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RF-based Traffic Detection

By

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Abstract:

Road traffic congestion estimation is a critical function that affects both developed and developing countries alike. In this paper, we present Monitor as a novel RF-based traffic detection system capable of detecting the existence of objects, i.e. vehicles or humans within the area of interest. Compared to the current approaches for traffic estimation, Monitor is low-cost, does not disrupt traffic during installation, works for non-laned traffic, and does not require active user participation. Our approach is based on the fact that the presence of an object in an RF environment affects the signal strength, and hence can be used for detecting objects.

We present the Monitor system architecture and how it uses statistical techniques, based on the mean and variance of the received RF signal strength, to detect the presence of objects. Implementation of Monitor on standard RF equipment shows its capability of detecting the presence of objects with high accuracy highlighting its promise for different vehicle-related applications, surveillance applications, border protection against illegal crossing , intrusion detection security systems and many other applications.

Keywords:
Traffic congestion, wireless signal and object detection

1. Introduction:

Traffic estimation is an important problem that affects different aspects of the social, ecological, and economical aspects of a society. Clearly, a system for traffic congestion

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estimation can have an impact on different aspects of the society. A number of systems over the years have been proposed for congestion estimation. These systems can be categorized into two groups: infrastructure-based and distributed approaches.

Infrastructure based techniques include loop detectors [1], magnetic sensors [2], acoustic sensors [3], and computer vision techniques [4]. These systems have the advantage of not depending on input from the users. However, they require special hardware to be installed at the points where cars are to be detected. In addition, some of them do not work for non-laned traffic, which is the norm in developing countries, and may disrupt traffic during installation. On the other hand, distributed estimation techniques depend on sensors attached to the cars or the users. For example, the Mobile Millennium project [5] depends on GPS-enabled cars or high-end phones with users to detect congestion. Other systems depend on the data collected by the cellular provider, e.g. [6]. These systems have the advantage of not requiring special infrastructure to operate. However, they suffer from the limited availability of cars and high-end phones with GPS receivers, which is even worse in developing countries.

In this paper, we present Monitor as a novel RF-based traffic detection system. Monitor is based on the fact that the presence of objects in an RF environment affects the received signal strength in different ways based on their size, material and/or geometry, and hence can be used for detecting objects in an area of interest, i.e. vehicles and humans. Monitor depends on applying statistical techniques to the received signal strength to detect the presence of objects in an area of interest. Other than the traffic estimation applications, object detection has many other applications including, but not limited to object tracking for security reasons, border protection , intrusion detection, surveillance and localization applications. Evaluation of Monitor in an actual environment shows a good probability of detection of objects using nominal RF equipment.

The remaining of this paper is organized as follows. Section 2 presents the design of Monitor. Section 3 shows our testbed and evaluation results. Finally, we conclude the paper and give directions for future work in Section 4.

2. THE Monitor SYSTEM

In this section, we give the details of Monitor and how it leverages the received signal strength for object detection. We start by giving an overview of the system and principals of operation followed by the details of the detection process.

a) System Overview

Our system is based on the fact that RF signals are affected by changes in the environment [7]. The existence of an object within the wireless signal coverage affects the received signal strength (RSSI) based on the object's size, geometry and material

making it possible to detect the object existence. The RSSI experiences significant temporal and spatial variability. The spatial variability is caused by the multi-path effect and changes of distance between the transmitter and receiver. The temporal variability is caused by the movement of objects within the signal range.
Figure 1 shows the raw RSSI for three cases: silence, car, and human based on real experiments. The figure shows that both the human and car lead to changes in the mean RSSI.

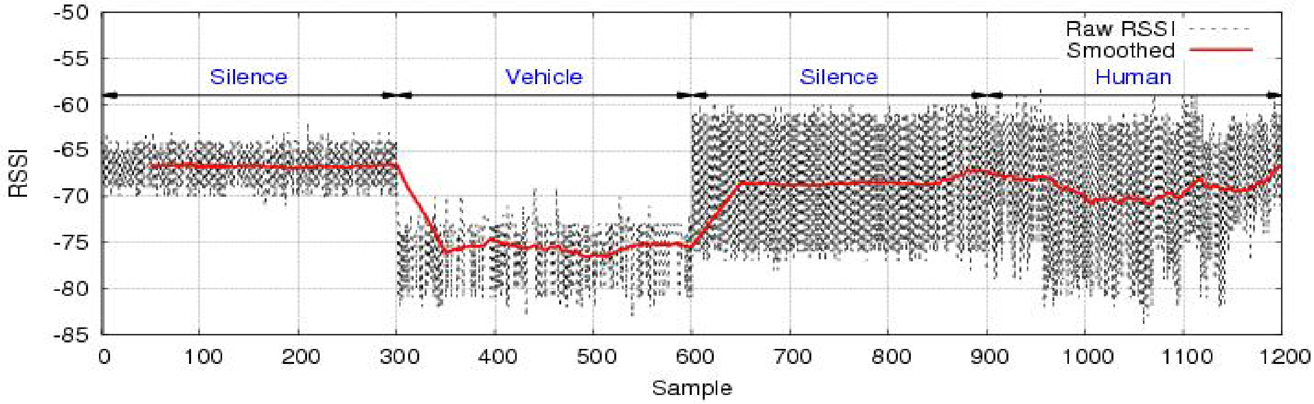


Figure (1): *Raw RSSI readings, mean, and variance for the three cases of silence, human, and car presence.*

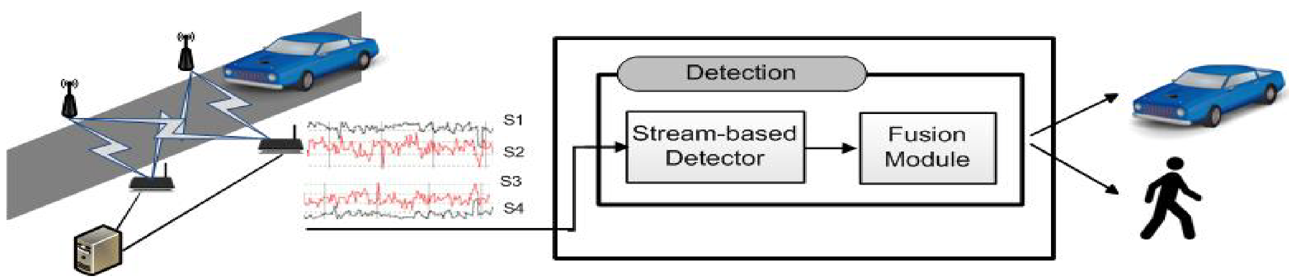


Figure (2): *Monitor system architecture.*

Monitor leverages this behavior to detect different objects as shown in Figure 2. The installed nominal RF equipment sends periodic RF frames that are received by the other nodes and whose RSSI is recorded. These streams are then processed by the detection module to detect the presence of an object. The next subsection gives the details of the detection module.

b) Object Detection

The RSSI pattern in silence periods is stabilized around an average value with some noise and fluctuation (Figure 1). The existence of an object affects the RSSI pattern causing it to shift up or down, based on the constructive of destructive interference of the multipath effect induced by the object's presence. Therefore, for detecting the existence of an object within an area of interest, Monitor compares two moving averages of the RSSI of a single stream with different window sizes. The intuition is to compare the long term signal behavior, representing the static environment, to the short term behavior, representing the current state. If there is significant change, based on a threshold, then an object is detected.

More formally, let Si represent the RSSI sample i from one wireless stream. The long term ($\alpha_{l,k}$) and short term ($\alpha_{s,k}$) averages are defined as follows for time index k:

$$\alpha_{l,k} = \frac{1}{w_l} . \sum_{i=k}^{k+w_l-1} S_i \qquad (1)$$

$$\alpha_{s,k} = \frac{1}{w_s} . \sum_{i=k+w_l}^{k+w_l+w_s-1} S_i \qquad (2)$$

where w_l and w_s are two parameters representing the long and short window sizes respectively.

When the relative absolute difference between the two averages, $\alpha_{l,k}$ and $\alpha_{s,k}$ exceeds a threshold Ʈ , Monitor detects an object at time $t = k + w_s$. Figure 1 shows the effect of applying the moving average technique to the raw RSSI values.

The figure shows that the moving average technique can detect the presence of objects with high accuracy (spike above the threshold). However, there are some false positive and negative cases due to the signal noise. To further reduce this noise, Monitor uses two techniques: time latching and stream fusion.

The idea behind the time latching technique is to wait for the signal to become positive or negative for a certain time before the signal is considered above/below the threshold. This way, instantaneous fluctuations due to noise will not affect the overall accuracy.

Since each stream is noisy by itself, Monitor adds a fusion step that combines the detection output of the individual streams for better detection accuracy. This is based on a new parameter (N) that represents that number of concurrent streams voting for detection at the same time to declare a global detection.

c) Discussion

In the operation phase, after collecting RSS readings, the event detection module uses the moving average technique to detect the existence of an object.

Detection			
w_l	w_s	Ʈ	N
50	15	0.01	3

Table (1): *Default Values For The Different Parameters.*

3. Evaluation

In this section, we evaluate the performance of Monitor in an actual testbed. We start by describing the testbed followed by the evaluation results for the detection module. To show the feasibility of Monitor, we assume a single object, i.e. a human or vehicle existing in the area of interest, and leave the cases of multiple objects for future work. Table I summarizes the default values for the different system parameters.

a) Testbed

Figure 3 shows the experimental testbed. We used two Cisco Aironet 1131AG series access points (APs) to represent the transmitting units and two Dell Latitude E6510 laptops with Intel Centrino N 6200 AGN wireless NIC to represent the monitoring points (MPs). Each of the MPs records the RSSI from each AP leading to four streams of raw data for processing.

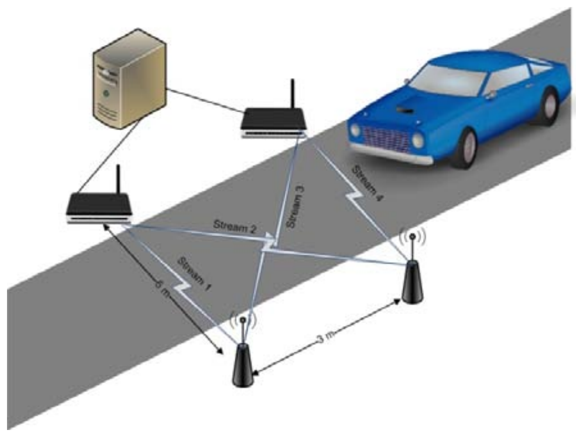


Figure (3): *Experiment layout.*

b) Data Collection

As discussed in Section II, we use the Received Signal Strength Indicator (RSSI) as the raw values. In the infrastructure mode of the 802.11 protocol (WLAN/WiFi), APs broadcast beacons typically every 100 ms. When a frame is received by a card, it not only extracts and supplies data to the higher layers, but also notes the RSSI values which are reported in the header of the link layer frame [8].

We have a total of 30 experiments representing three cases: silence period (10 experiments), a human entering the area of interest (10 experiments), and a car entering the area of interest (10 experiments). For each case, 600 samples are collected.

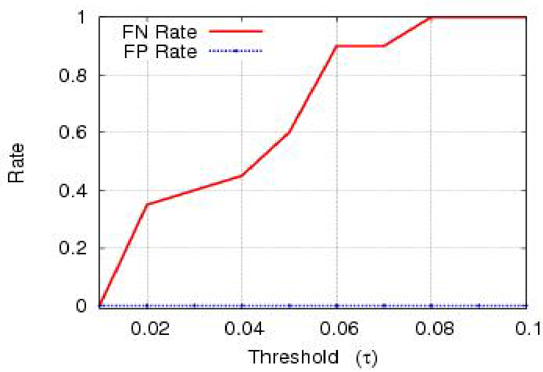
c) Evaluation Metrics

We use two metrics to quantify the performance of Monitor detection and identification:

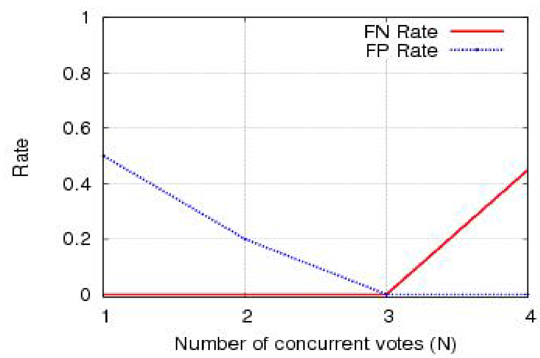
- *False negative rate:* For detection, this is the number of times the system misses the recognition of an object.

d) *False positive rate:* For detection, this is the number of times the system incorrectly identifies a silence period as an object.***Detection Results***

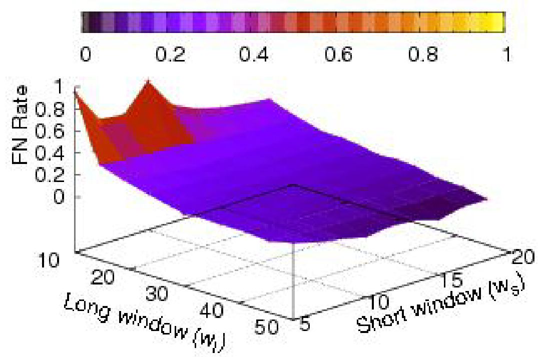
*I*n this section, we evaluate the effect of the parameters on the performance of the detection module: the threshold (τ), window sizes (w_l and w_s), and the number of concurrent streams required for detection (N).



(a) Threshold



(c) N



(b) Window Size

***Figure (4):** Effect of different parameters on the moving average detection technique.*

Figure 4 shows the results. The figure shows that as we increase the detection threshold, i.e. impose more constraints on the detection, the false positive rate remains at zero while the false positive rate decreases. We note that we can achieve both probability of detection equals one and zero false positive rate concurrently for $\tau = 0.01$.

For the effect of the window sizes, Figure 4(b) shows that a small long window (w_l) fails to capture the long term behavior, i.e. silence. A value for $w_l = 50$, $w_s = 15$ lead to both probability of detection equals one and zero false positive rate concurrently.

Finally, increasing the number of concurrent streams voting for detection (N) imposes more constraints on the detection process, leading to reduced false positive rate and increased false negative rate. A value of N = 3 leads to an optimal performance of probability of detection equals one and zero false positive rate.

4. Conclusions:

We presented Monitor as an RF-based traffic detection system. Monitor depends on the fact that the presence of objects in an RF environment affects the received signal strength based on the object properties. We presented the Monitor system architecture and the moving average and for detection of objects. Evaluation of Monitor in a real testbed shows that it can achieve accurate detection with zero false negatives and positives concurrently.

This paper showed the feasibility of Monitor as a traffic estimation system that is low-cost, does not disrupt traffic during installation, works for non-laned traffic, and does not require active user participation. Currently, we are expanding Monitor in different directions including larger scale experiments, identifying other properties such as the number and speed of objects, and experimenting with other RF technologies.

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