

Crowd monitoring and city sensing techniques supported by next generation mobile networks

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1. Introduction

In the aftermath of the COVID-19 pandemic, social distancing measures have reshaped our world, relegating public gatherings to a distant memory. Even as we move beyond the pandemic, limitations on the size of gatherings persist, making **crowd control** a paramount concern. The return of these mass gatherings brings with it the dual challenges of **security threats** and the potential for overwhelming foot **traffic congestion**.

2. Realistic generator of probe request traces

We addressed the problem of people counting and crowd monitoring leveraging WiFi probe request messages sent by smart devices carried by people on the move. Our first step was the analysis in [2], where we analyze in detail the behaviour of probe request messages and how different device vendors implement MAC address randomization techniques.

We propose a first-of-a-kind probe request generator (Fig. 1) which emulates in details real-world behavior patterns observed in our work [2]. The traces produced by our generator serve as the ground truth dataset for fine-tuning machine learning algorithms, specifically designed to quantify a crowd size. All the detail can be found in [1], and the code in a public GitHub repository [3].

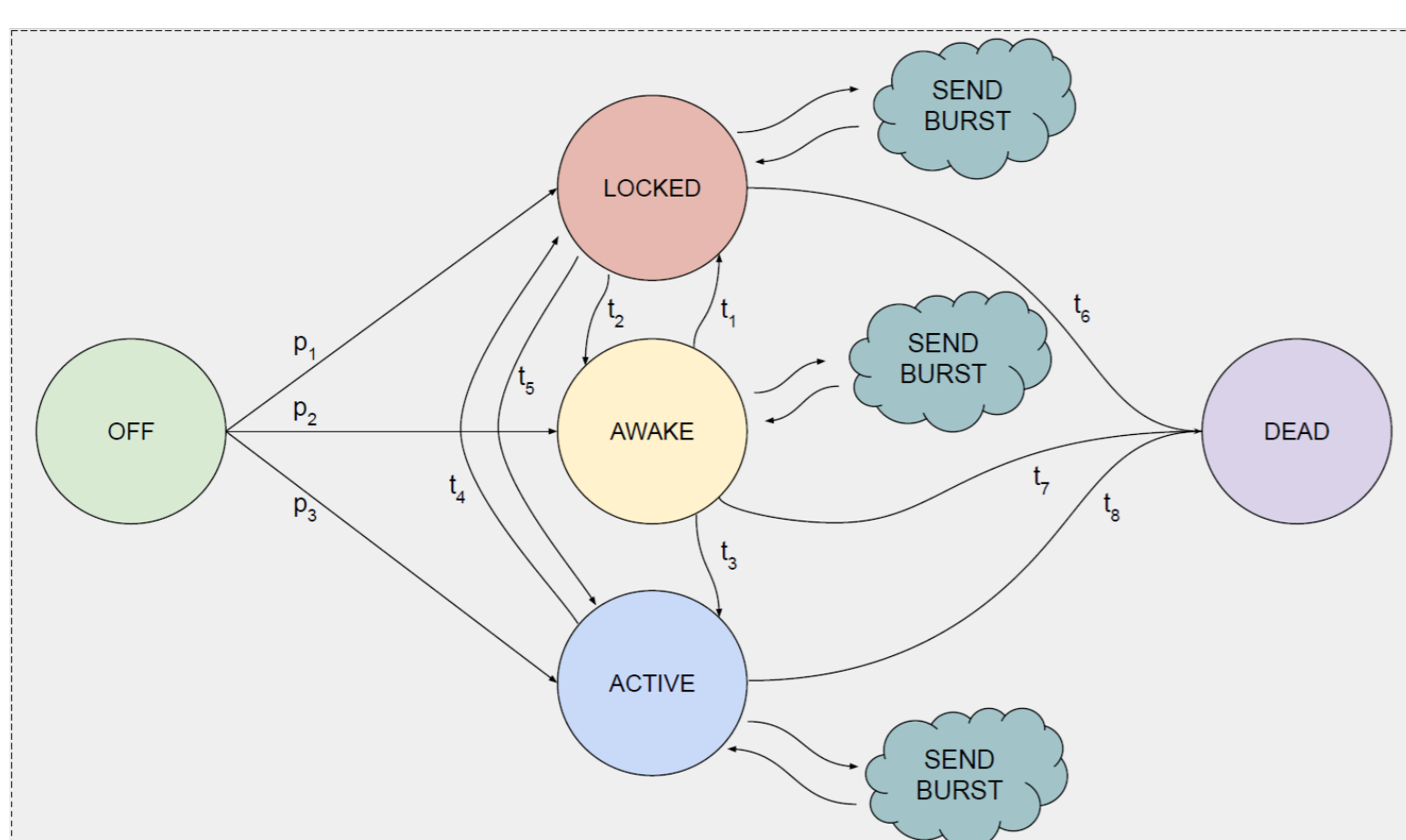


Figure 1. State-machine diagram of our probe request generator

3. Privacy-aware crowd monitoring

In [1] we presented, also, a novel crowd-monitoring technique that effectively utilizes probe request messages in conjunction with Bloom filters. By leveraging the formal deniability property, called γ -deniability, we demonstrate that introducing an anonymization noise and considering a γ equal to 1 we can preserve users' privacy, making our solution GDPR compliant.

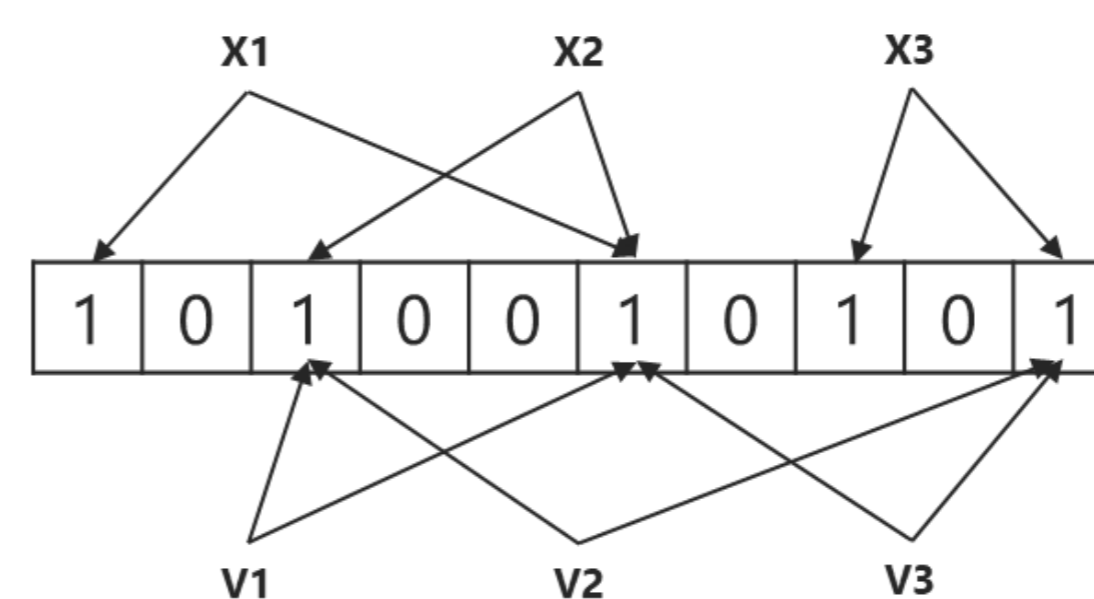


Figure 2. Bloom filter with hiding set.

4. Crowd monitoring hardware

Additionally, we have created an affordable, standalone and environmentally friendly method for monitoring crowd flows in diverse settings. Within the Raspberry Pi, a script pipeline captures probe requests, processes them using a clustering algorithm, and generates both a count and a Bloom filter for subsequent flow analysis.

Figure 3. Hardware solution composed of a Raspberry Pi 4 Model B, a USB WiFi dongle, and a USB LTE modem, all inside a waterproof case.



5. References

1. R. Rusca, A. Carluccio, D. Gasco and P. Giaccone, Privacy-Aware Crowd Monitoring and WiFi Traffic Emulation for Effective Crisis Management, IEEE ICT-DM 2023
2. R. Rusca, F. Sansoldo, C. Casetti, P. Giaccone, What WiFi Probe Requests can tell you, IEEE CCNC 2023
3. <https://github.com/riccardo-rusca/ProbeRequestGenerator>