mmSplicer: Toward Experimental Multiband Channel Splicing at mmWave Frequencies

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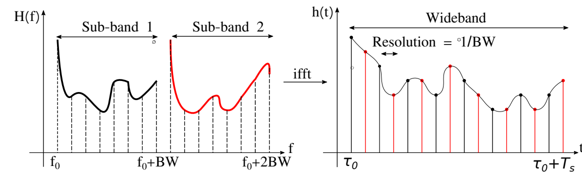
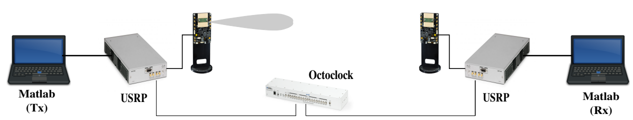
***Abstract*—Joint communication and sensing (JCAS) and wireless sensing in general are gaining ever more attention in the research community. In general, wide-band sensing is required for high accuracy of the obtained distance measurements. However, wide-band sensing requires comparably expensive hardware (in terms of invest as well as energy consumption). As a solution, channel splicing has been developed for wide-band sensing using multiple narrow-band measurements. Despite many theoretical concepts, channel splicing at mmWave frequencies is still widely unexplored. In this paper, we present mmSplicer, which extends a splicing algorithm from the literature. We implemented mmSplicer in an SDR-based testbed for channel splicing at mmWave frequencies. First validation results show very high accuracy of the channel impulse response (CIR) in time domain.**



(a) Sub-bands and full band



(b) mmSplice prototype

Figure 1. Illustration of the channel splicing concept and the mmSplice setup.

I. Introduction

Joint communication and sensing (JCAS) is an important technology relevant for both 6G and Wi-Fi7, with a primary focus on leveraging communication signals to support high-precision sensing application. Wi-Fi relies on channel state information (CSI) to characterize the multipath propagation channel. While a precise estimation of multipath component (MPC) parameters may not be critical for communication systems, where channel estimation primarily serves equalization purposes, it is particularly needed for sensing tasks, such as gesture detection [1], [2]. Achieving high-accuracy MPC parameter estimation demands a substantial bandwidth, translating to a high-resolution channel impulse response (1/bandwidth). However, hardware components supporting such bandwidths or high sample rates are costly and energy-inefficient.

A possible solution to extend the bandwidth without increasing the sampling rate is provided through multiband splicing. Multiband splicing merges multiple narrow-band subband measurements, in the range of tens of megahertz, to obtain, ideally, the same results as generated by a single wide-band measurement, as sketched in Figure 1a. This technique has drawn a lot of attention recently, with a few algorithms being developed addressing the issues of hardware distortions [3]–[6]. Nonetheless, existing work such as [7] focuses at low frequencies (i.e., 2.4/5 GHz), which are becoming even more congested. The ideal approach would involve making use of existing infrastructure and exploiting the available bandwidth offered in the mmWave frequency band. However, the main challenge of the high frequencies (e.g., 60 GHz) is the coherence time, which reduces for instance by a factor of 30 for a mobility speed of just 2 m/s. In the context of splicing, this requires reducing the number of narrow-band measurements (at most 50%) and still estimate the wide channel accurately.

In the following, we present *mmSplicer*, a 60 GHz channel sounder (see Figure 1b), integrating a two-stage multiband splicing technique that aims at characterizing the wide channel by using only 50 % narrow-band measurements to address the critical issue of coherence time.

II. Splicing Algorithm

This section presents a two-stage multi-band splicing algorithm, which reconstructs a high-resolution channel impulse response (CIR) from narrow-band measurements. The algorithm is an extension of the orthogonal matching pursuit (OMP)-based multiband splicing technique presented in [5]

Stage I: Clusters identification: The algorithm employs the estimated CIR from one narrow-band sample to identify *clusters*, each consisting of strong multipath components in close proximity (up to two samples apart). The strong components are identified as having magnitudes above a magnitude threshold from the 97th percentile. The clusters and their delays provide an first glance of the full channel CIR.

Stage II: Multi-band splicing: Now, the channel frequency response (CFR) samples acquired over multiple narrow-band measurements are combined into a vector. The sparse nature of the CIR is exploited and a sparse recovery algorithm is leveraged to obtain the wide bandwidth CIR. Specifically, we use OMP [5], which is an iterative grid based algorithm. We utilize the number of strong multipath components computed in the first stage, as a stopping condition to the OMP algorithm to estimate *additional* paths that fall into the clusters identified in the first stage. Compared to the alternative algorithms, OMP is well known for its low complexity.

III. Experiment Setup

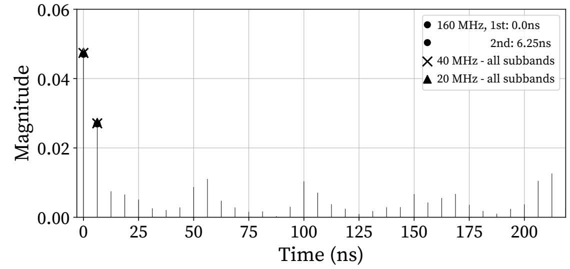
mmSplicer makes use of USRP software defined radios (SDRs) (e.g., X310) to perform the over-the-air communication, and MATLAB for the software implementation. We are particularly interested in orthogonal frequency division multiplexing (OFDM) waveforms used for JCAS. Therefore, the implementation follows the IEEE 802.11ac standard, with signal bandwidths of 20, 40, 80 and 160 MHz and subcarrier spacing 312.5 kHz. Sivers Semiconductor phase array antennas up-convert signals to 60 GHz. Clock synchronization is crucial especially in high frequencies [8]. For this initial validation, we use an external synchronization source (Octoclock) for this purpose. mmSplicer prototype is illustrated in Figure 1b.

We utilize MATLAB to generate and post-process the data, and UHD drivers to transmit/receive the signal. During post-processing, the time and carrier frequency offset are estimated and compensated per each received packet. The channel parameters (CIR and CFR) are estimated using the least square (LS) estimation technique. The estimation is performed using the legacy long training field (L-LTF), which is characterized by a repetitive pattern of the IEEE 802.11a LTF. Finally, the signal is decoded and demodulated. Channel estimation is performed using the frequency domain approach of the LS estimation technique. The frequency-domain approach acquires the CFR as $\hat{H} = Y./X$, where Y are the received samples, $\hat{H}$ is the CFR and X are the transmitted samples.

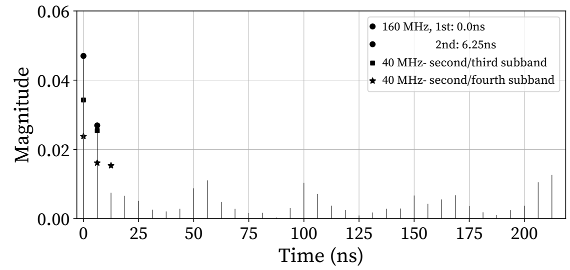
IV. Validation Results

All measurements at 60 GHz mmWave are conducted in a 12 m hall with aligned phased array antennas ensuring line-of-sight (LOS) communication. A 160 MHz signal is transmitted, and the channel estimation is performed in the receiver using the L-LTF. We exploit the recurring pattern of the L-LTF to emulate $4 \times 40\,\mathrm{MHz}$ and $8 \times 20\,\mathrm{MHz}$ narrow-band signals. We apply the two-stage splicing method on these measured subbands. The results are presented in Figure 2a, along with the full 160 MHz CIR (ground truth). The 160 MHz CIR reveals two strong MPC (the line of sight (LoS) path and a reflection at 6.25 ns). Additional low-energy spikes throughout the CIR are a consequence of filtering and we consider them as noise. Due to the low resolution, a single 20 MHz or 40 MHz bands would not distinguish the reflection component. Figure 2a illustrates that applying the algorithm across all narrow subbands (20 MHz and 40 MHz) yields highly accurate estimations of the strong paths in terms of amplitude and time delay.

We further explore the splicing performance applying it only to 50 % of the subbands. This significantly accelerates the time over which the devices jump at different center frequencies to acquire narrow-band measurements. We explore the two-stage algorithm across two 40 MHz configurations (see Figure 2b). The results show that the algorithm can consistently estimate the two nearby paths, across the two configurations. Addressing amplitude estimation offset in future work.



(a) Applied over all 20 MHz and 40 MHz subbands



(b) Using only 50 % of the 40 MHz subbands.

Figure 2. Estimated 160 MHz CIR using the proposed two-stage algorithm.

V. Conclusion and Future Work

We presented mmSplicer, a practical channel sounder that employs a two-stage multiband splicing technique. mmSplicer allows utilizing only 50 % of the narrow-bands to estimate the wide channel, thus, addressing the issue of the channel coherence time at 60 GHz. We validate the proposed two-stage multi-band splicing technique under ideal conditions, without hardware distortions. Our preliminary results are promising and lay a strong foundation for future optimization. As next steps, we aim addressing hardware distortions and synchronization issues, as well as compensating the amplitude offset.

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