"Wire is not dead": Wired-backscatter Communication for Breakage Detection in Electric Fences

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Abstract

Electric fences protect human habitats from elephant attacks in rural Sri Lanka. Maintaining such fences and in particular detecting breakages is tedious and expensive. In this paper we design a low-cost system to detect breakages in fences. We use low-power, low-cost sensor nodes deployed along the fence wires to detect the breakages. The nodes are assigned with unique node identifiers that indicate their location on the fence. The sensor nodes modulate the high voltage pulse on the fence to transmit their node ID to a master co-located with the fence-energizer. The absence of a node ID indicates a breakage at a location between the energizer and that node. Since the detector nodes use the fence-pulse, generated by the fence-energizer, as the carrier they consume only a small amount of energy. We show that this *backscatter-like* communication through the high-voltage fence wire reduces the implementation and running cost of breakage detection-enabled electric fences significantly.

Categories and Subject Descriptors

B.4 [**Hardware**]: INPUT/OUTPUT AND DATA COMMUNICATIONS

General Terms

Design, Reliability

Keywords

human-elephant conflict, electric fence, breakage detection, backscatter

1 Introduction

The human-elephant conflict is an on-going tragedy in the everyday life of rural villagers and farmers in many parts of Sri Lanka. Nearly 80 people and 200 elephants die every year due to collisions between them when elephants enter the farm lands and human habitats in search for food and water. While many illegal methods are in use to prevent elephants from entering human habitats, such as poisoning and shooting elephants, the only viable solution that has been tried so far is electric fencing.

People successfully use electric fences to protect human habitats and farm lands from elephants in various parts of the world [5, 7]. In Sri Lanka, over 3000 km of electric fences are deployed in affected areas with the support of the government and non-government organizations [4]. The total area covered by electric fences can be more than that since various communities and individuals build electric fences by themselves to protect their premises from elephants without the support of the government. The government has further plans to construct 800 km long fences in the year 2017 in seven wildlife zones in Sri Lanka [1].

Building an electric fence is not an easy task. The financial cost associated with building an electric fence mostly consists of buying an energizer, electric wires long enough to cover the targeted area and wooden or concrete posts as a support to the electric wires. Additionally, human labour is necessary to lay the wires and to build a housing for the energizer. There are ready-to-deploy electric fences available as commercial products. However, the price tags of such products with breakage detection systems are over $3000 from well known manufacturers. Due to these reasons, many human-elephant conflict affected areas are still not covered by electric fences.

Electric fences are prone to breakages because of falling trees on the fence wires and elephants damaging the wires and wooden posts. Locally built low-cost electric fences do not have any breakage detection mechanism forcing villagers to walk along the fence wire until they find the damaged place. Elephants are intelligent animals who easily identify a non-operating electric fence and then enter the protected area. Walking along a fence wire to locate a breakage is also risky because of nearby wild elephants.

Towards this end, we design a breakage detection system for electric fences that is low in cost, easy to maintain and most importantly makes it easy to locate breakages from a central location. In this paper, we present the design of a low-cost electric fence breakage detection system suitable for protecting remote villages from elephant raids. In our system, we employ a novel communication protocol that locates breakages in high-voltage electric fences.

2 Related Work

Researchers have attempted to design smaller scale low-cost electric fences against various medium-sized mammals such as wild bear and deer. Takeshi et al. [6] have presented a low-cost fence which can cover an area of about $1700\,m^2$. However, due to the smaller area covered by the fence wires in such applications, the need of a centralized low-cost breakage detection system does not arise. Additionally, the manual inspection of the fence wire does not cause any threat to the maintainer of the fence by the animal species they are considering.

Ferguson et al. [3] have done a study on the impact of an electric fence segment with over 90 km length to the wild animals living inside a national park. Their work suggests that it is necessary to have a continuous monitoring mechanism along the electric fence wire to identify problems that fences cause. For example, the data regarding the effort of animals to intrude into different areas outside the wildlife parks can help to identify necessary areas where the animals should be provided with passages through the fence so they can move out to other areas. The areas in the fence which have more frequent breakages by elephants can indicate the places where the passages should be.

There has been an attempt to place breakage detection devices along the fence wires and equip them with wireless radios to report the breakages to a central station [10]. When using low-power wireless radios along the lengthy fence wire, we may come across situations where the nodes are out of transmission range of the central controller and hence need to use multi-hop routing which wastes the energy on the forwarder nodes located closer to the central controller. Instead, we already have wires on the fence and high-voltage pulses which can act as a carrier wave to encode our data.

Time-domain reflectrometry is a method that can be used for detecting breakages in conductors such as coaxial and twisted pair cables [8]. In order to use this methods, the cable should be properly terminated at the end point and should have a uniform impedance. However, electric wires used in low-cost elephant electric fences do not fulfill these conditions as they are wound around fence posts and bended at different points in an ad-hoc manner.

In our previous work [9], we presented a low-cost electric fence that was able to communicate through the fence wire itself as the communication medium. It consisted of two modes: the fence pulse mode and the communication pulse mode with the fence periodically switching between the two. During the former mode, the fence operates with high-voltage pulses in order to deter elephants from the covered area. The latter mode uses low-voltage pulses where a central controller sends node IDs through the fence wire to nodes installed in wooden posts at different locations of the fence. The reception of a node ID indicates that the fence is working up to the node's location.

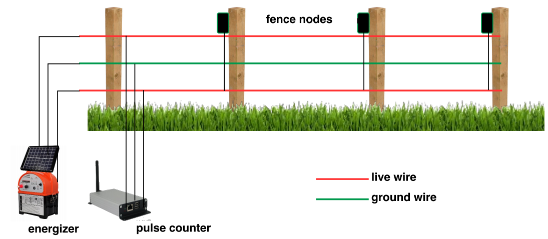


Figure 1: Components of the elephant electric fence breakage detection system. The *energizer* generates a series of high-voltage pulses at a constant rate which are randomly grounded by *fence nodes*. The *pulse counter* identifies the absence of pulses.

In order to achieve such a functionality, our previous fence consisted of complex hardware components which are prone to failures in real world deployments. Each node deployed in a wooden post of the fence uses a capacitive coupling mechanism using a copper strip placed closer to the fence wire to detect pulses. However, this detector is sensitive to other noise sources including the detector circuitry itself. Therefore, the accuracy of the pulse detection was low. Furthermore, the usage of a periodic low-voltage communication mode prohibits us from using an off-the-shelf electric fence energizer which only has a continuous high-voltage pulse generation.

3 Design

The purpose of an elephant electric fence is to deter intruding elephants without exposing them to a life threatening electric shock. Therefore, it is important to design electric fences adhering to the international standards and best practices of building electric fences. An important consideration in this context is the characteristics of the fence energizer that generates the high-voltage pulses. Due to the safety regulations of electric fence usage, the maximum width of the high-voltage pulse has to be 3 ms to avoid serious harm to the animal. In elephant electric fences, the common practice is to use a pulse frequency of 3Hz where 3 ms wide pulses occur with a inter-pulse spacing of about 300 ms [2].

Since a fault in the fence energizer can create life threatening situations to the intruding elephant, we design our breakage detection system to perform minimum interactions with the specific energizer used in the fence. This enables us to use any off-the-shelf energizer approved by the legal system and tune our breakage detection system to the energizer. In fact, the main weakness in our previous design of the fence breakage detection system [9] was the requirement to make significant changes to the energizer.

As Figure 1 shows, our fence breakage detection system consists of the three main components *energizer*, *pulse detector* and *fence nodes*. The energizer continuously generates high-voltage pulses. The pulse detector is connected to the fence wire in the same end of the fence where the ener-

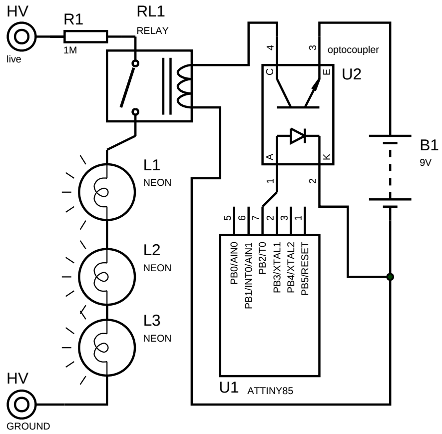


Figure 2: Schematic of a fence node. A relay switch is used to ground the wire according to the signals of a low-power MCU. Neon bulbs are used to drop the high-voltage of the fence pulses to a manageable level.

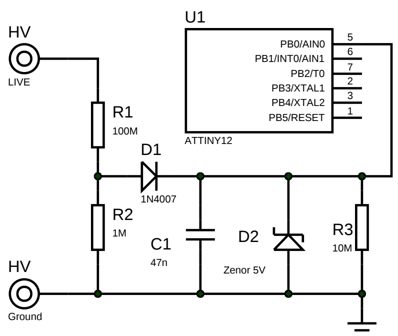


Figure 3: Schematic of the pulse detector. Neon bulbs are used to drop the high-voltage of the fence pulses to a manageable level which can be detected by an ADC converter in a low-power MCU.

gizer is located. It is designed to count the absence of pulses on the fence wire. The fence nodes are placed along the fence wire on wooden posts. They are designed to ground the fence wire, through a resistor, periodically in a way such that the pulse counter can uniquely identify which node grounded the fence wire at a particular instance. This enables the pulse counter to identify and locate a breakage in the fence wire.

3.1 Fence Nodes

The fence nodes are low-cost units consisting of an MCU and a few other necessary hardware components sealed inside a plastic container. Both live and ground wires of the fence are connected to each node as shown in Figure 2. Each fence node is capable of making a short circuit of the two fence wires at its location. The software running on each fence node MCU makes each node randomly wake up and short the fence wires for a unique time period before sleeping again. For example, the node with the ID n will randomly wake up and short the fence wires for a period of n pulses, while the node with ID m, where $m \neq n$, will randomly wake up and short the fence wires for a period of m pulses.

The periodic short circuiting of the fence wire by a node creates an absence of the high-voltage pulses for a time duration which is directly analogous to the ID of the node. Hence, each node is communicating its ID through the wire to the pulse counting system by modulating its ID to the high-voltage carrier wave of the fence. However, a fence node is not designed to get any feedback from the other nodes or pulse counter system. In that sense, these fence nodes are *transmit-only* nodes that use a wired-backscatter mechanism to deliver their node IDs to the pulse counter.

Fence nodes ground the fence wire at random times since they do not have any method to synchronize or control the access to the fence wire among themselves. Hence, there can be collisions when two nodes wake up and short circuit the wire within an overlapping time period. Such events can be reduced by carefully selecting node IDs. Additionally, when a node is conveying its ID by grounding the live wires, the fence is not capable of driving away an elephant if the latter touches the wire. The maximum inactive time depends on the largest node ID we use in the fence.

We design fence nodes to be attached to a selected set of fence posts so that the distance between two adjacent nodes is about 1 km. This selection of the distance between two nodes enable us to identify a unique 1 km segment in the fence where the breakage has occurred. A villager can visually observe the broken place within that segment to locate the actual breakage point. Reducing the distance between two nodes would increase the granularity of the breakage localization but increase cost due to the higher number of required nodes.

3.2 Pulse Detection

The pulse detector is a single component we attach to the fence from the end point where the energizer is located. It connects to both live and ground wires in the fence just like each fence node. Figure 3 shows the schematics of the pulse detector we use in our prototype. The ADC input pin of a low-power MCU is connected between the live and ground wires of the fence through a voltage divider. A few other components on-board provide protection for the MCU from reverse currents and at the same time minimize noises that can affect the detection of pulses.

The task of the pulse counter is to count the number of pulses that become absent in the live wire continuously, hence indicating a node ID. In order to keep track of the nodes, the pulse counter maintains an internal data structure which maps each fence node ID, its physical location and the time stamp of the last contact. At the beginning, the last contact time stamp is empty for all nodes. When a fence node wakes up and grounds the wire for a while, the pulse detector notices the missing pulses during that time period and keeps counting until the pulses reappear. Once the pulses become available again, the pulse detector can identify the node ID. The pulse counter then updates the relevant data structures, in particular the time stamp of the relevant fence node.

Even though each fence node wakes up at different random time periods, there is a maximum duration for a node to stay without communication. An absence of contact beyond that time period indicates a problem in the fence wire between the pulse counter and that fence node. The pulse

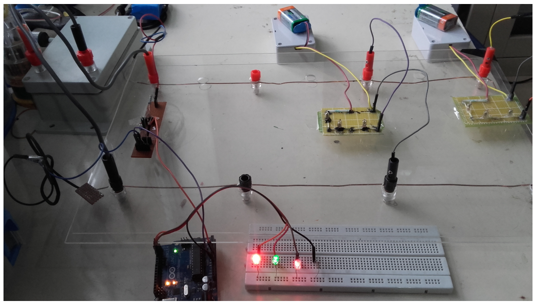


Figure 4: Basic hardware setup used to perform desktop experiments using two nodes for breakage detection.

counter is programmed to periodically go through the internal data structures and find nodes with missing contacts. Based on the locations of the missing nodes, we can point to the location of the fence where a breakage has occurred.

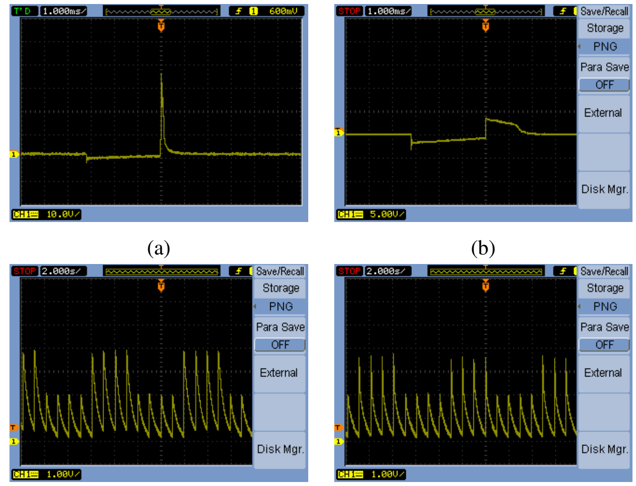
3.3 Probability of Collisions

As nodes wake up randomly and short-circuit the fence wires, we need to evaluate the probability that collisions occur, i.e., the times when two nodes or more short-circuit the fence wires overlap. When these times overlap, the pulse detector sees only one transmission and hence might miss transmissions or identify a transmission as from a different node. The latter happens when the overlapped duration has a length that corresponds to another node ID. In order to evaluate the probability of collisions, we perform Monte Carlo simulations. We assume that every node short-circuits the fence wires at least once to announce their presence within a time duration of six hours. For 10 nodes, collisions occur in less than 0.7% of the six hour periods. Note that more complex but efficient schemes are possible. For example, one could consider that whenever the pulse counter receives a message from the node that is the furthest away, it knows that there is no breakage even if a collision might have caused a missed transmission. We leave the optimization of the assignment of node IDs and transmission probabilities to future work.

4 Prototype Implementation

In order to explore the idea of communicating node IDs using fence pulses, we develop a fence prototype in a smaller scale that fits on to the top of a table. This prototype setup (see Figure 4) consists of two fence wires; a live and a ground wire. An energizer connected to the fence wires is inserting a high-voltage pulse with a width of 3 ms every 300 ms . For these experiments, we use a high-voltage pulse that reaches a maximum of 3500 V.

There are two nodes attached to the fence wires from two places with the hard-coded node IDs as 2 and 4. The AVR based MCU on each node is programmed to short the fence wires for a duration of 2 s and 4 s respectively at randomly selected points in time. The pulse detector attached to the fence counts the time durations where the fence pulses are absent indicating a shorted wire by a node. The duration of pulse absence directly relates to the specific node that shortened the wire which indicates that the fence wires are working properly up to that specific node. A LED indicator attached to the pulse detector displays the information about which segments of the fence wires are working and which are not.



(a) (b) (c) (d)

Figure 5: In (a), the original high-voltage pulse as seen from the oscilloscope is shown while (b) shows the pulse after shorting by a node. At the detector, (c) illustrates how the node ID 4 is detected which is smoothed further in (d).

Figure 5 shows the output of oscilloscope at various stages of the prototype setup. In Figure 5a, the original high-voltage pulse that is sent through the fence wire is picked from the oscilloscope after going through a voltage divider. When a node shorts the fence wire, the peak of the pulse decreases significantly as shown in Figure 5b. When the node with ID 4 encodes its ID to the fence pulses, the oscilloscope displays the output shown in Figure 5c. Further smoothing of the detection shows a better output as shown in Figure 5d.

5 Deployment Challenges

Our electric fence breakage detection system can identify and locate only certain types of breakages of the fence wires. In case of a breakage where the live wire and the ground wire touch each other, the fence stays grounded continuously. Then the pulse counter cannot identify the location of the breakage. In this case, the pulse counter can infer that the fence is not working properly and should be inspected manually. Additionally, breakages of the ground wire in the fence cannot be detected using our method.

6 Conclusion

In this paper we have presented a new system for breakage detection in electric fences used to protect humans habitats from elephants. In our system, an energizer regularly generates high-voltage pulses that are grounded by fence nodes that this way transmit their IDs to the pulse counter. Based on this information the pulse counter can identify where the fence is broken which makes fence maintenance more effective and cheaper compared to existing solutions.

Acknowledgment

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