# Poster: Synchronizing Spectral and Protocol Analysis for Complementary Troubleshooting of Wireless Standards

Dr. Vineeta Jain[a,b], Jakob Wicht[a], Ulf Wetzker[a] and Dr. Andreas Frotzscher[a]
[a]Fraunhofer Institute for Integrated Circuits, Division Engineering of Adaptive Systems EAS Dresden, Germany,
[b]LNM Institute of Information Technology Jaipur, India

## Abstract

The popularity of wireless networks is increasing swiftly in industrial manufacturing and automation. Although the technology is evolving rapidly, the transmission failures arising due to unfavourable signal propagation conditions and interference from co-existing networks are often difficult to diagnose. This may result in malfunctioned applications and Quality-of-service (QoS) deterioration. This work aims to augment the root cause analysis of such failures by synchronizing the records of spectral and protocol domains to complement precise information about a link with detected cross-standard interference and use it for further troubleshooting. We present the results of experiments performed on Wi-Fi as a proof of concept for the proposed approach.

## 1 Introduction and Motivation

The essential advantages of wireless networks in terms of flexibility and mobility have made them ubiquitous and indispensable in automotive, IIoT, military and production applications that have reliability and strict latency requirements. However, due to the presence of path loss, multipath propagation and interference from different communication systems co-existing in same frequency band, these applications suffer from serious degradation in Quality-of-service (QoS). This can lead to system failures and even economic losses due to delays in tightly coupled production processes, e.g. in the semiconductor or automotive industry.

To perform the root cause analysis for QoS degradation, the most common solution includes analysis of packet capture (pcap) files using analysis softwares like Wireshark, known as protocol-layer analysis. Although such analyses provide a deep insight into the network stack of the communication partners, the underlying physical causes remain unknown. To gain deeper insights into the physical layer, spectrum analysis offers significant advantages. It enables cross-technology analysis and detection of interference between different RF-Standards. Packet collisions of several competing transmitters can usually not be demodulated by the receiver, but can be detected in the spectrum as a clear overlap [4]. In contrast to protocol layer analysis, spectrum analysis provides very precise temporal information about the reception strength of a transmission, but does not provide any information about its content. Complementing the cross-RF-standard interference detection of the spectral domain with the MAC-Layer information from the protocol capture enables a user-friendly and in-depth investigation of QoS degradation problems [3].

Imperfections and errors within the receive chain of both methods complicate the synchronization of spectral and protocol traces. The first and foremost reason includes bursty packet losses in protocol-layer capture due to computer expansion bus (e.g. PCIe or USB) congestion, insufficient SNR (Signal-to-noise ratio) and high CPU load. In addition, the receive timestamps of the individual frames within the pcap file are assigned by packet analyzer operating in user space instead of the hardware, leading to considerable inaccuracies, resulting in compression of the packet spacing and jitter of the timestamps. Due to the above-mentioned reasons, a sophisticated algorithm is required to perform synchronization between both the domains.

The synchronization of spectral and protocol domains can be envisaged as a time-series analysis problem as in both the cases the sequence of data is ordered by time. In this paper, we propose to use well-established Dynamic Time Warping (DTW) method for sequence alignment between packets captured from both the sources. DTW takes into account temporal distortions like variable length and time delay, and applies non-linear mapping of one sequence to another to determine an optimal match [1]. It computes minimal warp path on an element-wise cost matrix calculated by using dynamic programming. The synchronization of spectral and protocol traces not only can be used for determining high-precision timestamps for root cause analysis of QoS degradation, but can also aid in RF-fingerprinting. To the best of our knowledge, we are the first ones to explore the concept of synchronization of spectral and protocol domains for the root cause analysis of transmission failures. In principle, this method of synchronization works with different wireless standards. In this paper, we performed all experiments for Wi-Fi as proof of concept.

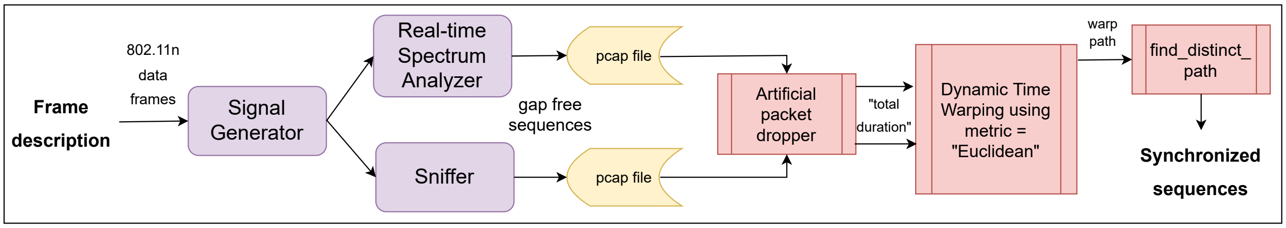


**Figure 1. Hardware and Software setup used for the proposed model**

**Table 1. Accuracy obtained for 10% packet drop**

| IFS | Loss in one source | | Loss in both sources | |
|---|---|---|---|---|
| | BS $< 5$ | BS $\geq 5$ | BS $< 5$ | BS $\geq 5$ |
| $1ms$ | 97.48% | 92.5% | 84.14% | 11% (BS=13) |
| $0.5ms$ | 97.49% | 88.33% | 57.79% | 4.9% (BS=15) |
| $0.025ms$ | 85.43% | 78.8% | 62.42% | 36.9% (BS=7) |

## 2 Method and Experiments

A labelled reference dataset is created for performing time series analysis using DTW. To generate frame sequences, a Rhode & Schwarz®SMBV100B vector signal generator is used in combination with Ellisys Bluetooth analyzer (to capture spectrum) and Sniffer (to capture protocol traces). For creating the reference dataset, we developed a control software for signal generator and connected all the devices using coaxial cables for improving SNR and avoiding interaction with external networks. A predefined sequence of 80,000 IEEE 802.11n data frames is generated at a center-frequency 5.5Ghz. We collected samples for different IFS ($1ms$, $0.5ms$ and $0.025ms$) and manually identified a gap-free sequence of packets from the captured sequence. For creation of test dataset, artificial packet drop using statistical distribution (gaussian) is introduced in reference dataset taking into consideration the frame parameters in real life scenario. Figure 1 shows the hardware and software setup used for creation of reference and test dataset.

Out of the various parameters present in spectral and protocol traces, we use the *total duration of the frame* (`wlan.duration`) as a feature for performing DTW using `euclidean distance` as a metric. The output generated by DTW is a warp path, i.e. matching pairs of frames from both the sequences. DTW may match a frame from one sequence to multiple frames of the other sequence, which is not the case in real life. Every frame of spectral trace should uniquely match with a frame in protocol trace. Therefore, we introduce a new module known as `find_distinct_path`, which identifies a unique optimal warp path from the generated one based on the cost matrix.

## 3 Results and Discussion

The proposed synchronization model is evaluated by running it against generated and labelled test dataset. We tested it against 10,000 packets with the packet drop rate from 0 to 10% with a burst size (BS) within the range $[1, 15]$. Table 1 shows the accuracy obtained for 10% packet drop. As shown in Table 1, the proposed approach performs really well for all cases when the packet loss is only present in one of the sources. Notably, when packet loss is present in both the sources and BS is also high, accuracy drops miserably. Thus, DTW is only efficient when either one of sources provides a perfect sequence of received packets or the BS $< 5$. The strongly decreasing synchronization capability of this method for longer burst errors is most likely due to the missing anchor points within the sequences. A significant improvement can be achieved by including an estimation of missed packets based on sequence analysis [2]. A further improvement is possible with the help of multi-level synchronization, where the first-level includes coarse-grained synchronization with very characteristic packets within the sequence and the second-level includes a fine granular synchronization within smaller sections. In this way, shifts within the protocol sequence due to burst failures can be reduced. As an avenue for future research, we envision to extend the presented work.

## 4 Conclusions and Future Work

In this poster, we proposed a model based on DTW to perform synchronization of spectral and protocol domains. Reference and test datasets are generated for evaluating the efficiency of the proposed model. The initial experiments conducted for synchronizing the spectral and protocol traces of Wi-Fi delivered promising results. In future, we aim to improve the proposed model by considering multiple features, weights and levels for synchronization.

## 5 Acknowledgements

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