Challenges and Initial Measurements on Communication and Localization for Mountain Bike Safety Applications

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***Abstract*— As of today, research in vulnerable road users (VRUs) applications is mainly focused on safety in urban road scenarios. There is little to be found in the literature with respect to VRUs in mountain areas, where mountain biking and hiking also present risks of collision. Here, it is not yet clear whether existing localization and communication technologies would provide sufficient performance in such harsh environments. In this work, we start answering this question by presenting the results of a measurement campaign which took place in a mountain area in Northern Italy during Summer 2024. With respect to localization, we show that global navigation satellite system (GNSS)-based localization alone often provides unreliable results due to vegetation and terrain. Trilateration with Bluetooth Low Energy (BLE) and beacons mounted at fixed positions performs well in some circumstances and can be used to enhance GNSS, however, we also observed many unclear effects that require further investigations. Concerning communication, the results indicate that both direct short range communications (DSRC) and cellular V2X (C-V2X) works fairly well in most cases, but terrain characteristics might induce packet losses or low signal quality, whereas instabilities in GNSS fixes might also cause C-V2X outages.**

***Index Terms*—mountain biking safety; bike localization; bike-to-bike communications**

I. Introduction and Related Work

The research on safety applications for vulnerable road users (VRUs) is growing rapidly. The motivation is pretty simple, as VRUs have high chances to get seriously injured or to die in road traffic accidents. Statistics shows that VRUs account for 46 % of fatalities and 53 % of serious injuries in the EU [1].

The research field is already very wide as VRUs such as pedestrians or cyclists have different characteristics from the motorized vehicles that vehicle-to-everything communications (V2X) originally addressed. First, their mobility is not as constrained as for cars, so it is necessary to employ specialized techniques to predict their trajectory, besides properly localizing them [2].

Second, interacting with VRUs is not straightforward and indeed presents several challenges for human computer interaction (HCI) researchers [3]. While cars have dashboards to interact with the driver and safety actions can be automated (e.g., automatic braking), it is not yet clear how to properly inform VRUs of possible dangers, and automated actions are simply not possible.

Finally, communication with VRUs also presents a lot of challenges, starting from antenna placement on bicycles [4] where obstructions by the rider and limited space for installation of communication devices create additional challenges. With respect to pedestrians, one possible way of communicating with them is through their smartphones but technologies such as IEEE 802.11p never found their way into commercial devices.

Research in the field is thus very active, but so far the focus is only in urban areas. We raise the question if existing technologies can be adapted to enhance safety also in areas where V2X and VRU have not been considered yet. For example, an increasing number of people are spending their free time in the mountains for recreational and sport activities like hiking or mountain biking.

As recreational sport activities are a major source of accidents, injuries and related personal and societal cost [5], we think that application of modern V2X technologies should also be investigated regarding their potential to reduce such accidents.

As an example, we look into mountain biking, where on narrow and winding trails there is a constant risk of bike-to-bike collisions due to occlusions or blind turns, whereas on trails shared between hikers and bikers, both often come very close to each other, with all the risks that this entails.

In particular, riders pursuing jumps and fast trails in outdoor bike parks are at risk of injury leading to an impact on emergency services in areas where mountain biking is popular [6]. Trails that are ridden at high speeds having jumps and tight curves are not just dangerous, but also difficult to monitor for the riders themselves. In case of a sudden accident, stop of a rider or any other situation where an oncoming rider would encounter a blocked trail, there is a high risk for collisions or dangerous encounters between riders [7].

In general, injury rates while mountain biking can exceed 40 injuries per 1000 hours of activity, much higher than most other common recreational sports [8], [9], and around 5 % of injury are caused by collisions with other bikers [10]. Moreover, 7.6 % and 27.7 % of mountain bikers surveyed in [11] unexpectedly encountered another biker or hiker respectively at least once.

Research shows that signals to the rider (e.g., tactile, acoustic, or visual) ahead of risk areas can reduce the injury risk [6], [12]. Furthermore, in case of a crash happening in a remote

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area, it is difficult for the rider to call for help and be found by the emergency services due to the fact that there often is no cellphone reception in the woods or mountain areas where bike parks are located.

These remote locations present new challenges for the V2X and VRU research field, as both common communication and localization technologies might not work as well as in cities, and this has only sparsely been studied in the literature so far as research efforts target mainly urban environments. Some examples include studies testing cellular V2X (C-V2X) on bicycles [13], [14] in urban and rural areas, a study testing a multi-technology solution at an intersection in Bilbao [15], as well as testing Bluetooth Low Energy (BLE) within a university campus [16]. Other lines of work investigated particular aspects of localization accuracy with bikes in urban [17] environments and in forest conditions [18]. However, no studies on localization accuracy in a typical mountain bike setting exist.

The aim of this work is therefore to introduce V2X communications for mountain bikes and hikers as a new subfield of V2X / VRU research, to present use-cases and requirements, and to start bridging this research gap by showcasing the results of an initial measurement campaign which we conducted with prototypes during Summer 2024 in the Dolomite Mountains in Northern Italy. The objectives of these experiments were threefold. First, building an understanding how communication technologies such as IEEE 802.11p-based direct short range communications (DSRC) and C-V2X work in such environments and how suitable they are for mountain bike safety applications. Second, studying the localization performance of localization technologies like global navigation satellite system (GNSS) and trilateration using BLE-beacons in scenarios that are realistic for mountain biking to better understand achievable localization accuracy and its dependence on environmental conditions like forest canopy or slope inclination. Third, testing the feasibility of a smartphone-based biker-to-hiker safety application based only on technologies available in current smartphones (i.e., BLE and WiFi for communication, built-in localization APIs of typical smartphones).

This paper presents on the first two aspects, while smartphone-based biker-to-hiker safety warnings will be presented in future work. The results, although preliminary, already provide very interesting insights, paving the road for further research.

II. Use Cases and Requirements

In this paper, we are investigating two particular scenarios involving V2X and VRUs in mountain bike settings. *Scenario 1* is called *Mountain Bike Collision Warning (MBCW)* and addresses a biker 1 blocking a trail (e.g., because of a fall) and biker 2 approaching that position at fast speed. Biker 2 cannot see biker 1 in time to slow down because of obstacles blocking line of sight or because of biker 1 blocking the trail behind a sharp switchback corner. The goal of MBCW is to provide a warning to biker 2 via digital communication and a suitable user interface. This scenario is particularly relevant in dedicated mountain bike parks but also on natural trails that mountain bikers frequent.

Scenario 2 is called *Mountain Bike Hiker Warning (MBHW)* and is particularly relevant for trails shared between mountain bikers and hikers. Here, a frequent problem is when hikers walking downhill get approached and overtaken by faster mountain bikers. This often leads to problems or even accidents if mountain bikers do not sufficiently slow down or hikers do not notice mountain bikers and get scared by the sudden overtaking maneuver. In turn, this can create a lot of conflict and tension between hikers and bikers, which can escalate to policy debates to trail closures for bikers completely. We assume that the biker typically sees the hikers in time, but that the hiker might not see the hiker approaching from his back. So the primary goal of MBHW is to alert the hiker of the approaching biker, but optionally the application should also be able to alert the biker.

Both scenarios can be extended in various ways, for example, by also alerting rescue forces in case of a crash, or by providing crash and other statistics to bike park owners, but these extensions are left out of scope in this paper.

Based on an analysis of our two scenarios, we came up with a list of requirements and a system architecture which we briefly summarize here. The core technical requirements involve bike-to-bike and bike-to-hiker communication, absolute and relative localization, and suitable user-interfaces for bikers and hikers.

For **communication**, it should allow *infrastructureless and ad-hoc message exchange*, *allow to establish communication and exchange messages at low-latency*, and *allow communication at relative speeds of up to and even beyond* $50\,\mathrm{km/h}$. A particular requirement is that communication needs *to be possible in typical terrain* with features like *no to dense vegetation* and *slope inclinations between* $0°$ *and* $45°$.

While bikes can be expected to be equipped with dedicated V2X technologies like DSRC based on IEEE 802.11p or C-V2X, we cannot make this assumption for hikers, where we limit ourselves to technologies available in typical smartphones or smartwatches, i.e., in devices that hikers already carry with them today. Here, WiFi Direct and Bluetooth Low Energy (BLE) would be two alternatives to investigate.

Localization in the MBCW use case needs to provide an *absolute location accuracy of at least* $1\,\mathrm{m}$ and *an update rate of at least* $1\,\mathrm{Hz}$ to allow a sufficiently detailed localization on a trail map to then calculate a collision risk. For MBHW, absolute positioning is of lesser importance and we would rather require a *precise distance estimate with the same resolution requirements as above*.

Regarding operational conditions, localization needs to fulfill these requirements in exactly the same environments as for communication.

A natural choice for localization technology would be global navigation satellite systems (GNSSs), however, literature already indicates that a forest canopy and steep mountain slopes would challenge such technologies. In bike parks and for the MBCW scenario, we therefore consider infrastructure-assisted localization technologies like using BLE beacons and trilateration to be an additional option. Likewise, for MBHW, BLE-based signal strength or time-of-arrival might be used as alternative technologies for a distance estimate as well.

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In our initial measurement campaign presented herein, we wanted to provide a first assessment on how these various technologies for communication and localization would perform in a realistic environment. This is what we present next.

III. Measurement Campaign

The measurement campaign took place in July 2024 in Northern Italy. In particular, we selected three tracks: one bike park which is reserved to bicycles, one hiking trail that is shared between bikers and hikers, and a gravel road leading down a skiing slope. The first spot, named *Sassolungo Bike Park*[1], is located in Sëlva, Val Gardena and it is particularly interesting because it offers measurement spots with a wide range of characteristics ideal both for localization and communication experiments. This includes line of sight (LoS)/non-line of sight (NLoS) communication, portions with straights, curves, and hairpins, spots with flats or elevation drops, and different vegetation densities. The second spot is the hiking trail that goes from St. Jacob's church down to the village of Urtijëi[2], located in Val Gardena as well. The third spot is also in Val Gardena on a gravel road that is used for skiing in winter[3]. This spot is particularly interesting for localization, as it features a free LoS towards the sky but is in a valley surrounded by high mountains and has forest approaching the gravel road from both sides.

We identified 5 spots within the bike park (spot 1 – 5), 3 spots on the hiking trail (spot 6 – 8), and 1 spot on the gravel road (spot 9). Selection was based on their characteristics with respect to vegetation, presence or absence of LoS, straights and hairpins, and the like. Fig. 1 shows a photo of the first spot, which presents LoS characteristics, an elevation loss, and a hairpin. Due to space constraints, this work shows the results for a subset of the spots which we deem most interesting.

With respect to communication, we use the nfiniity CUBE EVK devices for our testing, as they offer both DSRC (IEEE 802.11p) and C-V2X technologies. In particular, with respect to C-V2X, the devices implement LTE C-V2X Mode 4, enabling to test the technology in the absence of base station coverage. We mounted the devices on a rack under the seat (see Fig. 2), stored inside a box to protect it from dirt and vibrations but leaving the antennas outside. It is worth mentioning that this antenna placement might not be the most favorable and can have a significant impact on signal reception [4]. Finding the best antenna placement is not trivial and would require further measurements, outside of the scope of this work.

We implemented a measurement application which sends frames bidirectionally between the two radios with a frequency of $10\,\mathrm{Hz}$ and logs both transmitted frames and received ones together with their metadata, such as received power, sequence number, transmitter and receiver position, etc. Both radios operate at $5.9\,\mathrm{GHz}$ but not simultaneously, so we repeated each experiment twice. To increase the chances of frame reception and collect as much data as possible, we used the maximum available transmission power ($23\,\mathrm{dBm}$) and the lowest modulation and coding scheme (MCS) (MCS 0 for C-V2X and BPSK R=1/2 for DSRC). In addition, C-V2X used blind hybrid automatic repeat request (HARQ) retransmissions, meaning that each frame was sent twice by the radio interface.

Regarding the experiment setup, we placed one stationary bike in a chosen place, for example behind a hairpin simulating a crashed biker, and we approached it riding a second bike (moving bike). We tested both technologies and different approach speeds but, in general, never faster than $20\,\mathrm{km/h}$ to maximize the amount of data collected and to avoid the risk of damaging the device due to vibrations.

For localization, we compared measurements using both GNSS and tri-lateration based on BLE signal strength measurements. Three BLE beacons emit periodic messages and a receiver on the bike measures signal strength, which gets translated to a distance estimate on which our tri-lateration is based. Note that in this paper we do not use a sensor fusion approach nor do we use advanced signal processing like filtering or dead-reckoning as our goal is to collect raw measurements from single technologies to identify how they perform in the given environments. Our future localization system will then build on these insights to use sensor fusion and a refined localization approach.

Our devices are Arduino-based platforms with an Arduino MKR Wi-Fi 1010 main processing platform which already includes the u-blox NINA-W102 BLE chip with internal antenna implementing the BLE 4.0 standard. For GNSS, we use the Arduino MKR GPS Shield which is based on a u-blox SAM-M8Q GPS module. This hardware is relatively basic, but was selected as it resembles low-cost hardware that might be used in consumer-grade bikes. Fig. 3 shows the device setup for the mobile bike unit as it was mounted on the handlebar our our test bike.

Besides the bike unit, we had three static beacon devices mounted on camera mounts with an identical device setup that we placed in our test locations at positions known to the localization system placing one beacon on the inner side and two devices on the outer side of the curves.

IV. Analysis of the Results

A. Communication

To analyze the data from communication measurements, we first perform a set of post-processing steps.We started by removing excess data from the log file. Then, based on the positions measured by the GNSS module, we estimated the positions of both bikes during the experiments. At certain measurement spots, due to the presence of dense vegetation or substantial vibrations, the coordinates measured by the GNSS module were of particularly low quality. Therefore, we developed a map-matching based algorithm which, assuming to know the coordinates of the trail, allows to align the acquired GNSS data with a known map of the trail. Thereafter, we computed the distance between the two bikes throughout the experiment, the number of packets lost and received, the latency, and we retrieved received signal strength indicator (RSSI) values from the log files. Finally, we proceeded to generate the results.

[1]Location: N46°51.8534′ E11°75.1613′
[2]Location: N46°57.3502′ E11°69.3224′
[3]Location: N46°58.0842′ E11°69.1810′

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Figure 1: Measurement spot 1.

Figure 2: Communication device mounted on the bike.

Figure 3: Mobile localization assembly (opened and mounted on the handle bar).

In the remainder of the paper, we will show the results for the packets received by the moving bike sent by the stationary one, and for the slow speed measurements only.

We start the description of the results from spot number 1. This spot presents no vegetation, it presents an elevation drop giving LoS in the first part of the trail and then turns slightly left before a sharp right hairpin with an elevation drop, where we place the stationary bike. Overall the trail length in this spot is $160\,\mathrm{m}$.

For this spot it is interesting to observe the RSSI. In particular, Fig. 5 show the RSSI of the frames received by the moving bike projected on the map for DSRC. Fig. 6, instead, show the RSSI for both technologies as function of the trail distance, i.e., the amount of distance to be travelled by the moving bike to reach the stationary one. We do not report the packet loss ratio (PLR) here as it was basically null for both technologies. It is still interesting to observe the behavior of the RSSI, which counter-intuitively becomes worse while approaching the stationary bike in the first $120\,\mathrm{m}$ of the trail. This is caused by the drop in the elevation causing an obstruction of the LoS. At $40\,\mathrm{m}$ the signal quality drastically improves but on the hairpin it oscillates with some deep troughs. While here almost all frames were received thanks to robust modulations and high transmission power, in other settings this might cause loss of communication and, consequently, failure in informing incoming riders.

Figure 4: Measurement spot 3.

The second spot we describe here is number 3, which is

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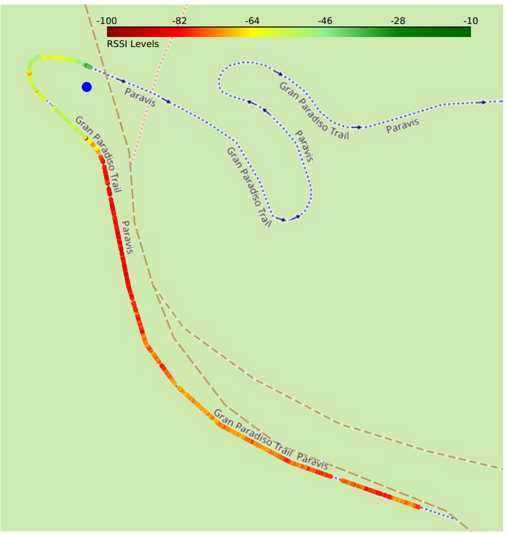


Figure 5: DSRC RSSI strength for spot 1. Map © OpenStreetMap.

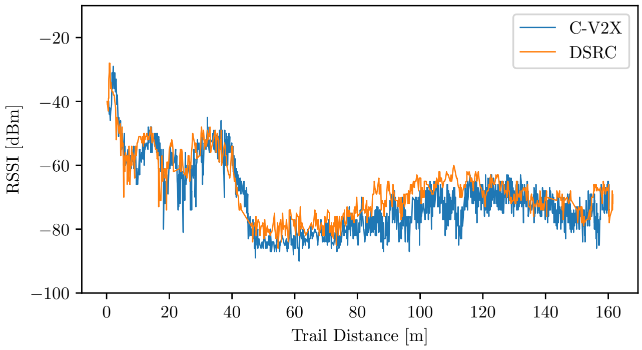


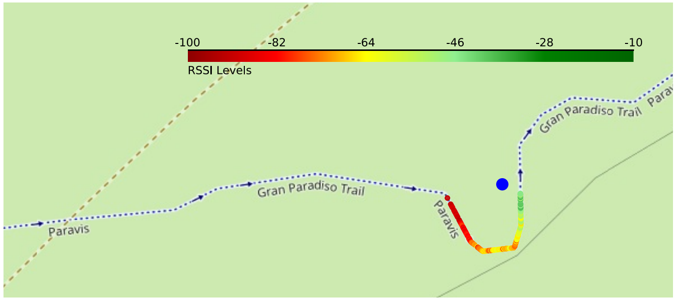
Figure 6: RSSI strength for spot 1 as function of the trail distance.

characterized by a straight road with small hills which then turns to the right before a left hairpin with a significant elevation drop. Fig. 4 shows a picture of the standing bike located after the hairpin, showing the elevation drop in the order of $3\,\mathrm{m}$ to $4\,\mathrm{m}$. The length of the trail over which we collect the measurements is around $90\,\mathrm{m}$.

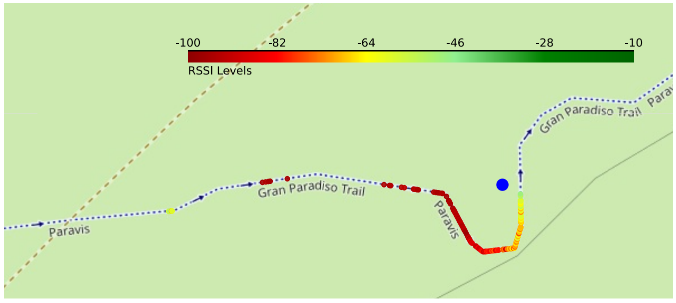
Concerning the results, Fig. 7 shows the RSSI on the map, while Fig. 8 shows the RSSI as function of the trail distance. At a first glance it is clear that the type of terrain makes the communication extremely challenging. Looking at Fig. 8, it is evident that even with the highest power and the most robust MCS it was not possible to receive packets up until $25\,\mathrm{m}$ of trail distance. There are some rare exceptions between 40 and $60\,\mathrm{m}$ for C-V2X which are probably due to the hills on the straight part, but the communication cannot be considered reliable. In fact Fig. 7 shows that continuous communication is possible only after the right turn and that the RSSI was above $-80\,\mathrm{dBm}$ only in the last $15\,\mathrm{m}$ before reaching the stationary bike. It is true that bikes do not travel very fast but in some spots braking might become dangerous. Considering the inclination of the hairpin in Fig. 4, both the application of the brakes or approaching it too slowly might cause tire slip, with the consequent risk of falling.

To further emphasize the problem, in Fig. 9 we plot the PLR for both technologies as function of the trail distance, grouped in $10\,\mathrm{m}$ bins. Besides the difference in performance showing that C-V2X has a smaller PLR compared to DSRC probably due to more robust MCS and blind HARQ repetitions, the graph clearly shows that communication experiences substantial losses down to $25\,\mathrm{m}$, where the loss is around $30\,\%$. This occurs with the highest power and the lowest MCS, meaning that if we want to improve packet reception we need to think to alternatives, either in terms of physical layer or from a protocol perspective.

The final spot we deem interesting analyzing is number 8. Differently from previous spots, which were located within the bike park, this is located on a hiking trail. In addition, this presents a lot of vegetation and the trail is characterized by a two consecutive hairpins, i.e., a right and then a left one. We place the stationary bike after the second hairpin and one interesting feature is that there is a large elevation drop between the starting point and the stationary bike (trail length $130\,\mathrm{m}$), with the moving bike having temporary LoS conditions when on the upper part of the road. Fig. 10 shows a picture taken on the upper part of the trail, showing the final left hairpin with the



(a) DSRC



(b) C-V2X

Figure 7: RSSI strength for spot 3. Map © OpenStreetMap.

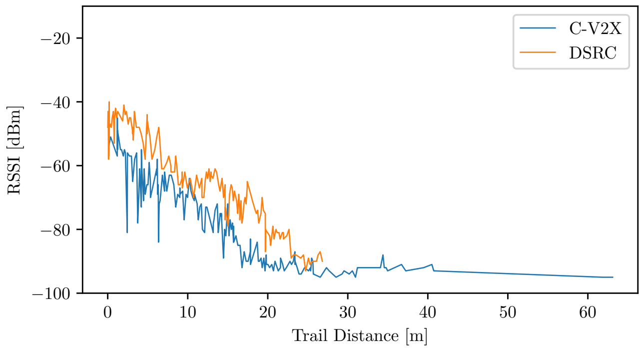


Figure 8: RSSI strength for spot 3 as function of the trail distance.

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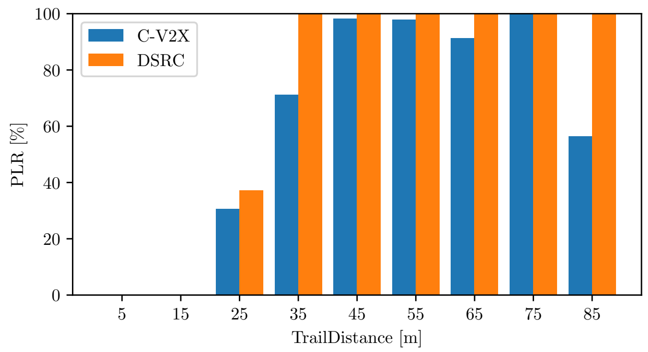


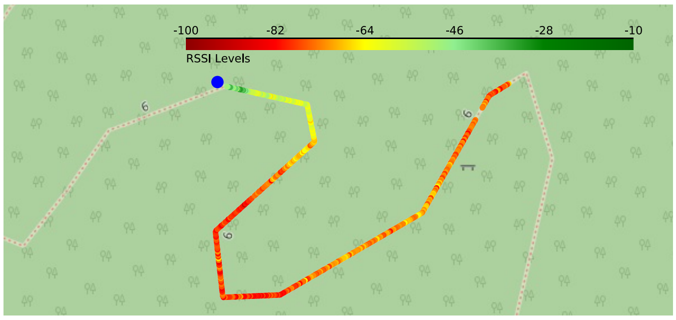
Figure 9: Packet loss rate for spot 3 as function of the trail distance.

Figure 10: Measurement spot 8.

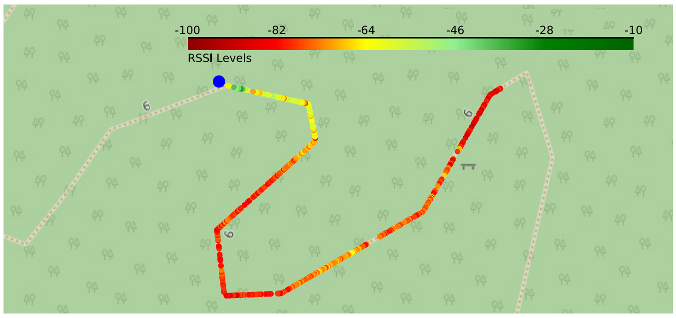
stationary bike. In that elevated position the moving bike is in LoS with the stationary bike, but loses LoS in the central part of the trail.

As for spot 3, we show the RSSI on the map (Fig. 11) as well as the RSSI as function of the trail distance (Fig. 8). Looking at the maps in Fig. 11 it is possible to see the effect of the temporary LoS communication in the first part of the trail, where the signal strength increases before decreasing again close to the first hairpin. This can be better appreciated looking at Fig. 12, where the signal strength tend to increase between $120\,\mathrm{m}$ and $90\,\mathrm{m}$ to the stationary bike, decreases between $90\,\mathrm{m}$ and $40\,\mathrm{m}$ by roughly $20\,\mathrm{dBm}$ before finally getting stronger and stronger as the moving bike approaches the stationary one in the last part of the trail. This indicates that trails with such characteristics could indeed favor communication ahead of time, but this of course depends on the situation, i.e., whether the dangerous situation has already occurred when passing through the "favorable" communication area.

As a final, but very important remark, consider the signal strength for C-V2X in Fig. 11b. It is possible to observe a small part of the trail between the starting point and the first hairpin where no data points are present. After a careful investigation, this was not due to packet lost due to low signal quality, but frames not being transmitted. This was caused by the loss of the GNSS fix, which is necessary for synchronizing channel access in C-V2X. This was not the only spot where we experienced this problem but, in fact, in all spots where vegetation might cause a poor GNSS signal and, in addition, the problem is worse when travelling at high speeds. We believe this aspect should be carefully taken into account, as the likelihood of loosing the GNSS fix in a forest is pretty high. In the case of temporary GNSS loss, even if the position to be sent can be extrapolated from sensor data, if the communication technology depends on a fix for transmission, safety might be at risk.



(a) DSRC



(b) C-V2X

Figure 11: RSSI strength for spot 8. Map © OpenStreetMap.

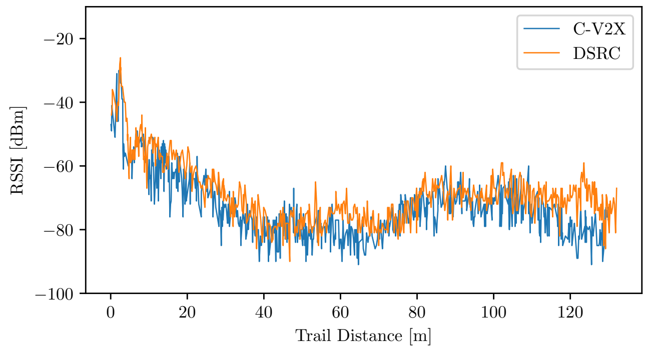


Figure 12: RSSI strength for spot 8 as function of the trail distance.

B. *Localization*

For localization, we again measured at the varying testing spots and measured at static positions and at different speeds.

Fig. 13 shows our measurement results for the localization of a bike placed for $30\,\mathrm{s}$ at a static position in the curve in between the three static (beacon) devices. The figure shows the position of the static devices, the GNSS measurements and the values calculated through tri-lateration based on distance estimates derived from RSSI measurements.

While spot 1 provides almost perfect reception conditions for both GNSS and BLE, one can still observe a substantial drift of both position estimates over time. However, for the requirements of localizing, for example, a crashed biker blocking the trail, the

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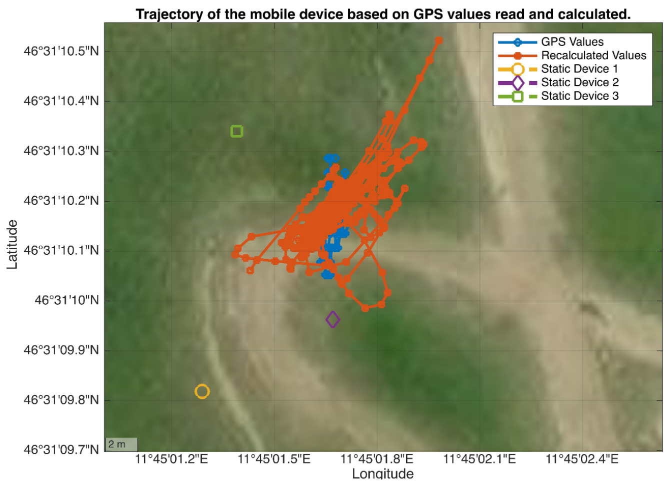

Figure 13: Spot: 1. Localization of static bike. Showing position of static beacon devices and measurement of a series of GNSS measurements and positions measured by tri-lateration using distance estimates based on RSSI values measured from three static (beacon) devices [19].

GNSS position alone is sufficiently accurate, especially when averaging some measurements over time.

Next, Fig. 14 now features measurements from a dynamic ride through the curve at two different speeds. For GNSS, one can observe a very good accuracy, following the trail very closely. At the same time, at higher speeds, the measurement frequency limits the accuracy somewhat. For BLE-based localization, the dynamic setting at $15\,\mathrm{km/h}$ provides also very reasonable accuracy, however, the covered area in which beacons from all three static devices were received and localization was thus possible, was very limited. At $25\,\mathrm{km/h}$, the BLE-based localization shows some very strange artifacts after entering the curve. As this effect sets in only in the middle of the curve, we suspect that some blocking of the BLE antenna by the body of the rider is responsible for these effects, which is much less visible at lower speeds. Investigating this effect definitely requires further measurements and tests.

For spot 9, we show only the measurement with a static bike as seen in Fig. 15. As one can see, BLE-based trilateration provided some reasonable position estimate, although some drift is observable similar to spot 1. More interesting are the effects of GNSS. Over the $30\,\mathrm{s}$ of the measurement, a huge position drift can be observed. It is clearly visible how a forest canopy at the sides of a track (even if zenith is clear) can lead to a huge drift in GNSS positions. Such findings are in line with what literature reports [18]. When running dynamic tests (figures not shown here due to space constraints), we could also observe similar artifacts in some of the runs.

V. Conclusions and Future Work

This work presents the results of a measurement campaign aiming at understanding to which extent existing technologies can support mountain bike safety applications.

With respect to *communication*, DSRC and LTE C-V2X seem both to work reasonably well, with C-V2X showing slightly better performance probably due to more robust MCS and to blind HARQ retransmissions. Still, the results show the impact of terrain and trail characteristics on signal strength, for example due to sudden loss of LoS in proximity of the transmitter. This means that such technologies might not always be able to inform incoming riders of a danger on the trail, especially if the danger is due to a fall that occurred a few meters ahead. Moreover, C-V2X is strongly dependent on GNSS fixes for synchronization, which might be lost in areas with a lot of vegetation. In such cases C-V2X stops transmitting and thus informing incoming riders.

With respect to *localization*, our tests led us to the conclusion that none of the investigated technologies provide satisfying results under all conditions.

Static scenarios always suffer from drifts. In case of a crashed stationary rider, averaging multiple measurements can enhance accuracy, but as our measurements at spot 9 have shown, in some reception conditions this might not be enough.

Then, scenarios with rider mobility in perfect reception conditions provide very good results for GNSS, but as soon as there are obstructions and reflections like in spot 9, artifacts appear that make localization a lot less reliable.

Here, localization should be enhanced with Bluetooth beacons in sufficient numbers to allow trilateration. However, in our experiments BLE suffered from low coverage of only three beacons. To provide better results, substantially more beacons would have to be deployed. Such a more dense deployment could also be limited to locations where GNSS is known to have poor reception.

However, our results were also limited by accuracy of the RSSI-based distance estimates. Here, Bluetooth 6.0 Channel Sounding is a promising standard to provide more accurate distance measurements. Unfortunately Bluetooth 6.0 devices where not available to us during our measurement campaign.

If coupled with data from Inertia Measurement Units (IMUs), we expect accuracy to be good enough even for advanced requirements.

So in our future work, we plan to investigate a localization approach based on sensor data fusion, to include Bluetooth 6.0 Channel Sounding and IMUs, to test with more beacons, and to also test with different hardware to investigate the particular influence of the specific chip sets.

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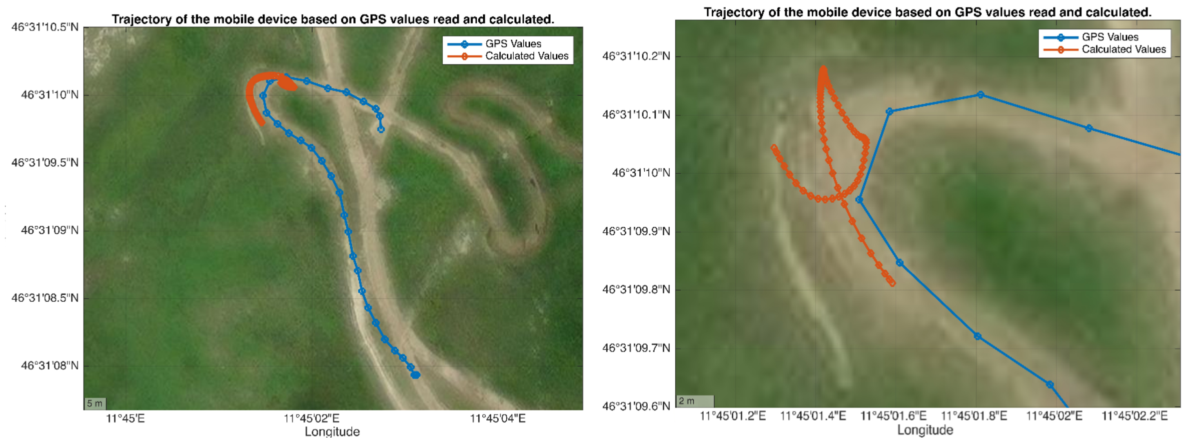

Figure 14: Spot: 1. Localization results of dynamic bike at 15 km/h (left) and 25 km/h (right) [19].

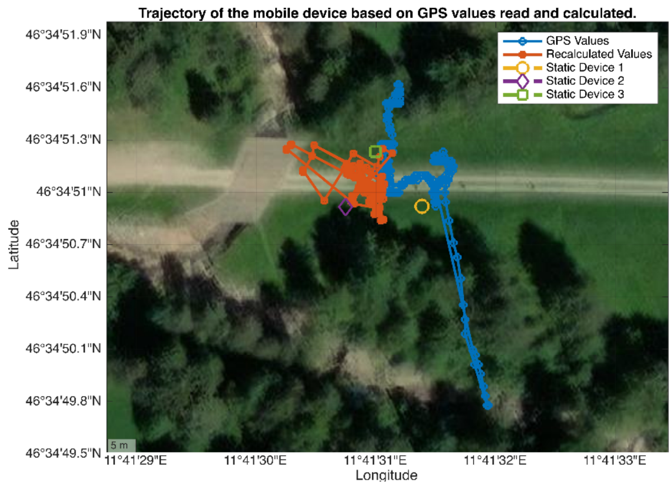

Figure 15: Spot: 9. Localization of static bike. Showing position of static beacon devices and measurement of a series of GNSS measurements and positions measured by tri-lateration using distance estimates based on RSSI values measured from three static (beacon) devices [20].

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