Multipath Parameter Extraction in 5G-NR Multi-cell Network Using Interference Cancellation Method

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Abstract—Passive channel sounding in live cellular network, where downlink signals of in-service base stations (BSs) are acquired to extract multipath propagation parameters, has attracted great interest from academia and industry in recent years. In this work, downlink signals of live 5G new radio (NR) multi-cell BSs were measured with a recent home-developed multi-antenna passive channel sounder. It was found out that the performance of multipath parameter extraction algorithm is severely affected by the existence of many interfering neighbor cells (which share the same frequency band as the serving cell) in the multi-cell measurements. For this reason, a novel algorithm based on the interference cancellation principle is proposed, which can effectively mitigate the impact of multi-cell interference and thus improve the parameter extraction performance. The effectiveness and robustness of the proposed algorithm is finally demonstrated by the passive channel sounding campaigns in live 5G NR multi-cell cellular network.

I. INTRODUCTION

Radio channel modeling is of key importance for network design, performance evaluation and system enhancement. Massive channel sounding campaign in real-world deployment scenarios is essential to develop accurate, reliable and representative channel models. For example, the standard 3GPP channel models are based on the geometry-based stochastic channel modeling (GBSC) framework, where its large-scale parameters and small-scale parameters should be determined based on channel data collected in reliable channel measurements in various deployment environments [1]. Roughly speaking, the main category of channel sounding contains active and passive channel sounding platforms. In the active sounding scheme, dedicated channel sounding hardware and sounding signals can be designed for the transmitter (Tx) and receiver (Rx). For example, popular active channel sounders can be time-domain channel sounder using correlative channel sounding principle [2], or frequency domain channel sounders based on Vector Network Analyzer (VNA) [3]. Active channel sounders are popular due to its flexibility in hardware and algorithm design [4], [5]. However, it is unable to capture the channels between the in-service BSs and mobile terminals.

Passive channel sounding, on the other hand, aims to measure the downlink signals of the in-service BS and extract the propagation channel parameters directly. Therefore, BSs in live network are used as the transmitter directly, while home-made receiver should be developed to demodulate the downlink signals from the BS for passive channel sounding. Passive channel sounding is attractive, since it measures directly the radio channels between the BSs and UEs in real-world deployment scenario, which is essential to achieve digital twin of the electromagnetic environment and virtual drive testing concept [6]. Passive sounding has been adopted in the early universal mobile terrestrial system (UMTS) network [7] for measuring channel parameters including delay, Doppler frequency and path loss (PL). In [8], [9], the passive sounding campaigns are conducted under the long term evolution (LTE) network to measure channel parameters, e.g. delay, K-factor, PL, and spatial correlation. Nowadays, passive sounding is important to explore the 5G channel characteristics due to the wide coverage of 5G commercial network [10]. With the help of passive sounding, the propagation characteristics of realistic communication scenario can be investigated efficiently. However, due to the co-existence of neighboring cells at the same frequency band, the received signals in the user equipment (UE) will suffer from the multi-cell interference in the live networks. That is, the signal received by the passive sounder will not only contain the downlink signal of serving cell, but also that of neighbouring interference cells. Consequently, the dynamic range of the passive sounding might drop dramatically, leading to performance deterioration in parameter extraction in the live network. This multi-cell co-channel interference issue is largely overlooked in the literature for multipath parameter extraction, to our best knowledge.

In this letter, the multipath extraction with the presence of multi-cell co-channel interference in 5G live network is discussed. By revisiting the interference mechanism in the passive sounding framework, a novel algorithm is firstly proposed to extract the multi-cell propagation channel. Different from [11], which only investigate the power characteristic of interference, the proposed algorithm aims to extract the multipath component (MPC) parameters of neighbor cells. The interference cancellation (IC) strategy is adopted in the proposed algorithm, which is able to split and then remove the interference. Thus, the proposed algorithm can effectively extract the channel parameters for all of the existing cells. To the best of our knowledge, this is the first time that the multi-cell channel parameter extraction is discussed in the literature.

II. PROBLEM STATEMENT

A. Passive Channel Sounding Framework

The passive sounding framework is illustrated in Fig. 1. In the downlink, the BS transmits the dedicated downlink signals towards the mobile UE, e.g., synchronization signal block (SSB, to provide synchronization in time and frequency for the UE to synchronize with the BS) and channel state
information reference signal (CSI-RS, to provide a reference signal for channel estimation at the receiver) [12]. Beamforming strategy is adopted in the downlink signal transmission in 5G network, where multiple transmission beams can be generated to guarantee the coverage of different regions. The beamformed downlink signals will be received by the UE after going through the multipath propagation channels.

The concept of passive sounding is to use the BS as the transmitter directly, and utilize the downlink 5G NR signal received at the UE side to perform the channel sounding purpose. Due to the adoption of beamforming at the BS side, the transmission beam can be considered as one antenna port in 3GPP specifications [12]. It is noted that the channel sounding for single BS beam in a single snapshot is considered in this work. Time-variant channels for multiple beams can be measured by performing multiple channel snapshot measurements for each beam sequentially. Consequently, the channel between the BS and receiving antennas for a single beam at a single channel snapshot can be modelled as a single-input multi-output (SIMO) system. Assume that \( x = \{x(f_k)\} \in \mathbb{C}^{K \times 1} \) is the downlink signal transmitted from the BS, where \( K \) denotes the number of sub-carrier occupied in frequency domain. Moreover, the number of antennas equipped on the passive sounder receiver is denoted as \( M \). Therefore, the signal received by the sounder receiver at \( k \)th frequency bin can be expressed as

\[
y(f_k) = h(f_k)x(f_k) + n_0(f_k),
\]

where \( y(f_k) \) is a \( M \times 1 \) received signal vector, \( h(f_k) = \{h_m(f_k)\} \in \mathbb{C}^{M \times 1} \) denotes the frequency response between the BS and \( M \) receiving antennas, and \( n_0(f_k) \in \mathbb{C}^{M \times 1} \) represents the complex Gaussian noise vector. As illustrated in Fig. 1, \( h(f_k) \) is determined by the MPC parameters \( \Theta \), where \( \Theta = \{\tau, \phi, \varphi, \beta_1, \beta_2\} \) denotes delay, azimuth of arrival (AoA), zenith of arrival (ZoA), and complex gains of different polarizations, respectively. Note that only parameters of receiver side are exhibited due to lack of information at the BS side in the passive sounding [10]. The frequency response between the BS and receiving antennas can be expressed as

\[
h(f_k) = \frac{1}{L} \sum_{l=1}^{L} \sum_{p=1}^{2} \beta_{l,p} \alpha_p \exp(j2\pi f_k \tau_l),
\]

where \( \alpha_p = \{\alpha_m,p\} \in \mathbb{C}^{M \times 1} \) denotes the antenna pattern of \( M \) receiving antennas for \( p \) polarization.

With the knowledge of transmitted signal \( x(f_k) \) and received signal \( y(f_k) \), the estimated frequency response can be obtained by the linear square (LS) channel estimation as

\[
\tilde{h}(f_k) = h(f_k) + \frac{n_0(f_k)}{x(f_k)}.
\]

### B. Multipath parameter estimation

Once we obtained the wideband channel frequency response per antenna elements on the passive channel sounder receiver, we can utilize multipath parameter estimator to extract the multipath components. In this work, we employ the classic space-alternating generalized expectation-maximization (SAGE) algorithm [13]. The channel parameters \( \Theta = \{\tau, \phi, \varphi, \beta_1, \beta_2\} \) can be estimated. For the sake of simplicity, the details of SAGE algorithm are omitted in this work, and readers can refer to [13] for details.

![Passive sounding framework](image)

**Fig. 1.** Passive sounding framework.

- **PDP Traditional**
- **PDP Proposed**

![PDP spectrum with different interference levels](image)

**Fig. 2.** PDP spectrum with different interference levels.

### C. Multi-Cell Co-channel Interference in Passive Sounding

In practical cellular networks, multiple BSs sharing the same frequency band can be visible for the passive channel sounder simultaneously. Deploying more BSs is beneficial to improve the network coverage. However, it will also lead to severe multi-cell co-channel interference issues for the passive channel sounder. In the 5G passive sounding, the SSB and CSI-RS are usually used as the sounding signals. In the practical NR network, these signals of different cells are usually configured in the same time-frequency resources. Thus, these sounding signals transmitted from the different cells are simultaneously received by the receiver.

Assume that \( N \) BSs are visible for the passive channel sounder receiver during the channel measurement. The sounding signal transmitted by \( n \)th BS is denoted as \( x_n(f_k) \). Moreover, the propagation channel between the \( n \)th cell and
the sounder is denoted as $h_n(f_k)$. Thus, the signal received by the sounder receiver can be expressed as

$$y(f_k) = \sum_{n=1}^{N} h_n(f_k)x_n(f_k) + n_0(f_k). \quad (4)$$

The estimated channel of the $n$th cell can be calculated as

$$\hat{h}_n(f_k) = \sum_{i=1, i \neq n}^{N} h_i(f_k)x_i(f_k) + \frac{\sum_{i=1, i \neq n}^{N} h_i(f_k)x_i(f_k)}{x_n(f_k)} + n_0(f_k). \quad (5)$$

With the presence of co-channel interference, the signal interference noise ratio (SINR) of the received signal reduces notably, leading to a significant reduction of dynamic range in passive sounding. As a result, the multipath parameter extraction performance of the serving cell will deteriorate.

To demonstrate co-channel interference effect, a propagation channel composed of three paths with power values $0$ dB, $-5$ dB and $-15$ dB and delay values of $90$ ns, $500$ ns, and $800$ ns is selected, respectively. Moreover, a second co-channel cell, with power values $0$ dB, $-8$ dB and $-8$ dB and delay values of $195$ ns, $600$ ns, and $900$ ns, is adopted as the the multi-cell interference. The relative power level $\eta$ is set as different values. The power delay profile (PDP) spectrum with the classical SAGE algorithm and the proposed algorithm under different interference levels is shown in Fig. 2. It can be seen that interference has a strong impact on the multipath parameter estimation performance. The dynamic range reduces notably as the interference goes up, leading to significantly deteriorated performance for the classic SAGE algorithm.

### III. PROPOSED METHOD

The elimination of multi-cell interference is important for the channel parameter estimation during the practical passive sounding. The interference cancellation method has found various applications in wireless signal processing [14]. Moreover, the IC strategy has also been applied in channel parameter estimation, see e.g. in [15]. In this work, we propose an IC-based algorithm to extract the multipath channel parameters in the presence of co-channel interference in passive channel sounding scenarios, as detailed in Algorithm 1.

At the beginning, the candidate cell list should be sorted by the SINR of PDP spectrum, so that the propagation channels of cells with higher SINR can be first extracted. At the start of each iteration, the interference of other cells is removed by the IC step, i.e., subtracting the production of constructed channel $\hat{h}_n(f_k)$ and transmitted signal $x(f_k)$. It is noted that the estimated parameter $\hat{\Theta}$ is utilized to construct the propagation channel of the $i$th cell, i.e., $\hat{h}_i(f_k)$, since $\hat{\Theta}$ can represent the practical propagation environment. After removing all the interference of neighbor cells, the residual signal $y_{res}^n(f_k)$ can be obtained. Similarly, the estimated channel parameters of $n$th cell can be obtained by performing the SAGE algorithm over the LS-estimated channel of $y_{res}^n(f_k)$. Compared with $\hat{h}_n(f_k)$ in (5), the interference term has been removed in $\hat{h}_{res}^n(f_k)$. Thus, the channel parameters of $n$th cell can be effectively extracted with the following SAGE estimator. Moreover, an incremental strategy is applied for extracted ray number $L$, which ensures that $\hat{h}_n(f_k)$ can better approximate $h_n(f_k)$ at each iteration. Therefore, the interference of $n$th cell can be removed more clearly at the IC step. Finally, the MPC parameters of $N$ cells can be estimated simultaneously after $P$ iterations.

The effectiveness of the proposed algorithm is numerically demonstrated in Fig. 2. With the proposed algorithm, the dynamic range of CIR does not deteriorate. Thus, the multipath parameter estimator can have a good performance with presence of various interference levels.

### IV. MEASUREMENT VALIDATION

#### A. Measurement Setup

The measurement validation is conducted with a homemade passive sounder, which is illustrated in Fig. 3. The left side contains an omni-directional antenna (DOA) array and a mobile battery. The ODA array is equipped with $160$ dual-polarized elements, covering $[0^\circ, 360^\circ]$ at horizontal range and $[0^\circ, 150^\circ]$ at zenith range. The radio frequency (RF) and post-processing platform is located at the right side, capable of converting the RF signal to the baseband IQ and executing the post-processing algorithm to extract the channel parameters.

As to verify the performance of the proposed algorithm, a measurement campaign is conducted under the practical $5G$ commercial network operated by China mobile communications corporation (CMCC). The measurement site is located...
TABLE I. The parameters of measurement campaign.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Band</td>
<td>N41 (2565 MHz)</td>
</tr>
<tr>
<td>Sub-carrier Spacing</td>
<td>30 kHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>100 MHz</td>
</tr>
<tr>
<td>Signal to Analysis</td>
<td>CSI-RS</td>
</tr>
<tr>
<td>Cell List</td>
<td>[122, 22, 84]</td>
</tr>
</tbody>
</table>

at china academy of information and communications technology (CAICT), Beijing, China. Table I lists the parameters of this measurement campaign. It is noted that there are in total three cells present in the measurement environment, whose primary cell identifies (PCIs) are also listed.

B. Measurement Results

![Fig. 3. The photo of passive sounder.](image)

The measurement data is processed based on the proposed algorithm and the traditional SAGE algorithm. Note that parameters of the proposed algorithm are set as $L = 5$, $\Delta L = 2$, and $P = 20$, respectively. Fig. 4 depicts the PDPs of three cells for these two algorithms. It can been seen that these cells have different power levels, where cell 122 has the strongest power, cell 22 has the mediate, while cell 84 has the weakest. Compared with the traditional algorithm, the improvement of dynamic range for PDP spectrum for these three cells is obvious, since the co-channel interference has been removed during the proposed algorithm. Therefore, more propagation rays, which has been buried by the interference, can be extracted with the proposed channel parameter estimator. It should be noted that the PDP spectrum of cell 84, which has the weakest power level, has been totally buried by the co-channel interference. That is, the traditional method can not extract the channel parameter of cell 84. However, the proposed algorithm, which removes the interference of other cells and extends the dynamic range of PDP spectrum, can effectively extract the propagation channel for cell 84.

![Fig. 4. The PDP spectrum of the proposed algorithm and the traditional algorithm for the measured results.](image)

Fig. 5. Angular profiles of multipath results for three cells. Fig. 5 depicts the angular profile of these three cells. For cell 122, the main paths with high power levels are directly originated from the 5G BS, and the other paths with lower power levels are introduced by the reflections of the buildings and trees. It can been seen that the AoAs of these strong paths mainly come from 50°, which agrees with the path trajectory. On the other hand, for the cell 22 and cell 84, which can be categorized into non line-of-sight scenarios, the multipaths mainly come from the reflections of environments. It can be concluded that the proposed algorithm is able to extract the multi-cell channel parameters effectively.

V. CONCLUSION

The propagation channel parameter extraction with presence of multi-cell interference in passive sounding is investigated in this letter. Based on the interference cancellation strategy, a novel algorithm to extract the multi-cell channel parameters is proposed, which is demonstrated to be highly effective in numerical simulations. Moreover, a measurement campaign is conducted in the live 5G network environment. The measurement results indicate that the proposed algorithm can effectively estimate the channel parameters of all visible cells.
REFERENCES

[1] 3rd Generation Partnership Project (3GPP), “Study on channel model for frequencies from 0.5 to 100 GHz,” 3GPP, Technical Report (TR) 38.211 v. 17.0.0, March 2022.


