Poster: MBHWS — a Mountainbike-to-Hiker Warning System

Max Hörmann*, Marcus Marx*, Michele Segata†, Michele Zucchelli†, Frank Kargl*
*Institute of Distributed Systems — Ulm University, Germany
*Department of Information Engineering and Computer Science — University of Trento, Italy
{max.hoermann,marcus.marx,frank.kargl}@uni-ulm.de, michele.zucchelli-1@studenti.unitn.it, michele.segata@unitn.it

***Abstract*—We present a novel application for V2X communication, namely a Mountain-Bike-to-Hiker Warning System (MBHWS), including requirements analysis, use-case description, prototype development, and technical evaluation and user-study.**

***Index Terms*—mountain biking safety; bike-to-pedestrian communication; vulnerable road-users; hiker warning system**

I. Introduction and Motivation

Due to increased popularity of outdoor sports, recent years have seen a surge in popularity of mountain biking and this is predicted to continue with annual growth rates of 6 % to 9 %. In areas where no dedicated trails exist for mountain bikers and trails are shared with hikers, this increasingly creates conflicts with hikers which feel annoyed or get scared by bikers approaching and overtaking them (in particular from the back). In the worst case, this can even lead to accidents and injuries. Analyses from specific areas like Slovenia [1] or Australia [2] consistently indicate that this is a conflict that cannot be ignored but needs to be addressed and managed.

In our scenario, a biker approaches a hiker from behind on a downhill slope at a significantly higher speed. The hiker would not notice the biker up until the very last moment, i.e., when the biker passes him or her at substantially higher speed and at relatively short distance scaring hikers or even triggering dangerous collisions. The scenario is depicted in Fig. 1. An early and unobtrusive warning to the hiker would mitigate the situation substantially and result in a much better coexistence of bikers and hikers on shared trails. In our research, we investigate a technical solution, leveraging information technology and wireless communication to produce a warning on a hiker's carry-on device.

II. Requirements Analysis

In our system model, shown in Fig. 1, a biker B is approaching a hiker H on a shared downhill trail from H's back. The overall goal of our system is to transmit a warning to the hiker for increased awareness and timely reaction. This warning needs to 1) reliably warn the hiker with sufficient advance time to react, 2) provide an intuitive information to H about the remaining time until the biker might overtake, 3) be unobtrusive to avoid disturbing hikers unnecessarily during their recreational activity.

To implement this, both B and H are each equipped with a telematics unit BT and HT that together implement the Mountain-Bike-to-Hiker Warning System (MBHWS).

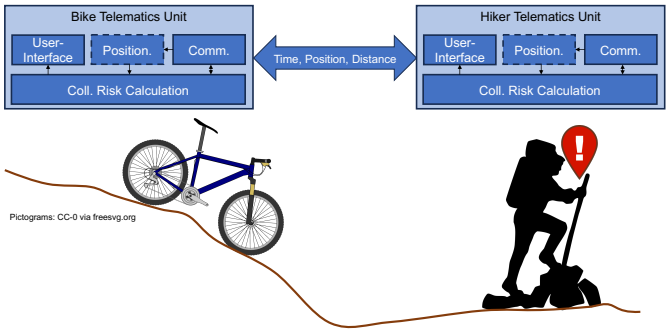

Figure 1: Visualization of Use-Case and System Architecture.

The telematics units share a common design implementing the following functional blocks:

1) communication to exchange necessary information, 2) a logic to calculate the distance between B and H or otherwise assess the estimated time-of-arrival (ETOA) that should be included in the warning, 3) positioning to periodically measure the positions of B and H which can contribute to distance estimates, and 4) a suitable user interface to deliver a warning.

We have systematically identified requirements for these components and evaluated suitable technologies to implement a prototype for such MBHWS. For the *hardware platform*, we identified the following requirements: cost, portability, computing power, battery capacity, and supported technologies for localization and communication. Requirements to be considered for *communication technology* include: ability for infrastructure- and setup-less operation, support for periodic one-way broadcast, range, data rate and latency, communication resilience in harsh outdoor environments, and availability in the target platform. Requirements for distance estimation include precision, update rate, and delay. For the user interface that conveys the warnings to the hiker (and possibly also to the biker), we consider the following requirements: unobtrusive warnings, suitable warning modality, and personalization.

Space limitations do not allow a detailed discussion of the requirements analysis and considered technology option. In conclusion, we opted for a smartphone-based app that relies on Bluetooth Low Energy (BLE) for communication and estimates distances based on position measurements of biker and hiker via Global Navigation Satellite System (GNSS) that are communicated to the other entity.

III. System Prototype and Evaluation

Based on the requirements analysis, we implemented a prototype as an Android app written in Kotlin that runs on smartphones mounted to bikes and carried by hikers. For localization, we rely on the Fused Location Provider API provided by Android which resorts to GNSS and Wi-Fi for localization. For communication, we use a BLE-service that periodically broadcasts the biker's UUID, position, altitude and speed. On the receiving side, the smartphone will use the position of the remote and own device to calculate a distance estimate and derive the ETOA based on the current speed of the mountain bike. The hiker's app will generate different and configurable warnings. Obviously, our prototype faces certain limitations, like limited battery lifetime due to very aggressive settings for localization and communication. However, these can be tolerated for an initial technical feasibility study.

We then conducted technical field tests in various locations in Southern Germany and in Grödnertal / Val Gardena in the Italian Dolomites to reflect a broad range of realistic environments.

Our evaluation showed that the Fused Location Provider was able to provide position updates at a stable rate of around $1\,\mathrm{s}$. Regarding accuracy of calculated distances, we took measurements using a setup where bike and hiker were statically placed at a known distance. Measurements shown in Fig. 2 indicate average distance measurement errors around $2\,\mathrm{m}$ in an alpine test site with coniferous forest, while measurements at the mixed forest test site show much larger fluctuation and inaccuracies reaching $7\,\mathrm{m}$ and more. So particular broadleaf trees pose a challenge for localization. At the same time, positioning in alpine and outdoor environments is known to perform particularly bad in stationary settings and we expect that positioning accuracy would enhance significantly for mobile bikers and hikers [3]. But even at this accuracy we expect our application to provide useful warnings.

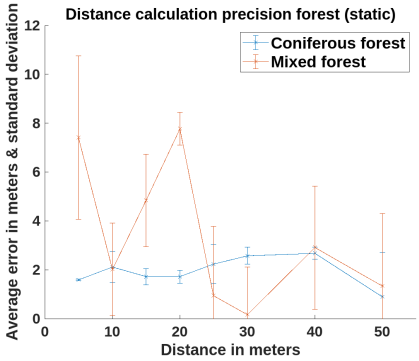

Figure 2: Distance calculation precision with static positions.

Regarding communication performance, BLE advertisements met and exceeded requirements with reliable delivery of beacons within a range of $50\,\mathrm{m}$. This allows for a warning time of $6\,\mathrm{s}$ at a relative speed of $30\,\mathrm{km/h}$.

In coniferous forest, first advertisements can be received at distances of $150\,\mathrm{m}$ and message reception stabilizes quickly as distances shorten. With free line-of-sight on a steep slope, communication was possible at distances of $200\,\mathrm{m}$. In the range between $0\,\mathrm{m}$ to $50\,\mathrm{m}$, the average inter-packet delay between two advertisements was stable below $0.25\,\mathrm{s}$ even without line-of-sight, and maximum inter-packet delay never exceeded $2\,\mathrm{s}$.

In conclusion, our initial technical evaluation showed that a MBHWS can be implemented on consumer-grade smartphones with sufficient performance in both localization and communication. At the same time, more in-depth evaluations will be required involving an enhanced prototype and a broader evaluation of technologies to get a fine-grained understanding.

We also conducted a pilot user study to investigate how hikers (for which the benefit is particularly targeted at) would perceive and accept our MBHWS, but also investigated which modalities for warnings might be preferred. The study had with 22 participants where those could experience our prototype with different warning modalities (acoustic vs. haptic).

In summary, the study revealed interesting insights into user acceptance and preferences. A MBHWS would allow substantially more people to react to overtaking mountain bikes with sufficient time to avoid critical situations and not be scared ($95.5\,\%$ with vs. $36.4\,\%$ without MBHWS) and user acceptance and adoption will be very high.

IV. Conclusion and Future Work

In summary, an MBHWS presents a novel application for Vehicle-to-X (V2X) communication and Vulnerable Road Users (VRUs) protection. Initial assessment of use-cases, scenarios, and requirements for implementing a MBHWS and our smartphone-based prototype build on GNSS and BLE advertisements as suitable base technologies showed general feasibility, and a pilot user-study with 22 participants revealed that timely warnings enhance awareness and avoid hikers getting scared by bikers. Users expressed high acceptance and willingness to adopt the solution. Our initial research also provided indications for interesting follow-up research. For example, Bluetooth version 6 introduces a channel sounding feature and such technology will also become part of future IEEE 802.11 bd devices. Once available, these technologies can be evaluated for their performance in our scenarios and particular focus should be put on certain types of forests were GNSS suffers from inaccuracies. Furthermore, IEEE 802.11 p or bd should be investigated as an alternative to BLE for communication. Better ETOA estimate and more refined user-interfaces need to be investigated, and larger user studies can provide additional insights into user adoption.

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