This is the authors' version of the paper. The final paper appears in the proceedings of the 15th International Conference on Telecommunications (ConTel '19), Graz, Austria, 3-5 July 2019

Evaluation of TETRA SDS Performance and GPS Accuracy in Real-World Scenarios

Martina Umlauft, Christian Raffelsberger
Lakeside Labs GmbH
Klagenfurt, Austria
lastname@lakeside-labs.com

***Abstract*—Terrestrial Trunked Radio (TETRA) is a communication system for public safety featuring voice, Short-Data-Service (SDS), e.g., for GPS updates, and data communications. This paper presents measurement results concerning GPS accuracy and SDS performance of several real-world scenarios using TETRA in trunked mode. In particular, we considered intra-cell communication, inter-cell communication, and stationary as well as mobile use cases. Besides lab settings, we also performed two different field tests of semi-realistic and realistic first responder drills. SDS delay was satisfactory in all scenarios but GPS accuracy of common TETRA handheld radios turned out to be limited, especially compared with current Android devices. This is yet another argument in favor of complementing the use of TETRA with other broadband technologies like LTE/5G, which would then not only enable multimedia communications but also give access to more accurate positioning.**

***Index Terms*—Performance evaluation, TETRA, Mobile communication, Global Positioning System**

I. Introduction

Terrestrial Trunked Radio (TETRA) is used by many emergency services in order to communicate during operations. Although its main usage is voice communication, TETRA also offers additional services such as the Short-Data-Service (SDS) [1] to transmit text messages, status updates, or the position of a user. To support the latter, many TETRA radios are equipped with a GPS receiver. Besides SDS, there is also a packet based data service that can achieve a theoretical data rate of up to $28.8\,\mathrm{kbit/s}$, if multiple slots are combined [2]. However, in practice significantly lower data rates are reported [3]. The lack of a broadband data service lead to discussions, that technologies such as WiFi Ad-hoc, LTE or the upcoming 5G standard will supersede TETRA as the main communication technology for emergency services. However, due to the high investment costs, it can be assumed that the existing TETRA networks will not be shut down in the near future but rather complemented by technologies that support broadband data communication. For example, the 4C4FirstResponder system [4], [5] is a demonstrator implementation of such an augmented system where TETRA and UMTS/LTE are combined. The system consists of a mobile first responder messaging application for Android smartphones and a command center management software which support communication between all different hierarchy levels, i.e. between first responders, their commanders and command centers. A communication module combines TETRA with broadband communication technologies such as LTE or WiFi. TETRA radios are controlled via the Peripheral Equipment Interface (PEI) over Bluetooth. Depending on the type of data, the communication module selects the most appropriate communication technology, e.g. LTE for transmitting images and TETRA-SDS for mission critical information. Thus, it is important to know the achievable performance of SDS-based text communication and whether to use the GPS position as reported from the TETRA or Android device. In the course of this work, we conducted a series of real-world measurement campaigns in order to assess the capabilities of TETRA. In particular, the performance of SDS delivery times and the accuracy of the GPS receiver were investigated.

The rest of the paper is organized as follows: Section II contrasts our results with existing literature and Section III describes our measurement setup. Section IV describes the results of measurements concerned with more abstract scenarios, in particular SDS delivery times and GPS accuracy in a moving vehicle, while Section V details our results for GPS accuracy obtained during two different field tests of semi-realistic and realistic first responder drills. Finally, Section VI concludes the paper.

II. Related Work

Compared to other wireless standards, there are very few performance evaluations considering TETRA. One reason may be that it is very challenging for researchers to get access to TETRA networks. Another reason may be that TETRA seems rather outdated, compared to recent technologies such as WiFi ad-hoc or 3G/4G. Hence, the vast majority of research articles discusses how to use such wireless technologies in public safety scenarios [6]–[9].

Besides simulation studies like [10] the work closest to the study presented in this paper has been performed by Axiotis et al. [11]. In particular, they assessed the SDS transmission delay and message outage ratio in trunked mode for different message sizes and sending intervals. Depending on the message payload size, the average delay for an SDS transmission was between $0.4\,\mathrm{s}$ for $10\,\mathrm{bytes}$ of payload and $1.6\,\mathrm{s}$ for $190\,\mathrm{bytes}$ of payload. The message outage ratio was negligible for intervals of $1.5\,\mathrm{s}$ and $2\,\mathrm{s}$. The outage ratio increased to $1.6\,\%$ with shorter message sending intervals of $1\,\mathrm{s}$ and a message size of $190\,\mathrm{bytes}$. The measurement results for devices located in the same cell were similar to the results for inter-cell communication. In contrast to our experimentation study, no tests in mobile scenarios were performed.

Lehner et al. [12] evaluated SDS performance in direct mode operation (DMO) in a railway VANET scenario. In particular, the authors performed several measurement studies between a TETRA device located in a moving train and a fixed device. They presented a path loss model and the maximum transmission range of DMO mode in this environment. End-to-end transmission delays for SDS varied between 200 ms and 700 ms.

III. Measurement Setup

We measured TETRA performance with respect to two criteria: delay of SDS transmission and GPS accuracy. We used two Motorola MTP3550 handheld radios connected to the Austrian TETRA network in trunked mode. Bluetooth is an optional feature of this model that was not available due to missing licenses. Hence, we used RS232 serial to Bluetooth converters (type LM048) and serial cables to allow other Bluetooth devices to control the TETRA radios via PEI [1].

We developed a software (called KomMan) using the JAVA programming language that connects to the TETRA devices using PEI, in order to send and receive SDS and to request the GPS position. KomMan supports Windows, Linux, and Android OS. We tested SDS performance first with two stationary notebooks at the same office in Klagenfurt, Austria. To assess the performance when the devices are located at different cells, we performed measurements with one device in Klagenfurt and the other in Vienna, Austria (about 350 km apart).

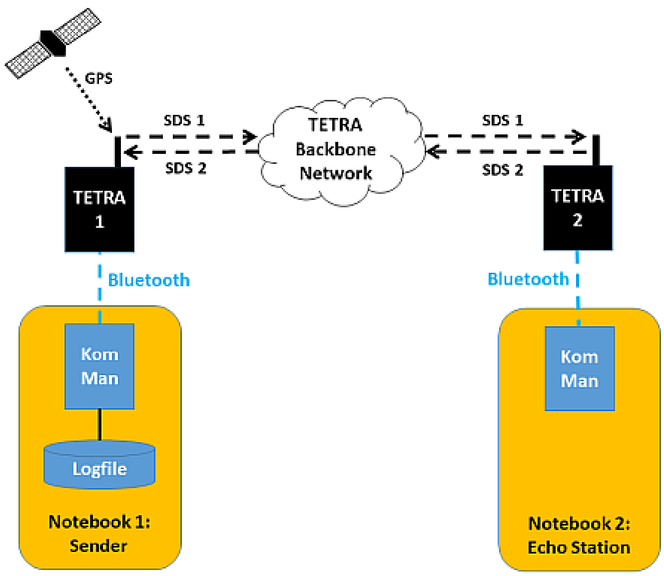

Fig. 1. TETRA Measurement Setup.

The measurement setup is shown in Figure 1: the first notebook used the PEI to create an SDS on TETRA device 1 which was then sent via the TETRA backbone network to TETRA device 2 and forwarded to notebook 2 via PEI. Notebook 2 echoed the SDS immediately back to the sending station where the round trip time was measured and logged into a file. Thus, the measured delay expresses the overall end-to-end delay, the transmission delay within the TETRA network and delays for processing and local communication via Bluetooth on both devices.

The GPS accuracy tests were performed for several different scenarios: first, we performed tests where one device was mounted in a vehicle (see Figure 2) driving on the highway from Klagenfurt to Vienna (and back), while the other device remained stationary in an office in Klagenfurt. The measured GPS positions were sent as part of the payload of the SDS. For comparison of the achievable GPS accuracy, an Android smartphone with a GPS logger app was used to log the GPS positions as received by COTS Android smartphones. Care was taken to turn off additional, accuracy-enhancing features like WiFi- and mobile network fingerprinting.

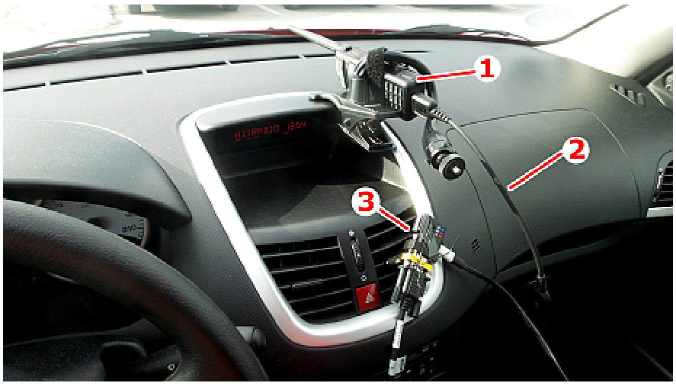

Fig. 2. TETRA Device Installation in Vehicle. 1 - TETRA Device, 2 - Serial Cable, 3 - Bluetooth Dongle.

Smartphones were used to control the TETRA devices and to record their GPS locations during the field tests (Figure3). In this setup, the Android smartphone connected to the respective TETRA device was set to query the GPS location via PEI and record it in a log file. To assess the accuracy of this measurement, the GPS location, as reported by the Android smartphone itself was stored as well.

Fig. 3. TETRA Device with Serial Cable, Bluetooth Dongle, and Android Smartphone.

IV. Technical Evaluation

A. SDS Performance

We measured SDS round trip times (RTT) with stationary devices in the same TETRA cell in Klagenfurt, sending an SDS every $5\,\mathrm{s}$. Figure 4 shows how the round trip time is dependent on the SDS payload length – for short messages with $20\,\mathrm{bytes}$ of payload most messages have an RTT of around $1000\,\mathrm{ms}$, for messages with $60\,\mathrm{bytes}$ of payload most messages have an RTT of around $1800\,\mathrm{ms}$. This also conforms to the results in [11]. Out of over 1000 messages sent we encountered no losses.

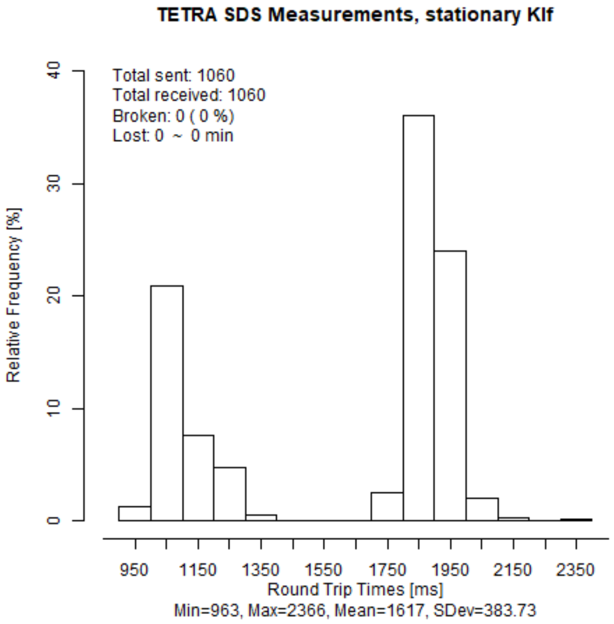

Fig. 4. SDS Round Trip Times with Stationary TETRA Devices at same Cell in Klagenfurt. Two Different Message Sizes: Left - $20\,\mathrm{bytes}$, Right - $60\,\mathrm{bytes}$.

As a next step, we measured in an inter-cell scenario with one stationary device in Klagenfurt and one device in Vienna (approx. $350\,\mathrm{km}$ apart). Figure 5 shows the results for messages with $20\,\mathrm{byte}$ payload length. For this setup most messages have an RTT of around $1250\,\mathrm{ms}$. Again we encountered no losses.

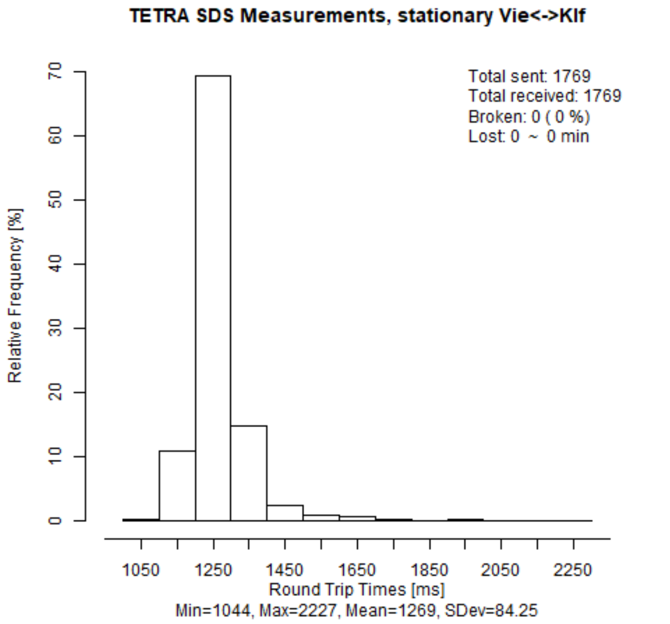

Fig. 5. SDS Round Trip Times with Stationary TETRA Devices at Different Cells – one in Klagenfurt, one in Vienna. Message Size $20\,\mathrm{bytes}$.

B. GPS Accuracy and SDS transmission in a Moving Vehicle

We measured SDS round trip times with the setup described previously (see Figure 1). The vehicle moved within the legal speed limits on the A2 highway connecting Klagenfurt and Vienna with speeds between $80\,\mathrm{km/h}$ (in route sections with road works) and $130\,\mathrm{km/h}$ (top speed limit on Austrian highways). We sent an SDS every $5\,\mathrm{s}$. Between December 2017 and February 2018 we performed several tests. Typically, weather conditions were cold but with clear skies.

As can be seen in Figure 6, the SDS round trip times along the way were for the most part below $2000\,\mathrm{ms}$. Since the

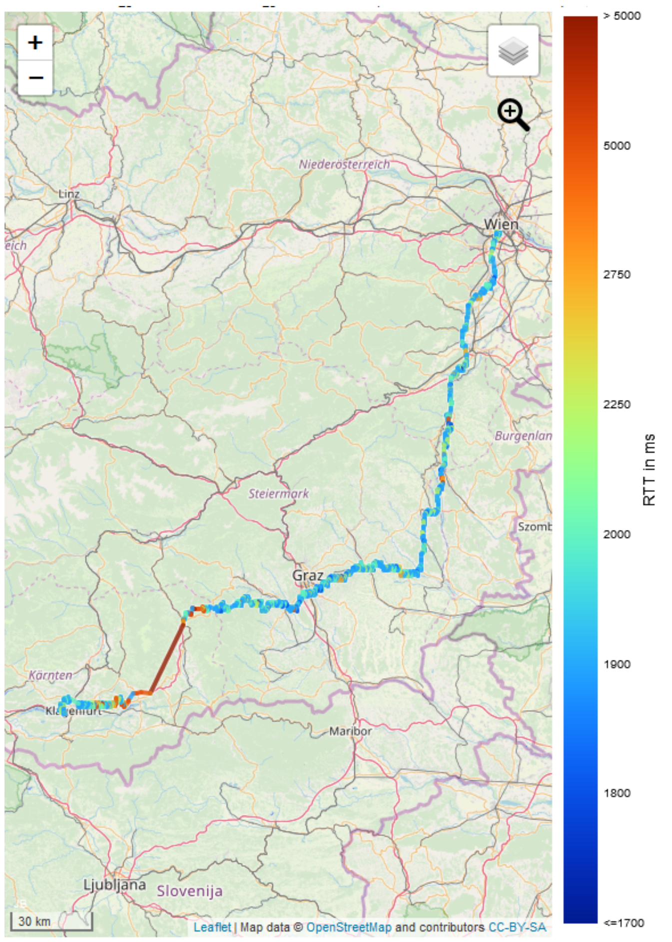

Fig. 6. SDS Round Trip Times and TETRA GPS Accuracy in Moving Vehicle.

TETRA network is not deployed over all of Carinthia, there is a section without TETRA network coverage. When coming close to the border of the reception area, the SDS transmission became slow before it eventually stopped during traversal of the non-covered area. This is visualized by the straight brown line on the map that does not follow the trajectory of the highway.

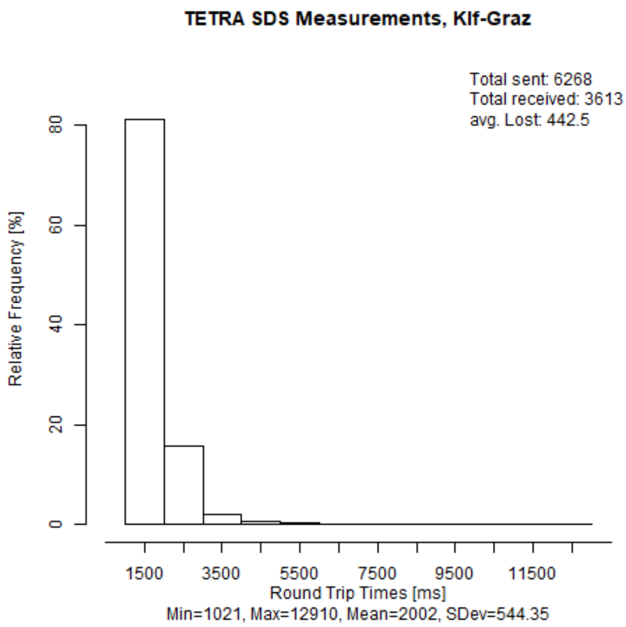

Fig. 7. Histogram of SDS Round Trip Times in Moving Vehicle, Section Klagenfurt - Graz, Aggregated over 6 Trips.

Details of the SDS performance are shown in the histograms in Figures 7 and 8. The analysis is split in two parts due to a rest stop of the driver at the rest station at highway exit Graz/Airport. We aggregated the data from six and five drives respectively. As can be seen, the main factor for SDS loss is the non-covered area in parts of Carinthia (between Klagenfurt and Graz, see Figure 6). On this section of the trip, on average around 440 SDS were lost due to missing network coverage which, at our sending rate of one SDS every $5\,\mathrm{s}$, corresponds to the approx. $37\,\mathrm{min}$ of driving time it takes to traverse the area without network coverage. There were also some SDS (less than 10 on average) where parts of the message were missing. These corrupted messages occurred at the edges of the covered area. Still, around 80% of the sent SDS had an RTT of $<2000\,\mathrm{ms}$. On the section of the trip from Graz to Vienna round trip times were below $2000\,\mathrm{ms}$ for more than 80% of the SDS and there was practically no loss of SDS. Since we stored the GPS position, as reported by the TETRA device, in the payload of the sent SDS, the message length varied between 50 and 60 characters for these experiments. We additionally ran one test between Vienna and Graz with a message sending interval of only $3\,\mathrm{s}$ which resulted in 20 messages incurring such a large time to receive to essentially be considered “lost” despite full TETRA coverage on this road section. The rest of

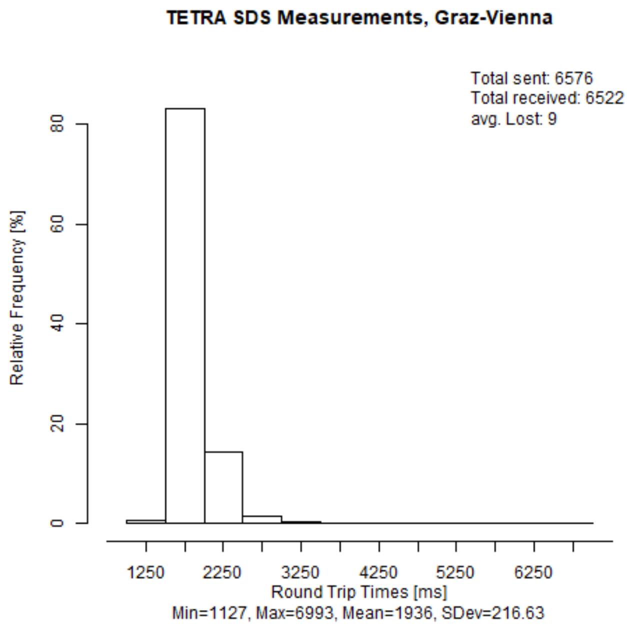

Fig. 8. Histogram of SDS Round Trip Times in Moving Vehicle, Section Graz - Vienna, Aggregated over 5 Trips.

the SDS were delivered with times similar to the $5\,\mathrm{s}$-sending interval scenario, though.

Figure 9 shows a zoomed-in view of the map of such a test drive. The GPS positions as reported by the TETRA device are marked in blue, while the GPS positions as reported by the Android device are marked in red. As can be seen, the GPS track from the Android device follows the path of the A2 highway truthfully, except for sections in tunnels (where there is no GPS reception). The locations of tunnels and loss of GPS match perfectly for the Android device. The GPS positions reported by the TETRA device, though, were not only impacted by the tunnels, but also didn’t follow the path of the highways truthfully for uncovered sections. Positions were off by several hundred meters, sometimes even by more than $1000\,\mathrm{m}$, even though the TETRA device was mounted near the windshield of the car to improve GPS reception. The Android device, on the other hand, had no problems receiving the GPS signal even though it was stored in a bag on the shotgun seat (i.e. under the roof of the car). This was tested with several different Android devices (Samsung Galaxy S4zoom smartphone, Samsung Galaxy ACE smartphone, Asus Nexus 7 Tablet) which all yielded the same accuracy (their traces were indistinguishable when plotted on the map). This effect was also observed in the field tests (see Section V) with yet other Android devices (Samsung Galaxy Note, Blackview BV6000) which all proved to be highly accurate with respect to reported GPS positions.

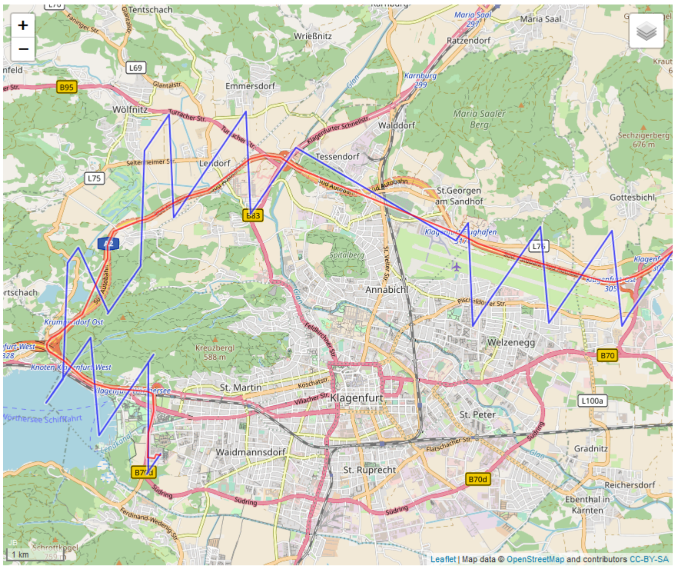

Fig. 9. GPS Accuracy of TETRA vs. Android in Moving Vehicle. Blue - TETRA, Red - Smartphone.

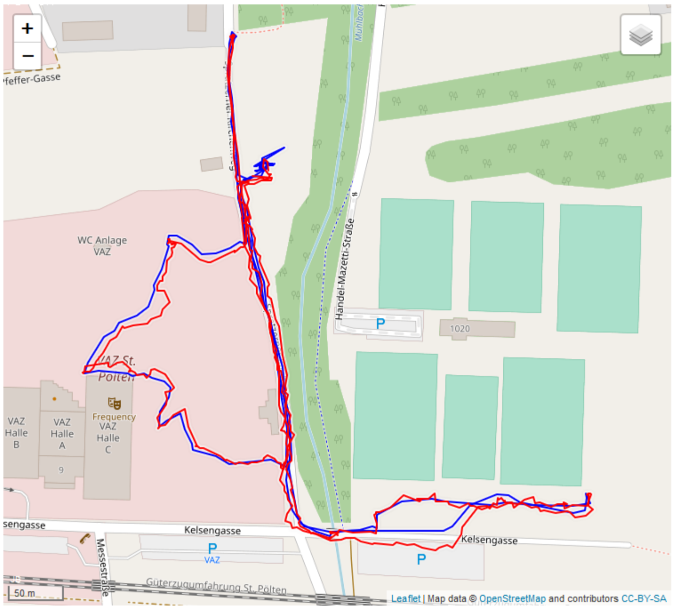

Fig. 10. Comparison of TETRA GPS Accuracy vs. Smartphone GPS Accuracy at Field Test 1 - Festival. Blue - TETRA, Red - Smartphone.

V. Evaluation in Real-World Settings

A. Field Test 1: Festival Scenario

This field test was performed at Frequency Festival 2018, on 17th of August and mimics the scenario of first responders or security personnel patrolling the festival area on foot, walking at a normal pace. Frequency is a large music festival held in St. Pölten (Lower Austria) with >200000 visitors over 4 days and several hundred first responders and security personnel on duty. The festival area consists largely of open spaces with few trees or buildings which allows for ideal conditions for GPS reception. Several tests with two TETRA handheld radios coupled to one smartphone each were performed. Tests were performed by researchers mimicking patrols of first responders or security personnel holding the devices in hand. Weather conditions were hot (approx. 35 °C) with clear skies.

The difference in GPS positions between the values reported by the TETRA device versus the values reported by the Android devices were below 20 m in this field test. Figure 10 shows one exemplary round of patrol; the GPS track as reported by the TETRA device is shown in blue while the track as reported by the Android device is marked in red.

During this field test we also observed some SDS loss (outages) when trying to send several SDS back to back with less than 1.5 s between `send` commands. During pre-tests in our offices, we had been able to send SDS without outages with just 1 s or even 500 ms wait time between commands. Since there were a large number of first responders with TETRA devices on the festival site, we figured that this might influence SDS loss in the cell. We therefore experimentally raised the wait time between SDS to 1.5 s at which time we could detect no further loss when sending several SDS back to back. This also conforms to the results obtained by [11].

B. Field Test 2: Fire Fighter Drill

This field test was performed in the course of a regularly conducted practice drill for the voluntary fire fighters of Gumpoldskirchen, in which they practice response to an industrial accident on the premises of a chemical company producing different types of gases (Figure 11). The assumption of the drill was that several gas cylinders were on the brink of catching fire. The premises contain several buildings and metal roofed-over structures where gas cylinders are stored, even though the central area with the gas cylinders presumed to be catching on fire was located in an open space. The TETRA and Android devices were worn by several firefighters and used for communication during the drill while recording GPS data in the background. The test was performed in the evening of the 27th of August, 2018. Weather conditions were warm (approx. 25 °C) with clear skies.

As can be seen in Figure 12, the differences between the reported GPS locations are quite large (in part >30 m) with the locations as reported by the TETRA device very volatile while the GPS positions as reported by the Android device conform to what was observed (by eye witnesses) during the practice. The inaccuracies and volatility of the locations as reported by the TETRA device could lead to serious errors in the understanding of the situational picture if the visibility of the scenario is low and commanders have to trust the data reported to the coordination center electronically.

VI. Conclusion

In this study we present performance measurements of TETRA SDS delay and GPS accuracy using two TETRA handheld radios in trunked mode. We studied same cell and inter-cell scenarios with the cells of the inter-cell scenario 350 km apart. For stationary devices we observed round trip

Fig. 11. Voluntary Fire Fighters at Field Test 2 - Fire Fighter Drill.

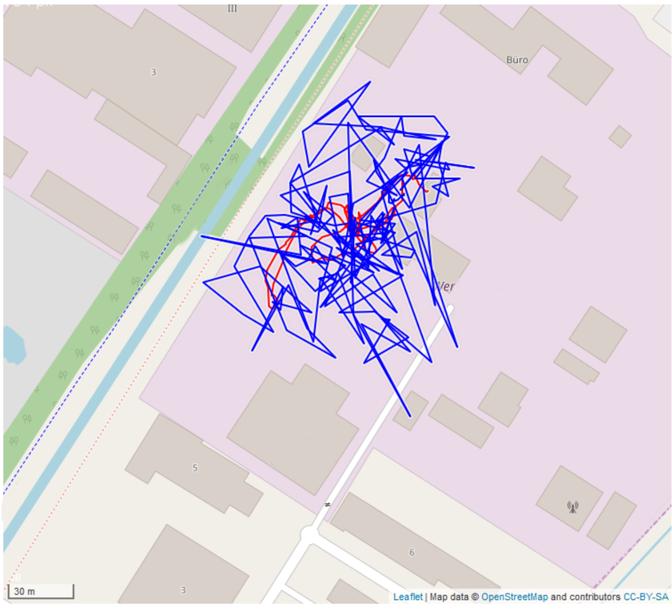

Fig. 12. Comparison TETRA GPS Accuracy vs. Smartphone GPS Accuracy at Field Test 2 - Fire Fighter Drill. Blue - TETRA, Red - Smartphone.

times of $<2000\,\mathrm{ms}$ in both cases. We further studied a scenario with a moving vehicle. Here we also observed SDS RTTs of mostly below $2000\,\mathrm{ms}$ apart from losses due to either coming near to an area without TETRA coverage or when shortening the sending interval to $3\,\mathrm{s}$ between SDS. Measured SDS delivery times correspond to the results from literature (see Section II). Also, we experienced similar effects of SDS outage as reported in literature when sending several SDS back to back with less than $1.5\,\mathrm{s}$ waiting time between `send` commands in a cell with many other TETRA devices.

We further studied GPS accuracy for the moving vehicle scenario and for semi-realistic and realistic first responder drills; a festival scenario with personnel on foot patrol and a fire fighter drill. The GPS measurements showed large deviations from the true position, especially in challenging environments. In the case of the moving vehicle the error was often greater than $1000\,\mathrm{m}$. Different TETRA devices might provide better GPS accuracy, but if positioning is to be used for the situational picture, it is advisable for first responder organizations to test their device accuracy and, in light of discussions to augment first responder communications with COTS devices (Android, iOS), their GPS functionality should be used as their accuracy is consistently better.

ACKNOWLEDGMENT

The work presented in this paper has been conducted within the 4C4FirstResponder project and has been funded by the security research programme KIRAS of the Federal Ministry for Transport, Innovation, and Technology (bmvit). The authors thank the project partners Joanneum Research, Eurofunk Kappacher GmbH, Dräger Austria GmbH, IFR, University of Graz (Department of Sociology), the voluntary fire brigade Gumpoldskirchen, and the Federal Ministry of the Interior (Section I). The maps have been created with an adapted version of the *GPX Viewer* tool by Jürgen Berkemeier [1].

REFERENCES

[1] ETSI, "Terrestrial Trunked Radio (TETRA); Voice plus Data (V+D) and Direct Mode Operation (DMO); Part 5: Peripheral Equipment Interface (PEI)," ETSI project, Tech. Rep. EN 300 392-5 V2.2.0, 2010.

[2] ——, "Terrestrial Trunked Radio (TETRA); Voice plus Data (V+D); Part 2: Air Interface (AI)," ETSI project, Tech. Rep. EN 300 392-2 V3.4.1, 2010.

[3] D. I. Axiotis, A. K. Salkintzis, and D. Xenikos, "IP transmission over TETRA packet data service: Simulation and measurement results," *Wireless Personal Communications*, vol. 47, no. 4, pp. 523–540, Dec 2008.

[4] C. Raffelsberger, M. Umlauft, A. Kercek, A. Almer, T. Schnabel, and P. Luley, "Flexible Kommunikations-und Informationslösungen für eine optimierte Einsatzführung von Interventionskräften," *Lecture Notes in Informatics*, vol. 259, pp. 1791–1803, 2016.

[5] M. Umlauft, C. Raffelsberger, A. Kercek, A. Almer, T. Schnabel, P. Luley, and S. Ladstaetter, "A communication and multi-sensor solution to support dynamic generation of a situational picture," in *3rd International Conference on Information and Communication Technologies for Disaster Management (ICT-DM)*. IEEE, 2016, pp. 1–7.

[6] T. A. B. Nguyen, F. Englert, S. Farr, C. Gottron, D. Bohnstedt, and R. Steinmetz, "Hybrid communication architecture for emergency response? An implementation in firefighter's use case," in *International Conference on Pervasive Computing and Communication Workshops (PerCom)*. IEEE, 2015, pp. 524–529.

[7] C. Raffelsberger and H. Hellwagner, "Overview of hybrid MANET-DTN networking and its potential for emergency response operations," *Electronic Communications of the EASST*, vol. 56, pp. 1–12, 2013.

[8] T. Doumi, M. F. Dolan, S. Tatesh, A. Casati, G. Tsirtsis, K. Anchan, and D. Flore, "LTE for public safety networks," *IEEE Communications Magazine*, vol. 51, no. 2, pp. 106–112, February 2013.

[9] M. Usman, A. A. Gebremariam, U. Raza, and F. Granelli, "A software-defined device-to-device communication architecture for public safety applications in 5G networks," *IEEE Access*, vol. 3, pp. 1649–1654, 2015.

[10] D. Kuypers and M. Schinnenburg, "Traffic performance evaluation of data links in TETRA and TETRAPOL," in *11th European Wireless Conference 2005*, vol. 2, Nicosia, Cyprus, Apr 2005, pp. 645–651.

[11] D. I. Axiotis and D. G. Xenikos, "On the performance of TETRA short data service-transport layer," *Wireless Personal Communications*, vol. 43, no. 4, pp. 1121–1135, Dec 2007.

[12] A. Lehner, C. Rico García, and T. Strang, "On the performance of TETRA DMO short data service in railway VANETs," *Wireless Personal Communications*, vol. 69, no. 4, pp. 1647–1669, Apr 2013.

[1] https://www.j-berkemeier.de/GPXViewer/