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Blind-Turn Obstacle Alert System

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ABSTRACT

Roads the world over have blind, dangerous turns where a convex mirror is either insufficient or un-place-able due to (a lack of) terrain features. Drivers have severely reduced reaction times should traffic or obstacles exist around these bends.
I propose an early warning system to detect objects around the bend and relay this information to oncoming drivers with quick-to-read LEDs, giving them time to reduce their speed or, in some cases, alter routing.

The system should be fairly simple and therefore cheap to deploy at numerous locations. By building a star network of sensors and lights around a mildly more powerful gateway unit, the system can be self-contained to reduce latency and infrastructure requirements. Should the infrastructure exist, the gateway can pass information collected to a broader cloud. By keeping power requirements down and employing solar panels, the system should be capable of sustaining without maintenance for years at a time.

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INTRODUCTION

Driving through the mountains of California is a fact of life for millions of Americans. Vehicles wind up and down highways that overlook sheer cliff faces, often driving 60+ miles per hours on roads subject to mudslides, downed trees or powerlines, fires, and accidents. Being sculpted into the face of the mountain means these roads commonly have sharp turns around blind corners, be that at highway speeds or remote stop signs. Similarly, the mountainfolk may live behind unpaved, bi-directional lanes with all of the same characteristics. Even at residential speeds, these cliff-side bends make accidents potentially lethal.

IoT offers a novel solution, allowing information about objects beyond the blind turn to be relayed to oncoming drivers. At a minimum, the system needs a sensor (array) to gather information about the blind space, actuators to alert on-coming driving of the existence (or lack thereof) of obstacles, and a base station to coordinate the two sets.

Device Considerations

Because of the disruptive nature of rerouting traffic flows, these systems should anticipate operation with minimal external intervention for *years* at a time.
No assumptions can be made about available networks as these blind turns are frequently in *areas with poor cellular reception and minimal infrastructure*. Therefore, systems should be self-contained, with optional external interfaces.
The controller has greater flexibility in placement and environment and thus greater flexibility in ability. The *sensors and actuators must be extremely limited* as they will be expected to operate on battery power for years at a time.
Beyond battery life, *latency*, *particularly from sensors to actuators, is critical*. This requirement can be tempered somewhat via careful LED placement, but better latency provides greater flexibility in how far away from the turn the LED can be placed and still be useful to the driver.

Security Considerations

The system will have a presence adjacent to mostly unmonitored roadways, opening the physical attack surface. While this should be factored in, *malicious impact is limited* to LEDs displaying incorrect or misleading information. At current scope, systems would be unable to identify vehicles and thus have little worth pillaging.

System Overview

Each implementation is a single 'system' composed of *3 types of devices*: a controller, one or more sensors, and one or more actuators.

The controller is necessary to aggregate information gathered by the sensors, parse and filter it, and then decide if an actuator should be illuminated. By offloading aggregation, coordination, and networking to the controller, the sensors and actuators can consume less power and operate for longer. The controller is the central hub, but also the most flexible with in its placement. While the sensors and actuators must be placed roadside, in relative precise positions, the controller can be placed aloft and out of the way, ideally in a location to allow supplemental solar power.
The actuators are simple sets of LEDs, placed somewhere visible to oncoming drivers. They illuminate green if no hazards are detected around the bend; orange if conditions are unclear or there is a repeated, albeit moving hazard (such as traffic); and red if an unmoving, or incoming hazard is detected. A smoothing mechanism, implemented in cooperation between the controller and the actuators, will be required to prevent rapidly changing visual signals.
The sensor array is composed of two devices: one device to detect the presence of an object and a second device to detect speed and direction of vehicles. The former is to ensure proper detection for slow- or non-moving obstacles, such as traffic or downed trees. The latter is primarily intended for use in single-lane scenarios so the system can determine if a vehicle is moving towards it and therefore towards a vehicle on the other side of the turn.

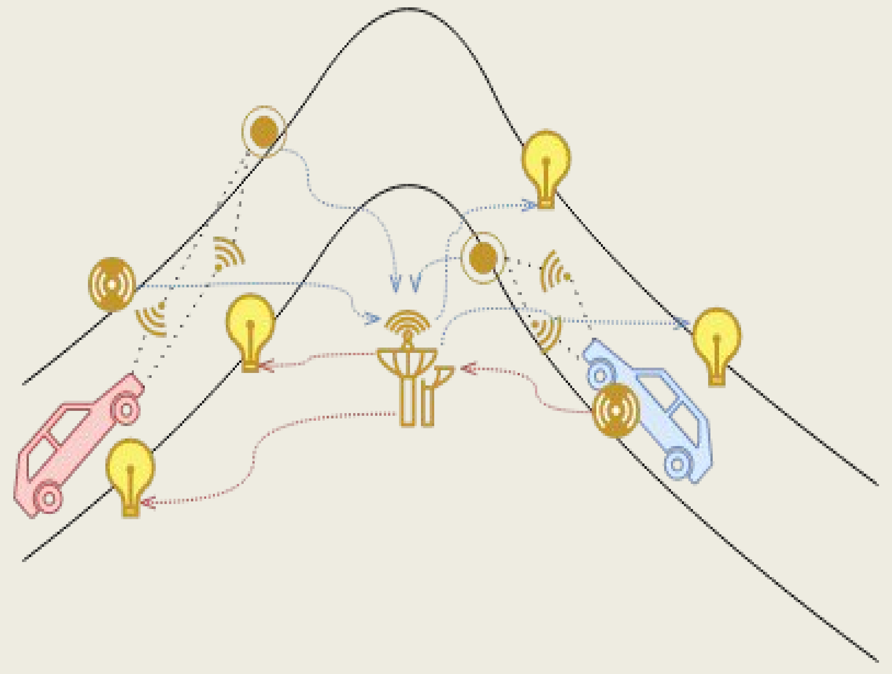


Figure 1a. Two vehicles sharing a single lane in opposite directions.

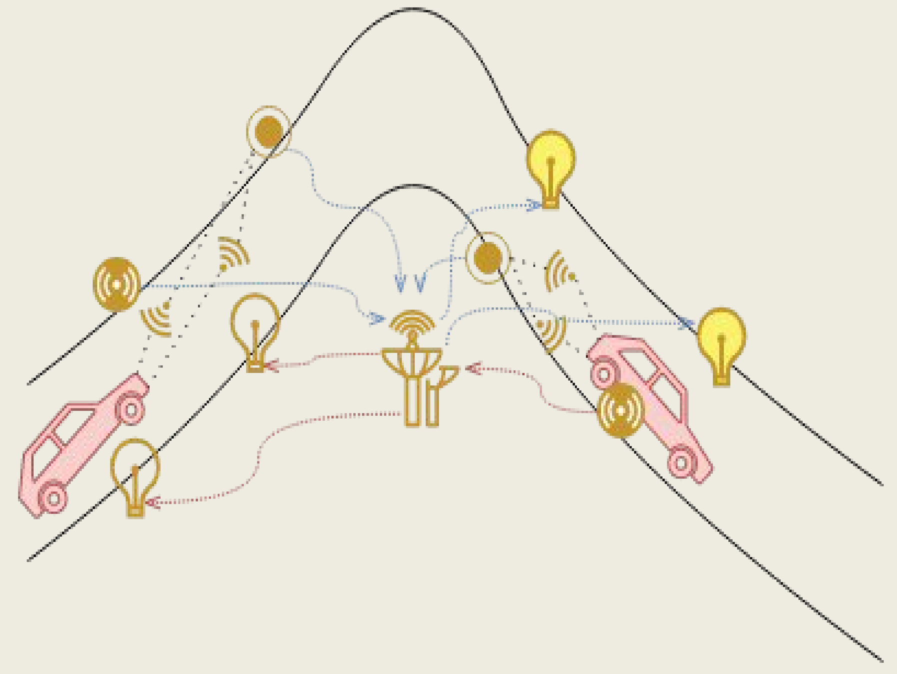
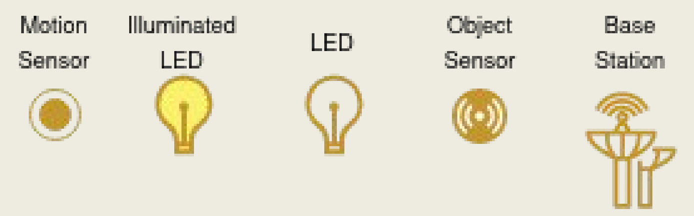


Figure 1b. Two vehicles sharing a single lane in the same direction.



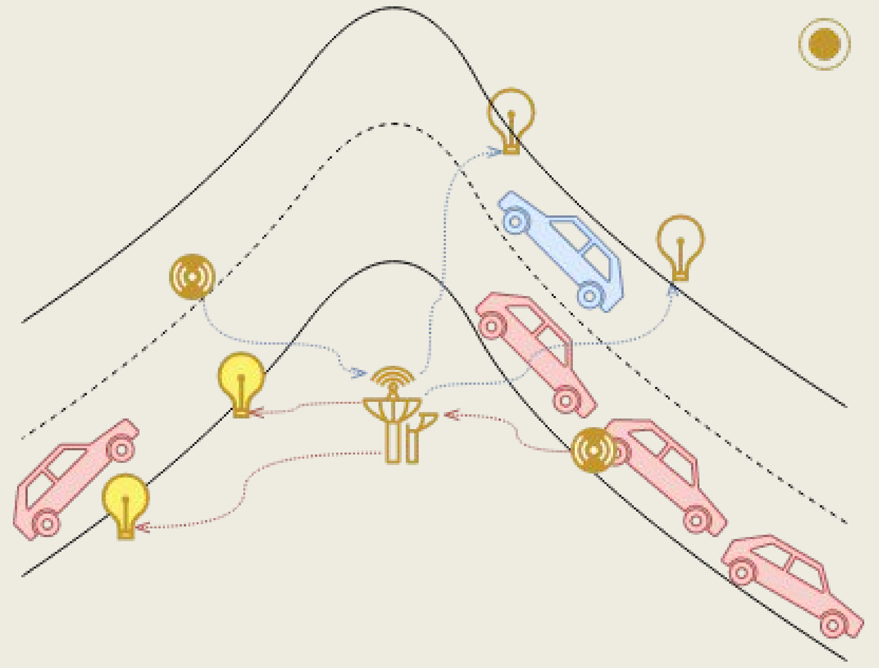


Figure 2a. A multi-lane road with traffic around a blind turn.

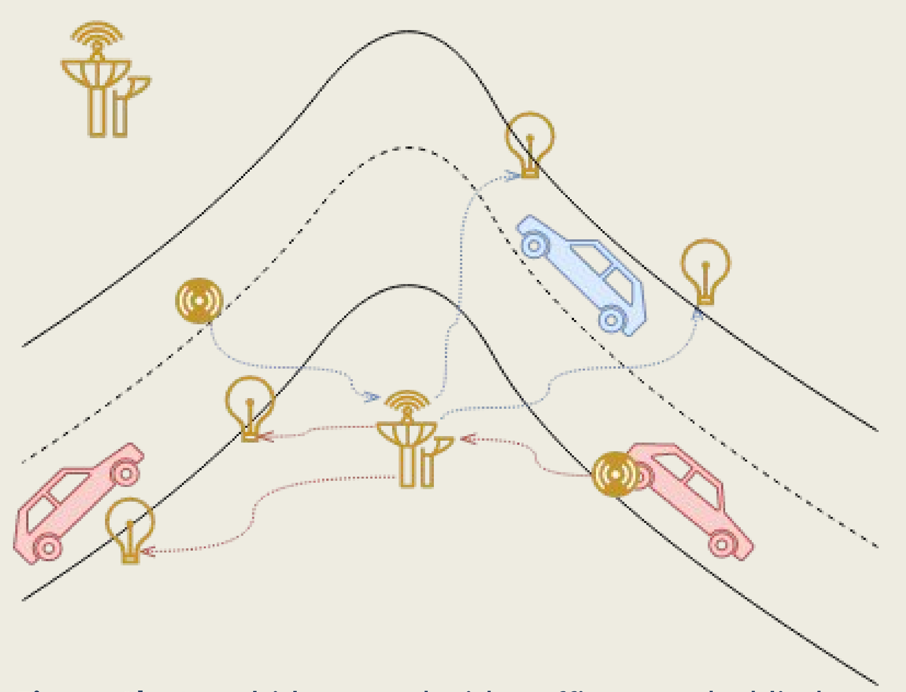


Figure 2b. A multi-lane road with traffic around a blind turn.

Figures and iconography made with diagrams.net.

Network

With its (theoretical) latency[1], rapid scalability, and self-healing nature, Thread is a tempting candidate for network protocol. However, this system is entirely self-contained, requires a specific leader node (the controller), and gains no direct benefit from IPv6 interconnection; the ancillary features of Thread, like partitioning and REED promotion. Therefore, *Zigbee is a more practical choice*. It has high delivery rates even up to $40m^3$, supports the 915 and 868MHz bands for lower bandwidth and power consumption, can optionally support router devices to extend the network distance, has a negligible energy usage gain when using AES encryption[3], achieves outstanding small-packet latencies with high baud rates[3] and more-than-serviceable small-packet latencies even with low baud rates[3]. Zigbee is an ideal fit, though testing will be required to validate actual, usable numbers.

Bluetooth Low Energy could likely also satisfy the system's requirements with a point-to-multipoint setup where the controller acts as master.
LoRaWAN's extremely low power requirement and reliable range-through-surfaces are interesting, but the latency (~400ms[2], upwards of a full second) is untenable and range much beyond LAN is unnecessary.

Open Questions

There are a handful of unclear elements to the proposal that must be resolved before final proposal.

1) How are vehicles detected? While we can use rebounding IR (a regrettably power-hungry sensor) to track the speed and direction of vehicle in the direction sensors, the system needs a way to check for slow-moving or motionless objects with the critical zone sensor. This could be a tripwire system, but that will further increase the power requirements for the sensor array.
2) How is the base station powered? Ideally, the base station is battery powered and supplemented by a miniature solar array that provide just enough trickle charge to allow it to keep pace with the RFD sensors. The feasibility of this will be highly dependent on cost, location of system, and final power draw of the base station.

References

1) Bluetooth Mesh, Thread, and Zigbee Network Performance Benchmarking - Silicon Labs. (n.d.). Silicon Labs. https://www.silabs.com/wireless/multiprotocol/mesh-performance
2) A. Pötsch and F. Hammer, "Towards End-to-End Latency of LoRaWAN: Experimental Analysis and IIoT Applicability," 2019 15th IEEE International Workshop on Factory Communication Systems (WFCS), Sundsvall, Sweden, 2019, pp. 1-4, doi: 10.1109/WFCS.2019.8758033.
3) Haque, K. F., Abdelgawad, A., & Yelamarthi, K. (2022). Comprehensive Performance Analysis of Zigbee Communication: An Experimental Approach with XBee S2C Module. Sensors, 22(9), 3245. https://doi.org/10.3390/s22093245