

Implementation of SDR-based 5G NR Cell Search Equipment

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Abstract— This paper describes an initial implementation of software defined radio (SDR) based 5G new radio (NR) cell search equipment. The proposed equipment is capable of detecting NR cells by decoding synchronization signal block (SSB) transmitted by gNodeBs in the vicinity. A step-by-step implementation of the cell search is given. The measurement results are compared with the results obtained using commercial 5G measurement equipment. The performance results validate that the proposed SDR-based equipment can successfully decode SSB and detect the same cells as the commercial measurement devices.

Keywords— SDR, USRP, 5G, NR, Cell search, scanner.

I. INTRODUCTION

The fifth generation (5G) new radio (NR) standard [1] – [3] developed by the third generation partnership project (3GPP) introduces several enhancements over the Long Term Evolution (LTE) networks. In particular, the major focus in 5G networks is given to enhanced mobile broadband (eMBB), ultra-reliable low latency communication (URLLC), and massive machine-type communication (mMTC). This classification has only artificial meaning and is only needed to simplify the definition of requirements for the technology specification. For instance, there may be cases when the application may require high level of reliability, but with no constraints on latency, or vice versa.

In order to provide 5G service for end customers network operators have to perform measurements not only during initial deployment, but also during network operation for efficient resource utilization and cell optimization. These on site measurements can guarantee that the desired level of quality of service (QoS) is guaranteed and satisfies end users.

In our previous work [4] we already developed LTE control channel analysis equipment called AlteTRi, which is capable of measuring current resource utilization, as well as the amount of data traffic transmitted through the shared data channel. This further allows performing analysis of cell spectral efficiency and other important cell parameters.

This work shows the initial steps towards the implementation of measurement platform for 5G NR networks similar to AlteTRi. Here we provide an initial synchronization procedures for cell search. The output of such procedures is the decoding of master information block (MIB) and finding

physical cell identifier (PCI). In order to validate the implemented equipment the real-filed measurements have been made and compared with the commercial network scanners. Performance comparisons show that the implemented SDR-based equipment can successfully decode SSB and detect the same cells as the commercial devices.

The rest of the paper is organized as follows. In section II background and related work is given. In section III some details on the implementation are provided. In section IV the measurement results are presented. Finally, section V concludes the paper.

II. BACKGROUND AND RELATED WORK

In order to enable devices finding a cell when turning on or during a handover process, a synchronization signal (SS) is periodically transmitted by each gNodeB in the system. The synchronization signal consists of two parts namely Primary Synchronization Signal (PSS) and Secondary Synchronization Signal (SSS). PSS and SSS together with the Physical Broadcast Channel (PBCH) form a SSB. Note that even though the terms SSS, PSS, and PBCH have been used in LTE the term “SSB” has been first introduced in 5G NR. Figure 1 shows the structure of a single SSB. SSB structure is independent on the numerology.

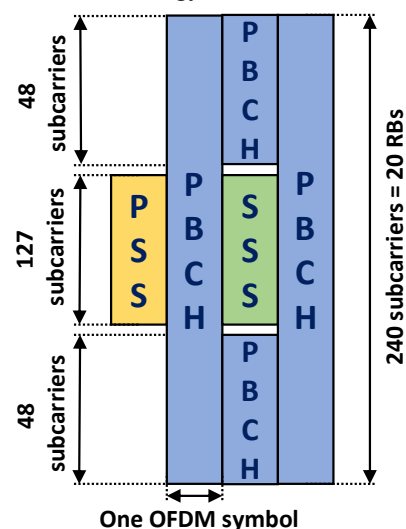


Figure 1. Time and frequency structure of a single SSB

In the frequency domain a position of SSB is determined by the synchronization raster, which is the new approach introduced in NR. Compared to LTE, where carrier raster has been used, the new approach provides much faster cell search due to the sparser synchronization raster. Another important difference to LTE is the ability to apply beam-sweeping for SSB transmission. Depending on the numerology and frequency range (FR) the pattern of SSB transmission may vary, but is always confined with 5 ms. SSB should be transmitted with the periodicity of at least 20 ms.

Several successful attempts have been made for LTE control channel analysis. For instance, the works in [5] – [7] implement a so called “LTE sniffer”, which is able to monitor LTE shared channel utilization by processing control channel of each user equipment (UE) in a cell.

In our previous work [4] we developed LTE control channel analysis equipment called AlteTRI, which is able to measure network utilization, traffic amount, and some other important cell parameters.

In this work, an initial attempt towards a control channel analysis for 5G NR is made. Note that the current implementation does not support control channel processing yet and supports initial cell synchronization only. We implement an SDR-based equipment, which performs cell search and compare the obtained cell information with the real commercial measurement device.

III. CELL SEARCH IMPLEMENTATION

The overall implementation of cell search consists of two major steps. In the first step a 5G NR signal is received and saved to file as complex in-phase and quadrature (I/Q) components. In the second step using a signal processing software the received signal is manipulated for PID extraction and MIB decoding.

Figure 2 shows the measurements testbed used in the first step. The universal software radio peripheral (USRP) X310 with UBX 160 daughterboard connected with PC through the PCIe interface has been used. In order to capture NR signal with high received signal strength indicator (RSSI) the antenna was mounted to the roof of the building connected to USRP with 10m length cable. The USRP hardware driver (UHD) has been used for saving I/Q samples to a file for further processing. X310 USRP supports the master clock rate (MCR) of 184.32 MHz, which is decimated by six in order to set the sampling rate to 30.72 Mps. Setting the sampling rate to 30.72 Mps does not allow to capture the whole resource grid of network resources. This, however, enough to capture SSB, which is what we need for the experiment. The frequency range (FR) 1 with n78 3.5 GHz band has been configured and the measurements were performed in Daejeon, Korea. There is no opportunity to verify FR2, because of no cells available. There are totally three network operators providing 5G NR services in Korea. The signals from each network operator have been collected to verify that the implemented equipment can perform cell search irrespective of each operator’s network configuration, since it is known that the operators utilize NR hardware from different vendors.

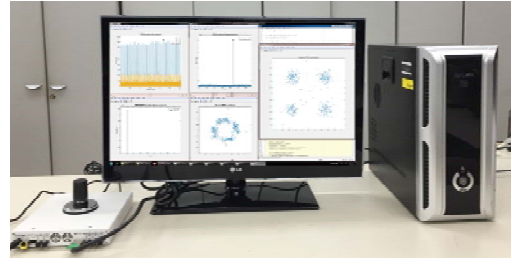


Figure 2. Measurement testbed

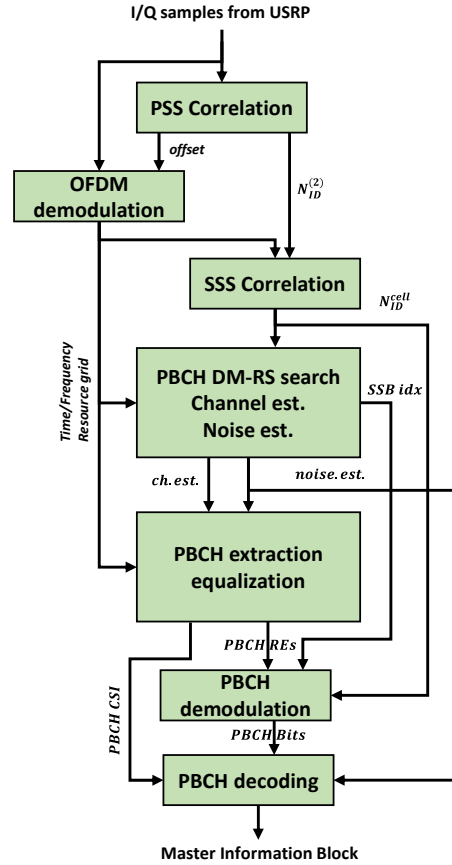


Figure 3. Flow chart of SSB processing

Figure 3 shows the flow chart of SSB decoding for cell synchronization. The implementation of cell search is performed using Matlab software [8]. The I/Q samples saved at the first stage are used now as an input to perform PSS search. The PSS search has been performed using the cross-correlation algorithm, in which the reference PSS sequence is created for the three sector IDs, i.e. 0, 1 and 2. Then each sequence is OFDM modulated to produce the reference waveform. After that each reference waveform is cross-correlated with the received waveform to find the sector id ($N_{ID}^{(2)}$) with the highest similarity. Similar to the PSS, the SSS is generated for each cell ID group $N_{ID}^{(1)}$. Then the cell ID group with the highest correlation is selected. Now the physical cell ID (N_{ID}^{cell}) can be calculated as $N_{ID}^{cell} = N_{ID}^{(2)} + 3 N_{ID}^{(1)}$. With the known cell ID the subcarriers corresponding to PBCH DM-RS can be extracted and correlated with each

reference PBCH DM-RS. The index of the strongest PBCH DM-RS corresponds to the least significant bits (LSB) of the SS/PBCH block index. With known PBCH DM-RS sequence a channel estimation for SSB can be created. In addition, additive noise estimation is performed. Minimum mean square error (MMSE) equalization is performed using estimated channel and noise information after PBCH subcarriers are extracted. The equalized PBCH symbols are demodulated and descrambled. In order to perform PBCH decoding channel state information (CSI) obtained from the MMSE equalizer is used. The decoding process consists of the rate recovery, CRC decoding, polar decoding, and descrambling. Finally, master information block (MIB) information can be obtained by using 24 bits of decoded PBCH transport block. The MIB includes the information of system frame number (SFN), subcarrier spacing for system information block 1 (SIB1), frequency offset between SSB and resource grid, position of the first downlink (DL) DM-RS, PDCCH/SIB related information, indicates if a cell is barred, and if intra-frequency cell reselection is enabled.

IV. MEASUREMENT RESULTS

A series of real field measurements have been performed in Electronics and Telecommunications Research Institute (ETRI) [9] Daejeon campus to verify the performance of the implemented equipment. The verification has been done by comparing cell information, such as cell ID and MIB information, between the implemented equipment and R&S TSME 6 drive and walk test scanner [10].

The following figures show the results of each step of the figure 3 described in the previous section. A random cell with $N_{ID}^{cell} = 660$ has been selected to show these steps. Figure 4 shows the PSS correlation for three sector IDs 0, 1, and 2. The sector ID 0 was selected since it has the highest magnitude. The cell ID group with highest correlation is selected in the next step. As figure 5 shows, the cell ID group 220 was selected. Now, since both sector ID and cell group ID are known the cell ID can be found as $3 \times 220 + 0 = 660$, which is equal to the cell ID value obtained using TSME 6. Similar to the figures 4 and 5, figure 6 shows the correlations for each possible PBCH DM-RS sequences. The index of PBCH DM-RS with highest correlation defines the LSBs of SS/PBCH block required for PBCH scrambling initialization. Figure 7 and Figure 8 show the PBCH constellation before and after equalization and CSI estimation, respectively. QPSK modulation is used for PBCH transmission.

In order to further verify the implemented equipment we performed measurements for the three different 5G network operators and compared the results with TSME6 scanner. The measurements have shown the identical results with the cell IDs of 214, 647, and 993. Performance comparisons have shown that the implemented equipment can detect 5G NR cells and decode SSB similar to the available commercial solutions. In most cases the location of SSB was found at the beginning of the synchronization raster. Such selection is reasonable because this allows faster cell synchronization for each UE during the cell search process.

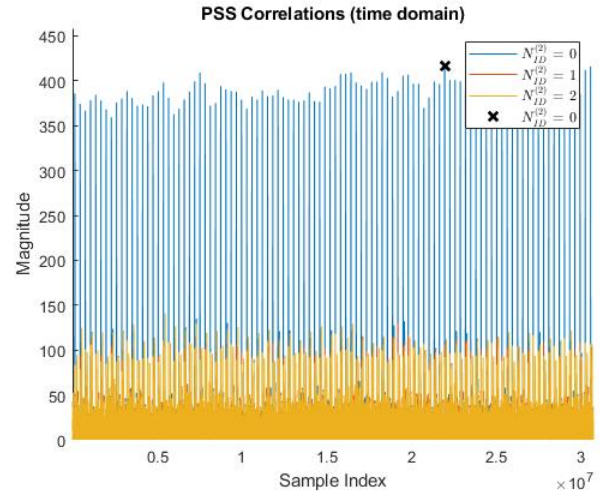


Figure 4. PSS correlations (The value with the maximum correlation is marked with “x”)

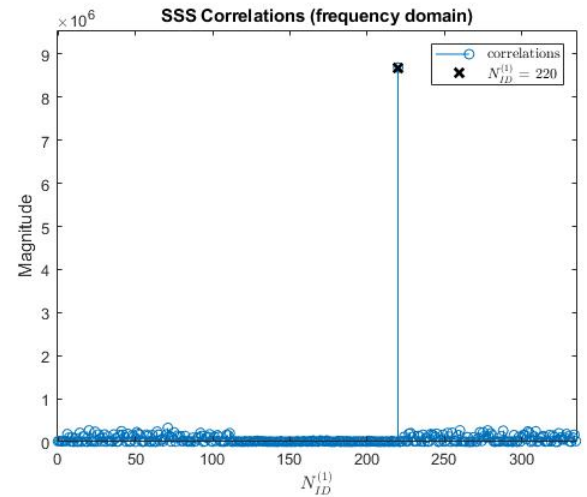


Figure 5. SSS correlations (The value with the maximum correlation is marked with “x”)

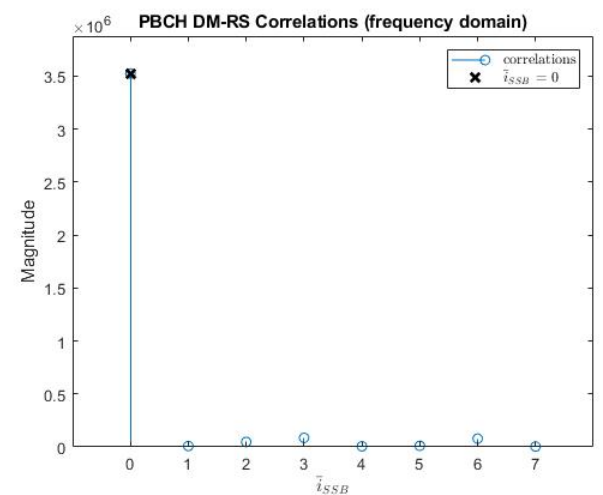


Figure 6. PBCH DM-RS correlations (The value with the maximum correlation is marked with “x”)

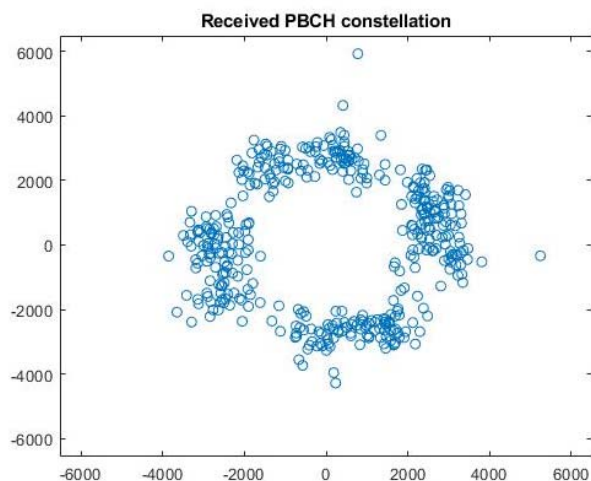


Figure 7. Received PBCH constellation diagram

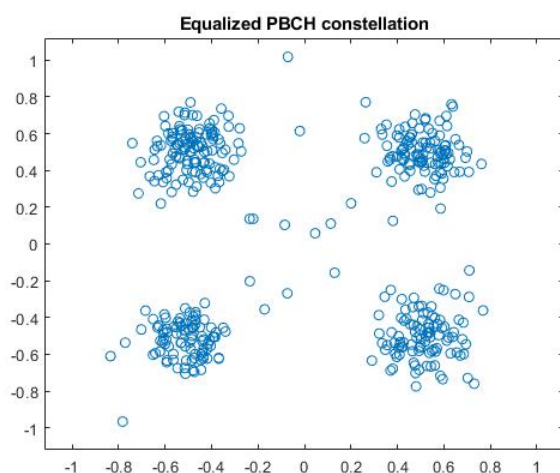


Figure 8. Equalized PBCH constellation diagram

V. CONCLUSIONS

This paper describes an initial implementation of SDR based 5G NR cell search equipment. The proposed equipment is capable of detecting NR cells by decoding SSBs transmitted by gNodeB. The overall process of the cell search is divided in two steps. In the first step I/Q complex samples are saved by using USRP X310 device and UHD. In the second step the I/Q samples are processed by software to retrieve cell ID and MIB information. A series of real field measurements have been made in ETRI (Daejeon, Korea) to verify the implemented equipment.

The obtained cell information has been also compared with the commercial scanners and it was found the results are identical. This is the initial step to the development of 5G NR network analyser, which may have broader range of capabilities, such as control and shared channel analysis.

The future work will cover millimetre wave (mmWave) FR2 cell search and control channel analysis implementation, which can enable deeper understanding of 5G NR network operation, management and resource utilization.

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