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Concept for an Integrated 5G and LoRaWAN Communication System for Search and Rescue Applications in Rural Areas

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Abstract

In this paper a concept for a communication and tracking system for search and rescue operations especially of rescue dog associations in areas with poor mobile coverage is proposed. The concept includes tracking devices for all team members and dogs, a smartphone app for in-field communication as well as a web-based software for mission management. To ensure reliable communication even in difficult terrain, a combination of public 5G and private long range wide area network (LoRaWAN) is employed. With the later serving as fallback communication link, when no data transmission over 5G is possible. To ensure data transfer in the narrow LoRaWAN band, various techniques like message compression are considered.

1 Introduction

For successful search and rescue (SAR) operations with rescue dogs in rural areas, communication is an essential factor. Rescue dog groups consist of a group leader and several search teams, each with one dog and two team members. During a typical mission, a search area of up to 40,000 m² can be covered. The group leader needs a software to monitor the current position of the teams and dogs as well as a possibility to communicate with the teams and to define search areas etc. Since rescue dog teams in Germany are volunteer organizations, only very limited funding is available for them. Furthermore, the licensed spectrum and services (e.g. TETRA) of other government rescue organisations are not available for them. Another challenge is the fact that SAR missions are often in remote and mountainous areas with a lack of public mobile networks. As it is crucial to efficiently share information in the group (e.g. hints, changed search area, end of mission), a research project of the Deggendorf Institute of Technology in cooperation with a rescue dog association and a rescue dog group deals with the existing challenges. The project aims to create a well designed combination of public mobile networks (5G) with a unmanned aerial vehicle (UAV)-based low-power, wide-area network (LPWAN) to temporarily fill blind spots in the network coverage. This should enable the transfer of mission-specific data as effectively as possible.

2 Related Work

Various approaches for communication systems were demonstrated in the context of SAR or disaster management. Douklias et al. show a communication system for SAR operations in urban area for volunteer organizations [1]. They combine IEEE 802.11ax and LoRaWAN, utilize the system on a mast and test it in various scenarios. As the focus is on disaster management, it can work completely independent of infrastructure, but nevertheless remote links like 4G and satellite are also possible. LoRaWAN is only used for the transfer of distress and critical messages. The approach shown is promising, but the operational conditions and the environment are different from typical SAR missions of rescue dog groups.

There are also various approaches for mounting the communication modules on drones. The authors of [2] propose an UAV based 5G for mission-critical communication. The system locates survivors after a disaster based on their user equipment (UE). To reliably locate the UEs, a damaged mobile network can be supplemented by UAV based picocells. Concepts were also developed for the optimal positioning of UAV-based mobile base stations in order to establish the best possible network for emergency communication [3]. Attaching radio modules to drones appears to be a good possibility for flexibly setting up a temporary communication network.

The integration of different LPWANs and 5G is part of many research projects which are shown in the survey of Chen et al. [4]. One project demonstrates the integration of an MQTT proxy in a LoRa network in order to collect sensor data over distances of up to 6 km [5]. It is an interesting approach, but the message size is not optimized as they use JavaScript Object Notation (JSON) messages even for the LoRa network. The authors of [6] go one step further with regard to the integration of 5G and LoRaWAN networks at the level of the network operator. Therefore, they propose a collaborative radio access network (RAN) and converged core network for the use case of a smart heating project. This approach could be promising, in the current project, however, no adaptation of the public network can be implemented. Torroglosa-Garci et al. propose two approaches to establish handover roaming between different wireless networks like LoRaWAN and 5G [7]. However, this requires adaptations to the 5G and LoRaWAN standard and is therefore, also not feasible for an existing network. Studies and simulations have also been carried out on selection algorithms for LoRaWAN gateways depending on the duty cycle of the downlink channel [8].

3 Concept

3.1 System Overview

In order to support SAR operations of rescue dog groups with a stable communication system, an easily and quickly deployable system is necessary. This system should use the public mobile network whenever a communication between the UE and the base station can be established. As protocol for the transmission of the messages over the mobile network, MQTT with JSON objects is chosen. MQTT is chosen because it fits well to map the hierarchical structure of the rescue groups to a data structure. Furthermore, it is easily extendable, for example to add another rescue dog group. By using different quality of service (QoS) levels of MQTT, the delivery of the most important messages between the gateway and the teams can be assured even if the mobile data link is broken for a short time. If the mobile connection can not be established or is lost, a private LoRaWAN network without cloud-connection acts as fallback link. The LoRaWAN network server used for this purpose is based on the open source implementation ChirpStack[1].

The central technical component of the base setup which is shown in Figure 1 is a communication hub with gateway between 5G, LoRaWAN and WiFi. This hub can be ground- or UAV-based. The SAR missions of the rescue dog teams are managed and monitored by a group leader who uses a web-based system for this purpose. The individual components are described in more detail in the following paragraphs.

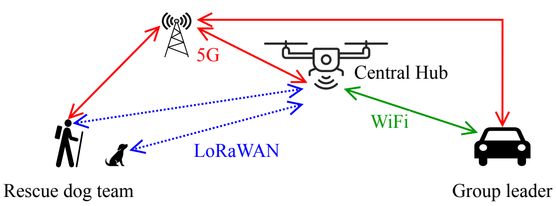

Figure 1. System overview

Dog collars send regular position updates. Apart from the GNSS receiver necessary for this purpose, an inertial measurement unit, a switchable strobe light which can be enabled by team members and a LoRaWAN communication module are integrated in a waterproof package. The components are powered by a LiPo battery. Charging circuitry and battery are also integrated into the collar. LoRaWAN enables communication according to three different classes A, B and C. The classes define the communication process between gateway and device. For the tracker class A is chosen, as it enables uplink messages at any time.

[1]https://www.chirpstack.io/

Smartphone app and dongle: The troop members are equipped with an Android smartphone with a custom app. They can register for the mission and a specific search team by scanning a QR-code with the app at the beginning of the SAR mission. During the mission, the app displays the assigned search area and tracks of all team members. Additionally, it is used to control the strobe light of the dog collar and to interact with the group leader.

Due to the higher bandwidth, the preferred transmission path between the gateway and the smartphones is over the mobile network (5G). The smartphone app checks for a possible connection to the gateway by performing ping tests. If the connection is not possible, the data is sent to the LoRaWAN dongle to use the fallback link. For this purpose an USB- or Bluetooth-connection between the smartphone and the developed LoRaWAN dongle is established. The dongle compresses the relevant information of the JSON objects in LoRaWAN messages and sends them via LoRaWAN. The app is able to buffer the messages and (re-) send them over the mobile network as soon as the 5G link is reestablished. The interval for position updates is flexible and can be reduced, when the high bandwidth of the public network is available. The dongle is implemented as LoRAWAN class C device. This allows reception of downlink messages at almost any time and provides multicast support.

Group leader software: It is intended as a tool for the group leader to manage the whole mission which includes assigning search areas, managing team composition, etc. In return the group leader also receives the current position information of all group members and dogs. Furthermore, the software includes a communication interface to all troops and a connection to third party services, e.g. weather data. The prototype of the group leader software is implemented in Node-RED.

Communication hub: It is the central point for all communication according to Figure 2. Therefore, a Mosquitto[2] MQTT broker is integrated in the hub. It also acts as gateway to map data between LoRaWAN, 5G and WiFi. Therefore, it is made up of a LoRaWAN gateway, a 5G modem and a WiFi access point. The messages are mapped between the LoRaWAN data format and the JSON data structure of MQTT. Therefore, a mapping service encodes the information, to reduce the amount of data transmitted over the LoRaWAN link.

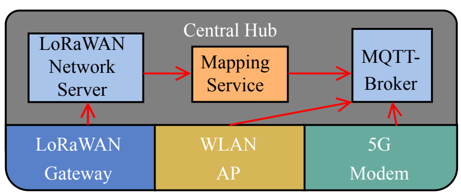

Figure 2. Communication hub

[2]https://mosquitto.org/

To cover a larger area, an optional extension with an additional lightweight communication hub is intended (Figure 3). The extension hub consists only of a LoRaWAN gateway, 5G modem and a WiFi repeater. It is connected to the MQTT broker of the central hub using an IP-connection over the mobile network or WiFi. The central hub takes care of the logic and control of both hubs.

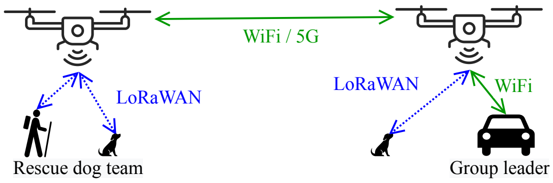

Figure 3. System extension

3.2 LoRaWAN Bandwidth Utilization

The legal conditions, frequency ranges and restrictions in terms of time utilisation for LoRaWAN vary from region to region. In Europe, the ETSI limits for the frequency range between 867.1 – 868.5 Mhz are a duty cycle of 1 % and a transmission power of 25 mW ERP [9]. This frequency range is divided into eight uplink channels with a bandwidth of 125 kHz, which are modulated in chirp spread spectrum (CSS). Channel 2 is an exception, which can use a bandwidth of 250 kHz with spreading factor (SF)7.

For the downlink the RX1 receive window uses the same channel as the preceding uplink. The additional RX2 receive window uses a frequency of 869.525 MHz (fixed SF12, 125 kHz bandwidth) [10]. To make the best possible use of the channel bandwidth, LoRaWAN features the orthogonal spreading factors SF7 to SF12. A higher spreading factor enables longer distances, in exchange for a reduced bit rate.

Message compression: The low bandwidth in combination with the duty cycle restriction of LoRaWAN poses a particular challenge. In order to comply with the duty cycle limitation a main focus must be on the compression of the messages. Therefore, a reduced data set is inevitable. On the basis of two messages, Table 1 shows the compression by using plain LoRaWAN instead of JSON-based messages. The first example is the heartbeat sent from the group members and rescue dog collars, which contains the latitude and longitude position as well as one byte status information. As this packet is in the default setting sent regularly every 20 seconds, it has a major influence on the data transmission and the duty cycle. Second example is the alarm message. It contains 9 Byte information of the position update and additionally up to 100 Byte for a text based emergency communication to the group leader.

The comparison shows a high compression of the information when using LoRaWAN messages compared to JSON based data. The additional overhead caused by the MQTT protocol and the transport layer is not taken into account here for the sake of simplicity.

Table 1. Comparison of the message size between LoRaWAN and JSON via MQTT

		Heartbeat [Byte]	Alarm [Byte]
LoRaWAN	Overhead	13	13
	Data	9	109
JSON	MQTT Topic	43	44
	Data	340	477
Compression		94.26 %	76.58 %

Conception of the uplink path: Due to the bandwidth limitations and duty cycle restrictions, the communication paths have to be planned carefully. The duty cycle is defined as ratio of the cumulated sum of transmission per observation period which is a sliding window of one hour for LoRaWAN [11]. In the uplink direction the main focus must be on the cyclic position update messages of the group members and dog collars as they have the biggest contribution in this path. Figure 4 shows the achievable update rate of the position update message with a maximum duty cycle of 1 % for various spreading factors.

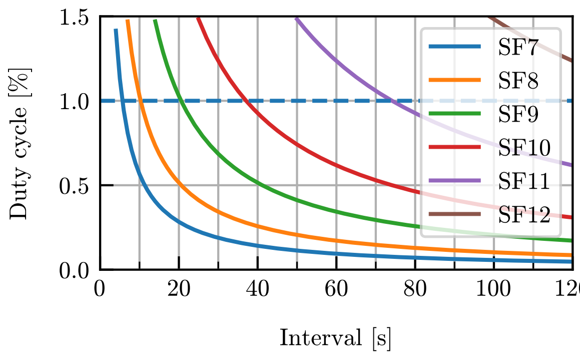

Figure 4. Duty cycle with different spreading factors and intervals between position update messages

In addition to the position update, further message transfer is necessary. For example, the alarm message which could include an information about findings. To reduce the amount of data, various standard messages (e.g. person found) can be sent by transmitting a simple alarm code. The group leader software and the smartphone app decode the message and display it in human readable form. In addition to that, a free text entry with up to 100 Byte is possible. Alarm messages with 100 Byte text every five minutes increase the duty cycle by 0.0684 % (SF7), 0.1196 % (SF8) and 0.2188 % (SF9). Due to the relatively large influence on the duty cycle, especially the free text messages should be used only in rare circumstances.

To make this additional communication possible at all, the duty cycle due to the position update messages must be significantly lower than 1 %. The standard interval of position update messages is set to 20 seconds to track changes in position and paths as quickly as possible. However, the interval between position update messages can be adaptively adjusted. This means if an alarm message is sent, the next position update message will not be sent, as the alarm message also contains the position. Additionally, the interval can be extended up to 60 seconds for a duration of 30 minutes to meet the duty cycle limitation. If one considers figure 4 it is obvious, that only spreading factor 7 and 8 are feasible for the system.

Downlink optimizations: The considerations for the uplink show, that a focus on the reduction and compression of the data is essential to meet the duty cycle restriction. Thus, for the LoRaWAN downlink, various measures are taken into account. First of all, the mobile 5G link is used whenever established. The communication is only handed over to LoRaWAN as fallback. To reduce the data traffic, LoRaWAN multicast messages for information which relate to more than one receiver (e.g. update of the search area) are used. Therefore, position information of the dogs and the troop members are collected at the gateway. If the mobile link is not established, the collected position data are sent as a multicast message to all members at once, in order to reduce the number and thus the overhead of the messages.

As a further option to limit the duty cycle, the update rate of the downlink path can be adaptive. Furthermore, messages from the group leader will be prioritised over position update messages at the gateway for the LoRaWAN link.

4 Conclusion and Future Work

The combination of 5G and LoRaWAN seems to be a good way to create a communication system for SAR applications in rural areas. However, when transmitting via LoRaWAN, the main focus must be on compliance with the duty cycle restrictions. Therefore, the amount of data must be kept as small as possible. To be able to test the system in practice, the next step is the implementation of the prototypical system and the test in relevant areas with the rescue dog group. This includes the evaluation of the performance parameters like coverage, number of participants and the percentage of successful message transfers.

The number of devices and the amount of data which have to be sent using LoRaWAN in the deployment scenario is currently seen as critical point. If the evaluation shows problems with the proposed setup, some options to solve the issues may come into account. One could be the new technical recommendation for media access using carrier-sense multiple access with collision avoidance (CSMA/CA) for LoRaWAN [12]. The implementation can be a major advantage with high data volumes in the future. However, currently no LoRaWAN nodes implementing CSMA/CA are available.

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