Demonstration Abstract: Detecting and Localizing Border Crossings Using RF Links

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ABSTRACT

Detecting and localizing a person crossing a line segment, i.e., border, is valuable information in security and data analytic applications. To that end, we use the received signal strength (RSS) measured on RF links between nodes deployed linearly along a border as a border crossing detection and localization system. RSS measurements from any single RF link are noisy and prone to variations due to environmental changes (e.g. branches moving in wind). The redundant overlapping nature of the links between pairs of nodes in our proposed system provides an opportunity to mitigate these issues. We propose a hidden Markov model (HMM) which models the RSS on network links as a function of the neighboring nodes between which a person crosses. We demonstrate that the forward-backward solution to this HMM provides a robust and real time border crossing detection and localization system.

1. MOTIVATION

Knowing when people leave one region and enter another is an important piece of information in an age of increasing security and data analytics. A person illegally crossing a national border, a driver passing through an intersection, or a shopper entering a certain aisle in a store are examples of "border crossings," i.e., people moving from one region to another by crossing a line segment.

In this demo abstract, we present a method for detecting and localizing border crossings by measuring line segment crossings. A similar idea of using line segment crossings is shown in movies like *Entrapment*, *Ocean's Twelve*, and *The Return of the Pink Panther* where if a thief breaks a laser's beam it sets off an alarm. Instead of lasers, we propose using received signal strength (RSS) measurements from a wireless RF link to detect line segment crossings. As in [1, 3, 2], we use a radio link as a *link line*, i.e., the line segment between transmitter and receiver, to detect crossings.

It is possible to detect link line crossings from the changes in RSS when a person is near the link line. When the power on a wireless link is concentrated in the line of sight multipath component, the RSS measurements will vary considerably when a person is near or on the link line but will vary little when he is far away. However, when the power of a wireless link is not concentrated in the line of sight multipath component, the RSS measurements can fluctuate considerably when a person is far from the link line and be relatively unaffected when a person is on the link line. Figure 1 demonstrates this phenomenon.

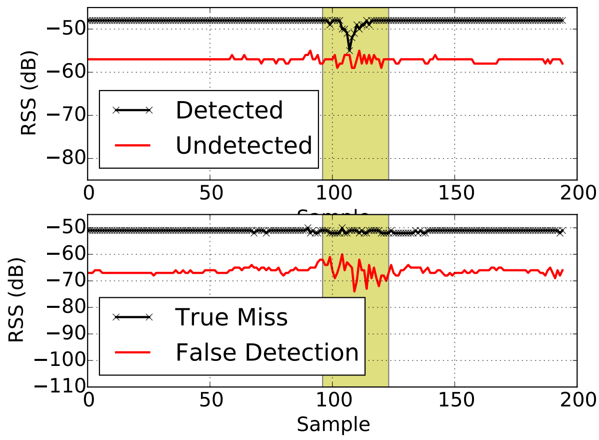

Figure 1: (top) Shaded region shows an actual crossing period. One link detects the crossing and the other link does not. (bottom) The shaded region shows a period where one link detects a crossing that did not occur while another link accurately detects no crossing.

In this demo abstract, we propose overlapping these link lines thereby gaining the ability to not only detect border crossings, but to localize where the crossing occurred. Compared to using individual link lines, our system is a more robust solution to the adverse effects of noise and environmental effects. In our system, link lines are overlapped by placing N nodes along the border, as is shown in Figure 2. Between each pair of neighboring nodes is a "short segment." These short segments break up the longer border into shorter segments and can be thought of as states in a border crossing. The state indicates on which short segment the person is currently located: either he is on one of the $N-1$ short segments, or he is not present anywhere along the border. One person is assumed to cross at a time. An example of how the states of the border crossings evolve over

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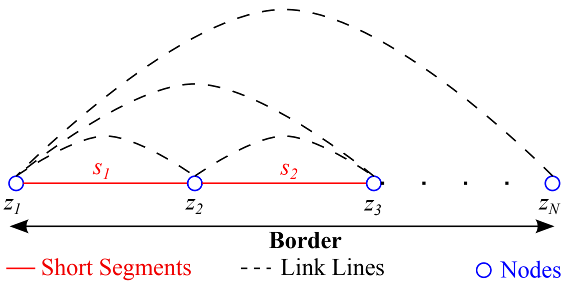

Figure 2: Border crossing system with N nodes. Short line segments are created between neighboring pairs of nodes. Link lines are curved in this figure for visual purposes only. In practice, the link lines are viewed as line segments with the nodes as their endpoints.

time is shown in Figure 3.

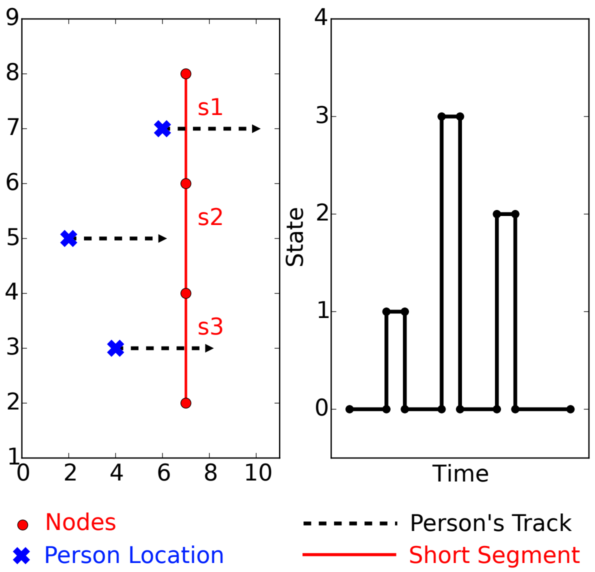

Figure 3: (left) Track of three people. (right) True crossing states as a function of time.

The way the states evolve over time lends itself well to using a hidden Markov model (HMM). In a HMM, we cannot observe which segment, if any, is being crossed; but we do observe the RSS vector measurements. This vector measurement changes in a probabilistic way based on the true state. The HMM allows us to use the probabilistic dependencies, i.e., the emission probabilities, between the RSS measurements and the states to detect the true state. In this demo, we use the forward-backward algorithm to estimate the current state.

An element of important consideration is that the emission probabilities are influenced by the environment in which the border is located. The wireless links situated in an outdoor environment will experience different fading patterns than links placed in an indoor environment. In an effort to make the setup of a border crossing system as straightforward and time-efficient as possible, we define emission probabilities for a given link line as a function of the statistics of the RSS while the border is vacant. As a result, the system presented in this demo abstract develops all necessary components of the HMM in real time with only a brief training period. We show an example of the real-time output of the HMM as a person crosses a border in Figure 4.

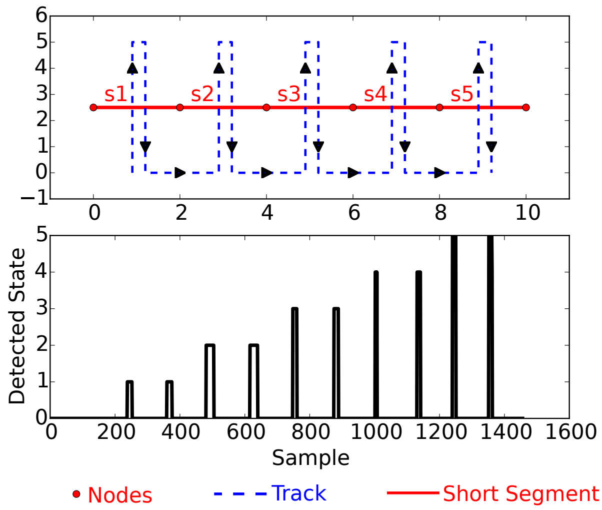

Figure 4: (top) Actual track. (bottom) Forward-backward algorithm output for the track.

2. DEMONSTRATION

To demonstrate this system, we deploy battery-powered nodes as is shown in Figure 2. The nodes are placed on podiums at a height of one meter. An additional node overhears the communication between the nodes and logs the RSS measurements from the wireless links on a laptop. The RSS measurements are then sent to a HMM which outputs the most likely state in real time.

A participant will be invited to cross between any pair of nodes. As the participant crosses the border, spectators will be able to see a graphical representation of the border. The short segment detected as crossed by the forward-backward algorithm will be highlighted. The highlighted segments will demonstrate that the system presented in this abstract can detect and localize border crossings.

3. ACKNOWLEDGEMENTS

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4. REFERENCES

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