehicle.
- **Mobility predication**. Because of the dynamic topology and the highly mobile node movement, predication and mobility model are very important for the design of network routing protocols for VANETs. Furthermore, the movement of vehicular nodes is usually constrained because of roads and streets, so if the speed and the street map are known, a prediction of the future vehicle's position can be made with on board sensors for providing useful information and vehicle position. GPS receiver system are widely used and deployed in order to provide information related to vehicle's location.
- **Various communication environments**. Typically two different communications environments are usually considered in VANET system. The first one is in the city area where usually there are buildings and obstacles that separate the streets and each node so it is not always possible to maintain a direct line of communications between mobile vehicles. The second one is the highway where the mobility of the nodes is higher compared with the city scenario and where the communications environment is less complex.

Propagation channel

In V2V communications scenarios a rapid changing environment must be considered because of the high speed of the nodes. The mobility of the nodes constitutes the difference between the V2V communication and public safety scenarios. The wireless communication system in VANETs must be able to deal with rapid changing channel conditions and high Doppler spreads. It can be assumed that Line of Sight (LoS) connection exists among adjacent cars, but there is always the case of the need of communication with farther away nodes. This means that the LoS assumption cannot be held leading to the use of non-Line of Sight (nLoS) connections. Links between nodes and infrastructure, such as traffic lights, are assumed to have a LoS connection due to the higher position of the access points.

In VANETs there is a typical radio wave propagation environment. In general, vehicles move on roads, but the environment can change from open farmlands to forests and large urban areas. The propagation environment in VANETs consists of large metal objects, which are changing position fast. VANET research converges to IEEE 802.11p, which is a Wi-Fi implemented for communication in the vehicular environment part of the Wireless Access in Vehicular Environments (WAVE) standard. The IEEE 802.11p extends the mature and proven 802.11 standards providing low latency access to the medium. The IEEE 802.11p standard operates on seven channels (5.8-5.9 GHz) and its communication range is expected to be in the order of 1km. The propagation models can be classified in deterministic and probabilistic models.

One of the well-known channel models suitable for very high mobility as encountered in V2V, is the WINNER 2 channel model [WIN2D112] which is used in the scenario D1- rural macro-cell. In this scenario, node speeds up to 200km/h can be supported, but there are some requirements such as, low delay spreads and the existence of large cells with LOS conditions.
As mentioned before, the topology in VANETs changes very quickly due to the high mobility. The change between LOS and NLOS connection between two nodes can happen for example when a third node appears into the way and blocks the LoS link, or when one node turns around a corner of a building. The communication among the nodes can also be achieved by using NLOS modeling.

2.2 Minimum technical requirements for SDR based validation

In order to evaluate the links-on-the-fly concept in different environments, all required mechanisms, coding techniques and protocols will be developed and integrated in real hardware devices with help of Software Defined Radio (SDR) platforms. The SDR Forum [SDRF] together with the IEEE P1900.1 group established a definition of SDR that provides a clear overview of the technology and its associated benefits. The SDR is simply defined as "Radio in which some or all of the physical layer functions are software defined". There are also some other definitions of the SDR technology, but generally this term describes the ability to modify a wireless radio device to perform differently, to improve its performance and be used for more than for one purpose. It’s worth to mention about the five-tier radio classification scheme, where tier 0 refers to a rigid hardware radio, while tier 4 is a fully flexible radio. The last one means a radio device with a programmable radio frequency that can capture and transmit a wide range of radio signals, as well as programmable baseband hardware. The fully flexible radio is considered for implementation and for the final testbed in the RESCUE project. It should support both single-relay and multi-relay cooperation. SDR technology is a promising way for development and configuration because most of the signal processing functions can be coded with efficient programming environment. The PC or laptop connected to SDR device allows also for quick and easy implementation of other ISO/OSI layers (e.g. MAC and network) of the wireless device. Traditional hardware based radio devices usually have a number of limitations and lack of flexibility in supporting multiple wireless standards or physical layer parameters. Occasionally, some modern devices might allow for some limited flexibility through a software control interface, such as choosing the radio channel, setting the modulation, channel width or transmit power level, but the basic function of the radio is usually fixed. Unfortunately, most of the physical layer functions can only be modified through physical replacement of electronics parts, e.g. RF integrated circuits, discrete RF and digital components, amplifiers, filters, custom-designed chips. This results in higher production costs and slower development of new protocols and architectures. In opposite, the SDR technology provides an efficient and inexpensive solution to create multi-standard, multi-mode, multi-band, and multi-functional wireless devices that can be simply modified using software upgrades. These devices can include field programmable gate arrays (FPGA), digital signal processors (DSP), general purpose processors (GPP), graphical processing unit (GPU), programmable System on Chip (SoC) or other more specific programmable processors. This allows new capabilities, algorithms and features to be added to the working wireless systems without requiring new hardware. As mentioned before, the usage of SDR technology significantly reduces the development time and costs.
At the first stage of RESCUE project we discussed the possibility of using different SDR platforms available on the commercial market. The detailed analysis of features available under different platforms allows us to choose the most promising, Ettus Research USRP (Universal Software Radio Peripheral) N210 platform as a common SDR solution for the RESCUE project [Ettus]. This was a good compromise between cost of SDR devices, their features and compatibility with GNU Radio software suite [GNUR] which allows to create very complex software-defined radio systems. Additionally some partners of the project consortium already have these devices and have a good experience with their usage and programmability.
GNU Radio is a free software development toolkit that provides the signal processing runtime and processing blocks to implement software radios with low-cost or medium-cost RF devices or without hardware in a simulation-like environment. It is successfully used for many years by scientific, academic and commercial applications to support wireless communications research. It also allows for implementation of real-world radio systems. GNU Radio applications are predominantly written using the

Python programming language. Moreover, the performance-critical signal processing path is implemented in C++. GNU Radio also supports development of signal processing algorithms using pre-recorded or generated data. This allows to avoid the need of specified RF hardware. GNU Radio is distributed under the terms of the GNU General Public License (GPL).
Ettus Research (now a part of the National Instrument company) specializes in low-cost but high-quality SDR systems. Its flagship product, the USRP (developed by Matt Ettus), enables users worldwide to address a broad range of academic, research, industrial and defence applications. The USRP devices were especially designed for accessibility. Moreover, the USRP products are controlled with the open source UHD driver. The USRP N210 provides high-bandwidth and high-dynamic range processing capability. The USRP N210 can be used for very demanding communications applications with fast and inexpensive development. This hardware is especially useful for applications requiring advanced physical layer design and prototyping. This also includes non-standard coding techniques which are considered in the RESCUE project. The product architecture is composed of a Xilinx Spartan 3A-DSP 3400 FPGA, 100 MS/s dual ADC, 400 MS/s dual DAC and Gigabit Ethernet connectivity to stream data to and from host processors. The USRP N210 can operate from DC to 6 GHz, however taking into account the testbed requirements we have chosen the SBX 400-4400 MHz Rx/Tx (40 MHz) RF daughterboard [SBX]. The SBX is a wide bandwidth transceiver that provides up to 100 mW of output power. The typical noise figure of SBX is 5 dB. The local oscillators for the receive and transmit chains operate independently. This feature allows for dual-band operation. The SBX is also MIMO capable, and provides 40 MHz of bandwidth. The SBX daughterboard can be especially useful for all applications requiring access to a variety of bands in the whole 400 MHz-4400 MHz range. This means that their applications can be compatible with the most popular wireless technologies: WiFi, Zigbee, WiMax, as well as S-band transceivers. In the RESCUE project we decided to use mainly the 2,4-2,5 GHz unlicensed band (this is also the requirement of the assumed channel sounder and antenna setup in the OTA testbed). The Fig. 2.3 presents the block diagram of the USRP N210 device.

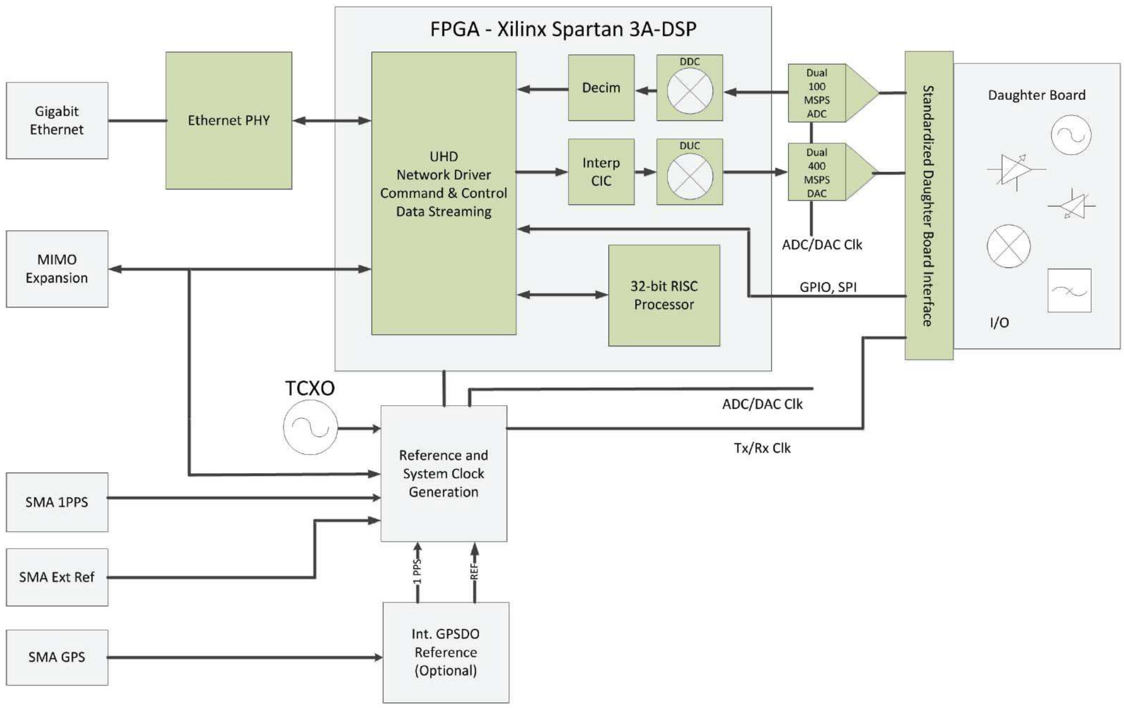


Fig. 2.3. Block diagram of the USRP N210 device [N210]

The expansion port allows multiple USRP N210 series devices to be synchronized and used in a MIMO configuration however in the final RESCUE testbed to avoid complexity (for regular operation one wireless node with MIMO support requires two SDR devices and two standalone computers) we decided to use SDR devices in SISO configuration. An optional GPS module can also be connected to N210 devices to adjust the reference clock to within 0.01 ppm of the worldwide GPS standard. The USRP N210 has the availability to stream up to 50 MS/s to and from host applications. User's applications can exploit the built-in FPGA through implementation of different functions, however the on-board 32-bit RISC softcore can be also reprogrammed if needed. It's worth to mention that Ettus also produces cheaper USRP N200 devices. The pro of N210 is that it provides a larger FPGA than the USRP N200 which is especially important for applications which requires additional logic, memory and DSP resources. The

Xilinx Spartan 3A-DSP 3400 also offers the possibility to process up to 100 MS/s in both the transmit and receive directions. What's more, the FPGA firmware can be easily reloaded through the 1 Gigabit Ethernet interface. The Table 2.1 presents the technical specification of the USRP N210 devices.

Table 2.1 USRP N210 technical specification [N210]

Conversion performance and clocks		
Spec.	Typ.	Unit
ADC Sample Rate	100	MSPS
ADC Resolution	14	bits
ADC Wideband SFDR	88	dBc
DAC Sample Rate	400	MSPS
DAC Resolution	16	bits
DAC Wideband SFDR	80	dBc
Sample Rate to/from Host (8b/16b)	50/25	MSPS
Frequency Accuracy	2,5	ppm
w/ GPSDO Reference	0,01	ppm
RF Performance (W/ WBX)		
Spec.	Typ.	Unit
SSB/LO Suppression	35/50	dBc
Phase Noise (1,8 GHz)		
10 kHz	-80	dBc/Hz
100 kHz	-100	dBc/Hz
1 MHz	-137	dBc/Hz
Power output	15	dBm
IIP3	0	dBm
Receive Noise Figure	5	dB
Power		
Spec.	Typ.	Unit
DC Input	6	V
Current Consumption	1,3	A
w/ WBX Daughterboard	2,3	A

Based on the information about SDR devices presented above it should be noticed that in the real field (and OTA) testbed, each of the SDR devices must be connected to the personal computer (PC), server or laptop which serves as a signal processing machine. Performance of the SDR devices, measured in processed (Mega) samples per seconds (M)S/s is highly depended on the computing power of the processing machine, because the process of samples processing is performed not by the Ettus N210 itself but by the processing machine. In RESCUE it is planned to connect Ettus N210 with laptop equipped with the Intel Core i7 CPU and a dedicated video card with the CUDA (Compute Unified Device Architecture) support. CUDA support is important mostly due to the fact, that with the use of GRGPU [GRGPU], which is a standalone GPU (Graphics Processing Unit) acceleration library for GNU Radio, it is possible to use both CPU (Central processing unit) and GPU in parallel to process the samples received form Ettus N210. This allows to increase the computing power delivered by laptop and therefore increases the efficiency of the RESCUE station. The Table 2.2 presents the technical specification of the laptop which is planned to be used as a processing machine of the SDR device.

Table 2.2 Processing Machine technical specification

Spec.	Typ.
CPU	Intel Core i7-4500U
Nr of Cores	2
Nr of Threads	4
Max Clock Speed	3.0 GHz
CPU Thermal Design Power (TDP)	15 W
Memory	8 GB – DDR3
GPU	Nvidia GeForce GT 750M
Nr of CUDA cores	384
GPU Memory	2GB GDDR5
Power Supply	90 W

When transmitting and receiving with the use of SDR, both the CPU and the GPU usage is usually about 100%, and their computing power is mostly consumed by SDR processes. That is why RESCUE station requires an external power supply. In such conditions using battery as a power supply would be sufficient only for a few minutes of the system run, which is too short time interval to perform the required experiments.

Therefore the real field test are planned to be performed indoor. RESCUE Stations will consist of a laptop and the Ettus N210 with proper dashboard and antennas, will be deployed for the duration of the tests in an indoor office and arranged in a manner similar to the one shown in Fig. 1. Minimal number of RESCUE Devices required for testbed in which the practical validation and verification of the RESCUE concept will be performed is three. It is also required to deploy at least one lossless and one lossy link among communicating stations.

In the testbed SDR Devices will operate in SISO (Single Input Single Output) configuration. To use SDR Ettus device in MIMO (Multiple Input Multiple Output) configuration a pair of USRP devices must be linked together with a dedicated MIMO expansion cable. That is why MIMO configuration would require twice as many devices. Besides, there is no need to use MIMO to prove RESCUE concept and that is the main reason why SISO configuration was chosen.

3. Selected scenarios for performance evaluation and validation

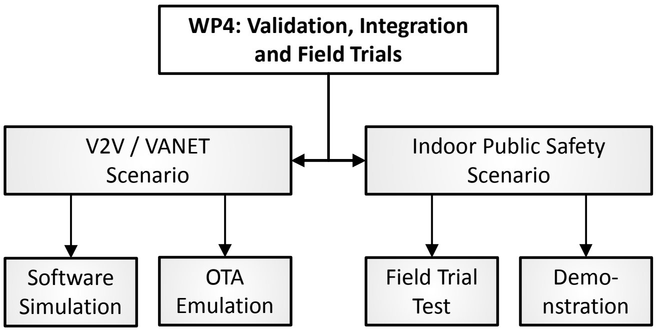


Fig. 3.1 Overview on the selected scenarios within WP4

The realistic evaluation and validation strategy within the WP4 aims to cover both main RESCUE use cases: the public safety and the V2V/VANET scenario. The Fig. 3.1 summarizes which scenario is considered for which specific validation method. Based on a MIMO channel sounding campaign the VANET will play a role for software simulation using geometrical based stochastic channel models as from WINNER [WIN2D112] and furthermore for the OTA evaluation using the SDR devices. The second part of validation will be performed in the public safety scenario by a field trial and the final demonstration. Due to technical limitations of the experimental SDR testbed the public safety scenario is based on an indoor emergency case.

3.1 Scenario for channel measurements and modelling

The goal of the channel sounding task [SS09, TST05] is to gather realistic propagation characteristics. Fig. 3.1.1 illustrate the principal work flow using measurement datasets to provide the evaluation/validation tasks as software simulation or hardware emulation (as OTA or as connected/hybrid approach) with realistic channel representations. It is possible to directly apply channel datasets from the channel sounding campaign for performance evaluations. This approach is the most realistic one, however it’s limitations arise from the measurement antenna dependency and is site-specific nature [TST05, SNT13, ST13]. The second approach uses the RIMAX estimator [R05] for a de-embedding of the measurement antennas and a subsequent embedding of more realistic application antennas at transmitter (e.g. base station) and receiver (vehicle or mobile) [KSKT11, KSST14]. This approach maintains to a large extent the realism of the direct use of measurement data and provides full flexibility in terms of the antenna used during the software or hardware based evaluation. Channel model based evaluations where the channel model is parameterized by intensive analysis of channel datasets are known as realistic and are widely accepted for link and system level simulations [D1.1, NSKT13].

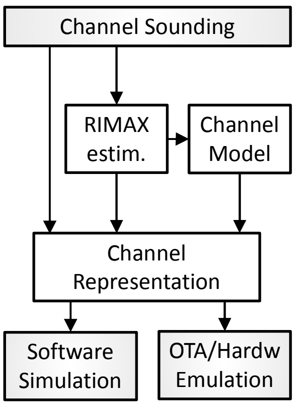


Fig. 3.1.1 Overview on the workflow of channel sounding data based validation methods

For the channel measurements and modelling the V2V scenario (also considered as VANET) as one of the RESUCE use cases [D1.1] have been selected. These channel data sets are subsequent analysed in order to derive new knowledge and understanding of the physical wave propagation within VANET. The special focus of this research work will be the analysis of the full 3D angular propagation characteristic (azimuth and elevation domain). Furthermore it is of importance to gather insight of the multipath clustering within these time variant V2V channels [SI14].

3.1.1 Measurement scenario

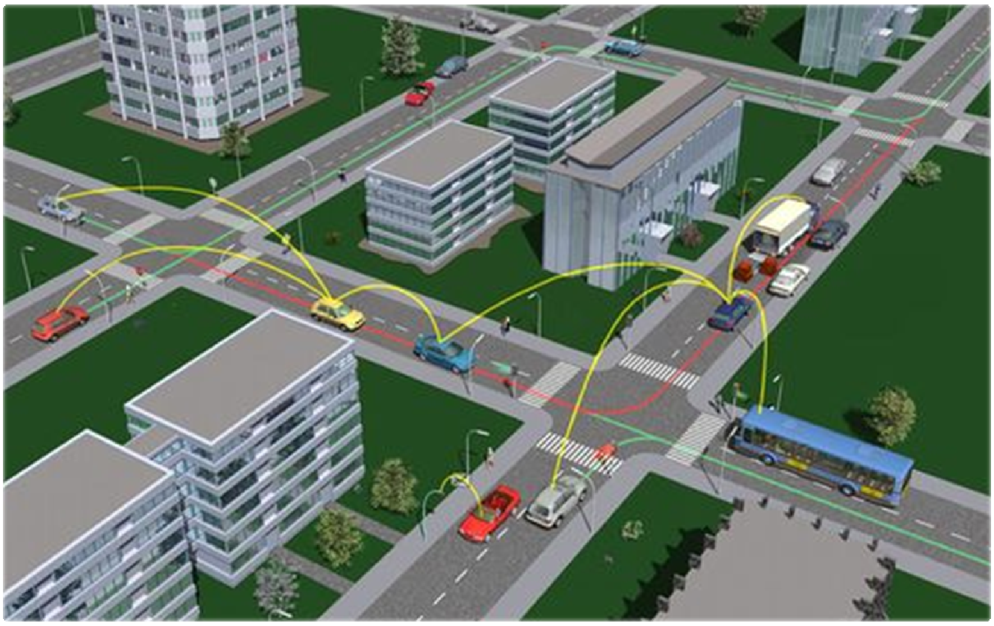
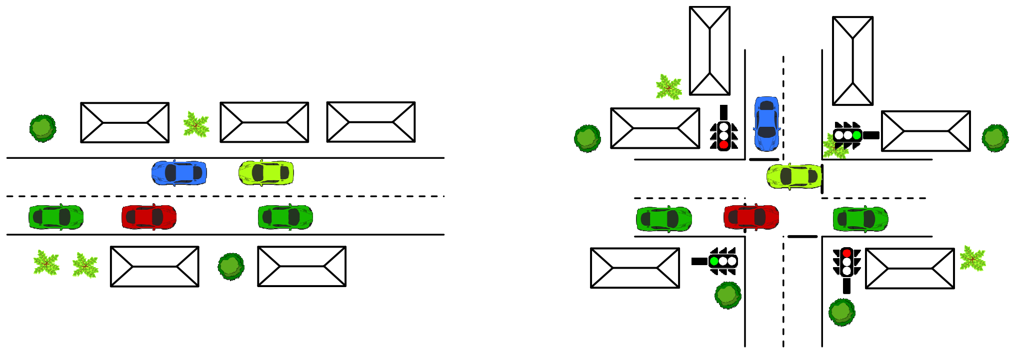


Fig. 3.1.1Typical setup for Vehicular2Vehicular and Vehicular2Infrastructure links (Source: CAR 2 CAR Communication Consortium)

A typical scenario for VANETs as V2V and V2I links is shown in Fig 3.1.1. However there will be many different other situations as within tunnels, over bridges, at highways or toll plazas and so on. Within WP 4 the focus for channel sounding will be at urban/sub urban environments as shown in Fig. 3.1.2. The two selected typical sub scenarios are the two street crossing and the normal street with passing or oncoming cars. Both are sketched within in Fig 3.1.3. The basic idea behind this proposal is not to cover a wide variety of V2V scenarios rather to represent simple daily applicable scenarios which can be provided by easy physical access and where no time constraints (access time) will restrict any planning of the channel sounding campaign. This is of special importance since the channel sounding task will perform various measurement runs (in a sequential manner) with the same technical setup but under different situations, e.g. LOS and NLOS between transmit and receive vehicle or with passing and no passing car and so on.

Fig. 3.1.2 Urban/sub urban V2V setup

From all these different measurement runs the directional multipath propagation by means of high resolution multipath parameter estimator [R05, LKT11] will be studied. The contributions arising from surrounding static buildings, trees and the dynamic ones from passing and oncoming vehicles are analysed and considered for the channel modelling [MTKM11]. Lossy (unreliable) links will be considered in situations where a change from LOS to NLOS propagation between transmitter and receiver occurs. These cases would happen when a 3rd vehicle is blocking the direct LOS or when one end of the links is moving around a corner, e.g. at a street crossing. Both can be investigated based on the planed V2V scenarios within Fig 3.1.3.



Normal street with passing and oncoming traffic

Street crossing

Fig. 3.1.3 Sketch of the two selected V2V scenarios in an urban/sub urban environment

3.1.2 Technical setup

<u>MIMO Channel Sounder Equipment and Measurement Antennas at TUIL, Ilmenau, Germany</u>

The MIMO channel sounder manufactured by the Medav GmbH (Uttenreuth, Germany) [Medav] is used for continuous real-time recording of a wideband MIMO channel matrix. Depending on the measurement setup and the antennas used, the sounder will emulate, e.g., cellular, WLAN, BS2relay, relay2user, peer2peer, V2X or V2V network scenarios. Together with calibrated high resolution antenna arrays the records are used to estimate the geometrical structure of the propagation channel (double directional). The resulting parameters are applied to reconstruct the virtual output of certain application specific antennas and to compare, e.g. their performance in the same propagation environment. These channel data can be convolved with some data source (symbol stream) signals to emulate a virtual electromagnetic environment in an OTA test setup.

<u>General channel sounder antenna setup</u>

Sounder system:

- Frequency range 1.8…2.6 GHz, 5.0…6.0 GHz
- 240 MHz Bandwidth
- Up to 1h real-time storage
- Full programmable transmit signal
- Multiband and multiple sounder operation
- Switched MIMO antenna access (full programmable)

Available calibrated high resolution antenna arrays:

- linear array (2.5 GHz, 8 elements, dual polarized, suitable to emulate base station)
- 2 cylindrical arrays (2.5 GHZ, 8 elements per ring, two stacked rings, dual polarized, suitable cover full azimuth and elevation angle and, hence, to emulate access points, relays, mobile terminals including peer to peer)
- various circular and linear antennas for 5.2 GHz
- integrated high power switch (up to 40 W)

Selected channel sounder antenna setup for RESCUE scenarios

Sounder system:
- Carrier frequency 2.53 GHz and 5.2 GHz
- Up to 100 MHz Bandwidth
- Tx and Rx antennas mounted at passenger car level
- Switched MIMO antenna arrays at both sides of the link
-

Antenna setup:
- 2.53 GHz: 2 cylindrical arrays with 8 elements per ring, two stacked rings, dual polarized,
- 5.20 GHz: 2 cylindrical arrays with 8 elements per ring, two stacked rings, dual polarized,
- All antennas with integrated high power switch (up to 40 W)

Fig 1 Available MIMO channel sounder at TUIL

Fig 2 Available circular antenna arrays dual polarized at TUIL

3.2 Scenario for verification within the OTA facility

The main goal of the verification within the OTA facility is proof the full functionality of the SDR platform together with the implemented new developed PHY and MAC algorithms. These tests will be performed under real world multipath propagation condition based on wireless signal reception at the antenna of the SDR devices. Whereby the tests can be performed without any restrictions wrt. frequency license issue and any weather condition [SK13]. Furthermore the emulation of the virtual electromagnetic environment is highly reproducible with that a wide range of PHY and MAC setups could be tested under the same propagation conditions and hence ensures a high flexibility and reliability of the performance investigation.

3.2.1 Emulation scenario

In Fig. 3.2.1 and Fig. 3.2.2 the emulation method is illustrated. The physical radio propagation between a base station, access point, mobile user and/or vehicles is measured by means of channel sounding and deeply analysed in a second step. Based on these results the wireless channel can be modelled and further be applied to be emulated within an anechoic chamber using the over-the-air method. The emulation of the dynamic wireless channel is performed by so-called fading emulators together with the derived V2V channel models. The illustration in Fig. 3.2.1 considers a vehicle-centric approach. Currently wireless devices in the size of laptops or smartphones can be tested within the “FORTE” facility at Ilmenau, so it fits well to the SDR platform considered in RESCUE. Vehicle-centric evaluations will not be possible during the RESCUE project however at Ilmenau a second much larger OTA facility called “VISTA” is currently under construction to allow real vehicle-centric system validations.

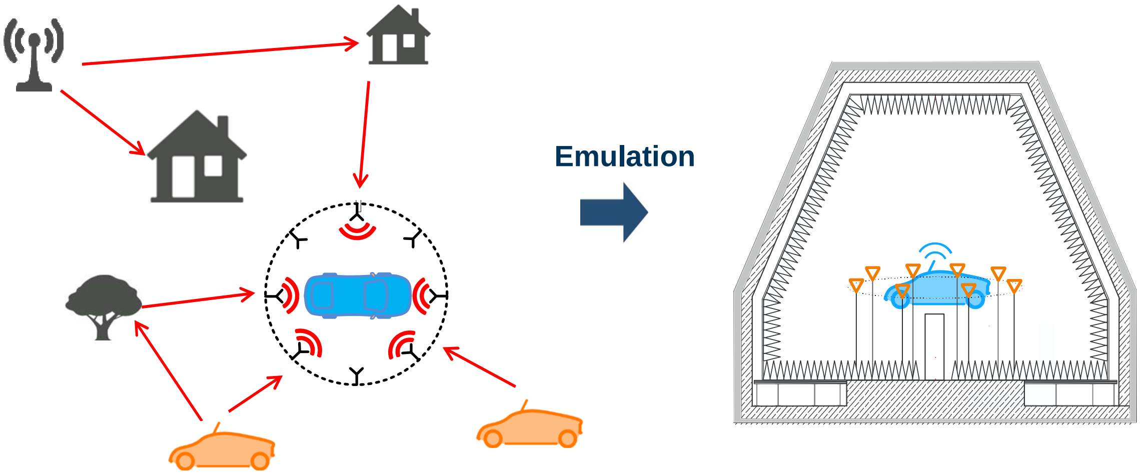


Fig. 3.2.1 Urban/sub urban V2V setup

As introduced above within the OTA facility based verification phase of the RESCUE project the considered scenarios will be derived based on the channel sounding and modelling work at Task 4.2 in WP4. So the selected sub scenarios street as shown in Fig. 3.1.2 and 3.1.3 with passing cars and street crossing will be also the selected scenarios for the OTA approach. Therefore no further descriptions on those selected scenarios will be given here.

3.2.2 Technical setup

<u>OTA Test System at TUIL, Ilmenau, Germany</u>

The Over-The-Air (OTA) test system is able to create a virtual electromagnetic environment under highly controllable and reproducible conditions [SK13]. Hence it allows to test/validate integrated hardware (demonstrators including antennas) under realistic channel conditions. This test method is cost efficient and independent from any outside weather conditions, radio frequency licenses a.s.o. The variety of created propagation channels is very flexible and are basically not limited to outdoor, indoor, LOS or NLOS or any other conditions. However limitations arise from the physical parameters of the test facility.
The OTA test system configuration as illustrated in Fig. 3.2.2 consists of following main parts:

- Anechoic chamber with installed antenna probe ring
- Radio fading channel emulator
- Base station, access point or any other system simulator
- Control unit

At Ilmenau an anechoic chamber with 100 dual polarized antenna probes is installed, see Fig. 3.2.3. Whereby 48 elements are mounted on a ring and 52 able to be flexible positioned.
For the radio channel emulation a connectivity setup with currently 12×32 physical channels (input × output) are available. The manufacturer for the emulator is the IZT GmbH (Erlangen, Germany). The signal bandwidth supported is 80 MHz at a frequency range of 0.35-3 GHz (for 4x4 channels up to 18 GHz) band. For cognitive radio applications two frequency bands with larger separation can be used for emulation but still with instantaneous bandwidth of 80 MHz for each band. The RF output power is limited to a maximum of +10 dBm.
For the generation of the delay characteristics two modes are available:

- Mode 1 Time domain processing similar to tap delay line
- Mode 2 Frequency domain processing.

Mode 1 supports 32 taps per physical channel. The delay accuracy is better 30 ps, phase accuracy better 0.1°, and channel update rate up to 100 kHz is available in the system. Furthermore, Mode 2 supports almost unlimited number of taps as well as the emulation of dense multipath components (DMC).
For the base station currently 1 *eNodeB* and 1 *femto eNodeB* for the LTE standard are available.

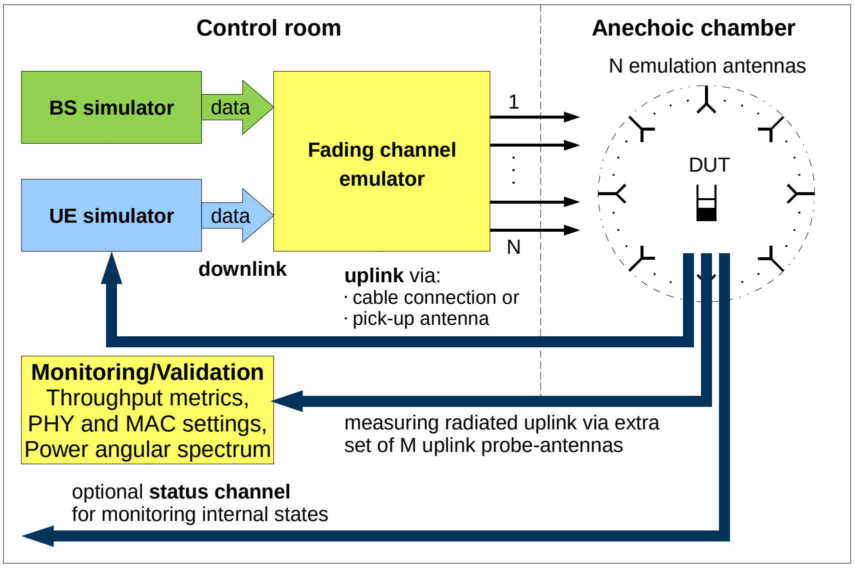


Fig 3.2.2: Principle sketch of the OTA test system

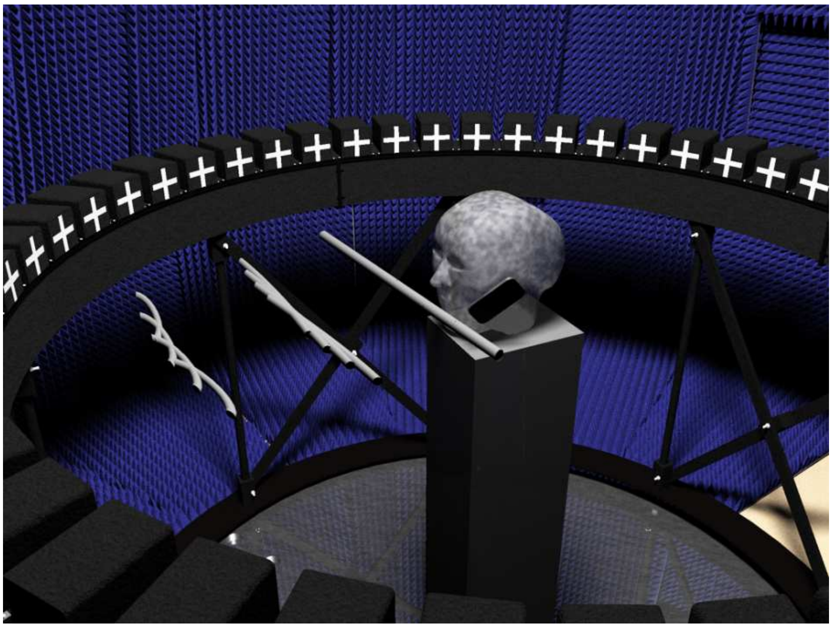


Fig 3.2.3: Part of the OTA test within the anechoic chamber, antenna probes at a ring and device under test

For the performance verification of the RESCUE PHY and MAC design in V2V applications the SDR testbed will be used. To ensure comparability with the test results from the real field test the same performance measures as defined for the indoor use case will be considered. A summary of those test scenarios can be found within Table 3.3.1 and the corresponding description in Chapter 3.3, however they will be adopted to be conform with the V2V use case.

3.3 Scenario for the real field test

The goal of the real field tests will be to verify the correct operation of a RESCUE network in an integrated testbed and prove that the "links on the fly" concept should be considered for further prototyping and commercial development. Furthermore, the real field tests will allow to quantify the exact performance gains when lossy links are used in a cooperative network. Finally, the tests will provide insights on how to refine the implemented solutions for future use.

The real field testbed will consist of a multihop network in which SDR devices are used. These devices will be deployed for the duration of the tests in an indoor office space (Fig. 3.3) in order to emulate a public safety operation taking place in indoor facilities, where rescuers need to maintain communication throughout such facilities as factories, warehouses, or residential buildings, e.g., in search and rescue operations. The communication channels in the network will mostly be non-line-of-sight, i.e., attenuated by walls and floors. Decreased power settings may also increase the presence of lossy channels. Furthermore, personnel mobility within buildings will allow to verify the network operation under dynamic connectivity and topology changes. Finally, an additional benefit of deploying the testbed in an indoor scenario is the availability of supporting infrastructure, e.g., power supply and Ethernet interfaces for testbed control and maintenance.

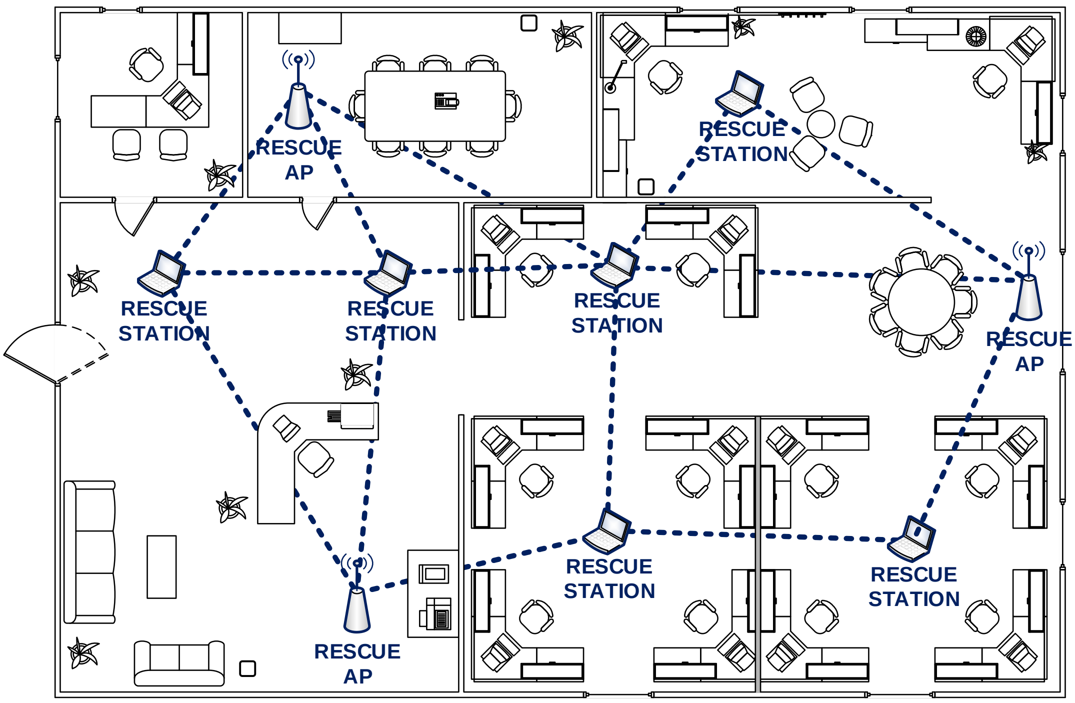


Fig. 3.3 Example placement and links between RESCUE nodes within an exemplary office building

The scenario descriptions are presented in Table 3. In all of them, the configuration of traffic generators will correspond to the traffic patterns mentioned in D1.1. Measurements will be performed for various packet sizes and a various number of traffic sources. All tests will be performed with and without support for lossy links enabled to quantify the performance gains introduced by RESCUE. Furthermore, all tests will demonstrate the performance of the integrated RESCUE components. The performance of the individual components (MAC, ARQ, routing, etc.) will be reported in D3.2 (simulation results) and D3.3 (experimental results from SDR implementations).

Table 3. Overview of scenarios for real field tests

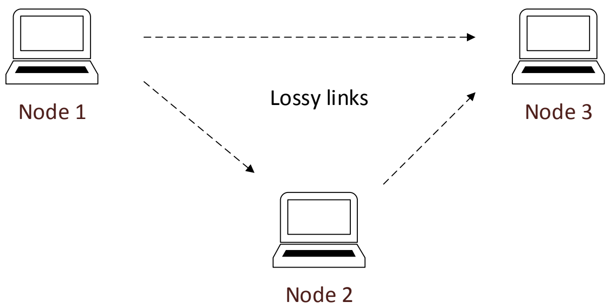
No.	Name	Output metrics	Comments
1.	Integrated operation of RESCUE components	Throughput, delivery probability ratio	Validates the "links-on-the-fly" concept

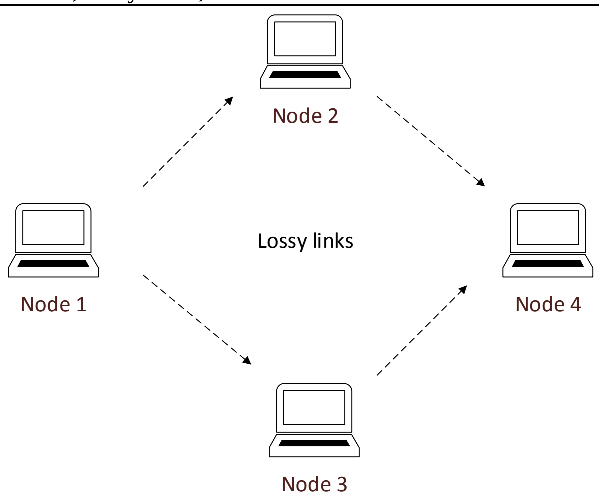
2.	Performance of the MAC protocol	Channel utilization (overhead introduced by the MAC protocol), collision probability, fairness	Tests for centralized MAC (traffic flow between stations and APs) and for distributed MAC (with APs disabled and communication directly between stations)
3.	Performance analysis of the routing protocol	Packet delivery ratio, communication overhead, end-to-end delay	Tests of both geographical and multi-path routing protocols
4.	Performance analysis of the ARQ protocol	Throughput efficiency (ratio of data packet transmission time to the total successful delivery time)	
5.	Performance analysis of the multirate algorithm	Throughput, frame loss ratio	First scenario with the multirate component enabled, comparison of results with/without multirate enabled

3.4 Scenario for the demonstration

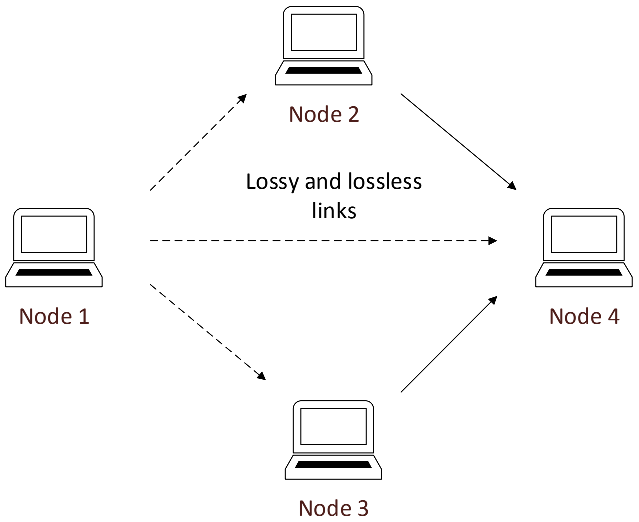
The goal of the live demonstration will be to verify the correct operation of a RESCUE network in a small-scale “portable” testbed, in which all network nodes are visible to the viewer. The demonstration will concisely exhibit the advantages of the “links on the fly” concept and prove that it should be considered for further prototyping and commercial development.

The demonstration testbed will consist of a limited number of SDR devices, preferably deployed in a single room. Lossy links will be achieved through low transmission power settings as well as artificially introducing obstacles in the link propagation path. The network topology will be arranged so that moving from scenario to scenario is fluid and showcases the adaptability of the system to current conditions. The traffic conditions will also be simpler in comparison to the scenarios described in Section 3.3, but will also reflect the considered indoor emergency use case.

<table>
<tr><th>No.</th><th>Goal</th><th>Topology</th><th>Outcome</th></tr>
<tr><td>1.</td><td>Demonstrate the advantages of RESCUE in a simple scenario</td><td>

3 nodes, lossy links, transmission of data from node 1 to 3</td><td>Turning on the relay node (node 2) gives significant increase in throughput and packet delivery ratio</td></tr>
<tr><td>2.</td><td>Demonstrate that RESCUE performs correctly also for indirect transmissions</td><td>

4 nodes, lossy links, transmission of data from node 1 to 4</td><td>Disabling the direct link between node 1 and node 4 and turning on the second relay node gives significant increase in throughput and packet delivery ratio in comparison to the previous scenario</td></tr>
</table>

3.	Demonstrate that RESCUE can choose the optimal path for data transfer	 4 nodes, lossy and lossless links, routing, transmission of data from node 1 to 4	Re-enabling direct transmission does not increase the overhead: at any time only the two best paths are selected for transmission

4. Conclusion

This deliverable describes the considered scenarios for different validation and performance evaluation approaches within the RESCUE project. Two use cases: the *public safety operations* and the *vehicular-to-vehicular* have been characterised within WP1. Based on this definition specific sub-scenarios have been discussed and selected.

In situations where the communication infrastructure is partially inoperable due to a disaster such as an earthquake public safety operations are required within outdoor as well as indoor scenarios. Since the rescue units are moving and i.e. the cellular network is not fully operable multihop communication between the entities of the rescue units is one solution to reach transceivers at larger distances. However in indoor situations the transmission of information will not be simpler because of non-line-of-sight propagation conditions. The latter scenario will be the selected one for the proof-of-concept field trials and a final RESCUE demonstration.

For the practical validation a testbed based on software defined radio (SDR) devices will be integrated. The SDR devices will be permanently connected to a control laptop and to a power supply, hence the mobility the SDR devices will be limited. This was one of the reasons why for the public safety operations the indoor scenario was selected, however the testbed is still in such a way flexible that topology changes and propagation characteristics (e.g. moving from LOS to NLOS) can be considered.

The second RESUCE use case (V2V) will be covered by the channel sounding campaign. The output of this campaign within 2 sub-scenarios: a street crossing and a street with passing and upcoming vehicles will be analysed to identify the directional multipath propagation in azimuth and elevation domain and furthermore to group them together into multipath clusters. Based on this research a WINNER like model can be extended to vehicle-to-vehicle propagation channels.
This channel model will be considered for performance evaluation based on software simulation and within the over-the-air (OTA) test method. The OTA facility is not depending on any weather conditions or limited to frequency licence and to V2V scenario only. Also other scenarios could be emulation within the virtual electromagnetic environment.

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