Intelligent Spectrum Sharing Between LTE and Wi-Fi Networks using Muted MBSFN Subframes

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***Abstract*—Due to the fast growth of diverse wireless network deployments, the radio spectrum is becoming scarce. Hence, it is beneficial that different radio access technologies share the spectrum in a harmonious way. In this paper, we propose a coexistence scheme between Long Term Evolution (LTE) and Wi-Fi networks that utilizes a Multimedia Broadcast Multicast Service (MBMS) over a Single Frequency Network (MBSFN) feature of an LTE network. MBSFN is an LTE feature that provides support for multicast/broadcast traffic. We propose an adaptive scheme that configures muted subframes, initially intended for MBSFN operation, to allow Wi-Fi transmissions. For the adaptive configuration of muted MBSFN subframes, the LTE eNB uses its traffic queue and the Wi-Fi spectrum occupancy information, which is determined by a convolutional neural network-based technology recognition and traffic characterization system. The standard LTE System Information Blocks are used to convey the updated configuration to the LTE UE. Hence, the proposed coexistence scheme doesn't require any modifications to a standard MBSFN-compliant LTE UE. Performance analysis is done for various traffic situations, and the results show that muted MBSFN subframe-based coexistence gives a 15% improvement in average aggregated throughput as compared to using Almost Blank Subframe-based coexistence.**

***Index Terms*—MBSFN, LTE, Wi-Fi, Technology Recognition, Spectrum Sharing, Software Defined Radio (SDR)**

I. Introduction

Due to the rapid growth and proliferation of wireless networks and the limited availability as well as the significant cost of licensed spectrum, the wireless networking industry is increasingly looking for opportunities to exploit the available unlicensed spectrum. For this reason, several variants of 4G Long Term Evolution (LTE) that take advantage of the unlicensed 5 GHz spectrum currently dominated by the IEEE 802.11 technology (also known as Wi-Fi) have been proposed [1]. To enable Wi-Fi transmission in the unlicensed spectrum, LTE can mute its transmission during some subframes called "Almost Blank Subframes (ABS)". Although LTE cannot transmit any data in ABS, it still sends control and synchronization signals, as well as broadcast data [2].

Many researchers have proposed different LTE and Wi-Fi coexistence schemes that utilize the concept of ABS [1]. Experimental analysis of ABS based coexistence on commercially available off-the-shelf (COTS) equipment shows that the throughput of the Wi-Fi network degrades significantly due to the Cell-specific Reference Signals (CRS) transmitted from LTE even if there is no LTE data traffic [3]. To tackle this problem, the CRS can be muted, decreasing interference with the Wi-Fi and hence improving its throughput [4]. However, for channel estimation, standard COTS LTE User Equipment (UE) expects CRS in each subframe. If the CRS are muted, the channel estimation has to be modified in such a way that it uses the available synchronization signals. Aside from the need to modify the UE-side channel estimation procedure, the less frequent and narrow band synchronization signal-based channel estimation is inefficient.

In this paper, we propose a coexistence scheme that utilizes the Multimedia Broadcast Multicast Single Frequency Network (MBSFN) feature of LTE. MBSFN-based evolved Multimedia Broadcast Multicast Service (eMBMS) uses certain LTE frames called MBSFN frames that are assigned periodically for multicast traffic. In an LTE MBSFN frame, up to six subframes can be used to send multicast data [5]. This MBSFN feature of LTE is proposed to be used to share resources between 5G New Radio (NR) and LTE networks as one of the standard Dynamic Spectrum Sharing (DSS) deployment options [6]. In LTE-NR DSS, muted LTE MBSFN subframes are used to allow NR transmissions.

This work proposes a novel LTE and Wi-Fi coexistence scheme that exploits the concept of muted MBSFN subframe-based DSS. In the proposed MBSFN-based spectrum sharing, the LTE uses certain frames while scheduling some frames with muted MBSFN subframes. By using muted MBSFN subframes, the time slots typically intended for eMBMS symbols in an LTE MBSFN frame can be freed up to be used for Wi-Fi transmission instead. With the help of the MBSFN feature, the LTE eNB can use its System Information Block (SIB) transmission to communicate the MBSFN configuration to its UE. This way, the LTE UE is aware of the muted subframes, and hence, there is no need to modify the channel estimation at the UE side.

In the 3GPP standard [7], the eNB configures MBSFN parameters based on the multicast traffic at the connection initiation phase of the multicast stream and the configuration is fixed until the UE leaves the multicast service. As this static MBSFN parameter configuration is spectrum inefficient, we propose a scheme that assigns muted MBSFN subframes adaptively. The LTE eNB uses the LTE traffic queue and estimated Wi-Fi Channel Occupancy Time (COT) to configure the number and periodicity of muted LTE MBSFN subframes. The LTE eNB uses the Technology Recognition and Traffic Characterization (TRTC) model proposed in our previous work in [8] to estimate the Wi-Fi COT and schedule its resources accordingly. On the other hand, Wi-Fi uses its Carrier-Sense Multiple Access with Collision Avoidance (CSMA-CA) protocol to sense and transmit in the muted LTE MBSFN subframes. The main contributions of this work are summarized as follows:

- Implementation of the muted MBSFN subframe feature in a Software Defined Radio (SDR)-based LTE eMBMS solution.
- Implementation and analysis of LTE and Wi-Fi coexistence with muted MBSFN subframes using fixed MBSFN parameter configurations.
- Propose and implement an LTE and Wi-Fi coexistence scheme based on an adaptive allocation of muted MBSFN subframes considering LTE traffic load and COT of Wi-Fi estimated using TRTC model.
- Performance comparison of the proposed muted MBSFN-based coexistence scheme with an ABS-based coexistence solution using an experimental SDR-based testbed.
- For reproducibility and benchmarking, the proposed solution is made open source and available to the research community [1].

II. Problem Definition and System Model

In this work, the concept of MBSFN-based LTE and NR DSS is modified to enable the coexistence of LTE and Wi-Fi. In the proposed scheme, subframes designated for unicast LTE traffic are used by LTE, while MBSFN subframes designated for multicast traffic (Multicast Transmission CHannel (MTCH)) and control information (Multicast Control CHannel (MCCH)) are totally muted. For each muted MBSFN subframe, the first two OFDM symbols are reserved for LTE Physical Downlink Control CHannel (PDCCH) and CRS, while the remaining time can be used by Wi-Fi. According to the standard [5], a multicast frame is scheduled with a certain MBSFN frame periodicity P_{mu}. In each MBSFN frame, N_{mu} subframes can be assigned for multicast traffic.

In the semi-static resource allocation of the standard eMBMS [7], fixed values of N_{mu} and P_{mu} are configured during the connection initiation procedure. However, due to the dynamic nature of LTE and Wi-Fi traffic, setting fixed values of N_{mu} and P_{mu} is not spectrum efficient. To address this challenge, this work uses a dynamic MBSFN parameter configuration [9] to adaptively configure muted MBSFN subframes.

In MBSFN-based eMBMS, a multicast LTE frame with N_{mu} muted MBSFN subframes is scheduled periodically in every P_{mu} frames. As per standard, the possible values of N_{mu} are $\{1, 2, 3, 4, 5, 6\}$ while possible values of P_{mu} include $\{1, 2, 4, 8, 16, 32\}$ [7]. With these possible values, only up to 60% of the total spectrum is assigned to Wi-Fi, which makes it inefficient and unfair when the LTE traffic queue length (θ_{lte}) is less than 40% of the maximum system capacity of the LTE network (C_{max}). As a solution to this, the proposed scheme can schedule additional N_{bs} ABSs (subframes with PDCCH, CRS transmissions but muted PDSCH) in each LTE frame. In this case, the LTE frame has N_{bs} ABSs and N_{mu} muted MBSFN subframes. For a given MBSFN frame, the number of subframes assigned for LTE scheduler (N_{lte}) is given as:

$$N_{lte} = \begin{cases} 10 - (N_{mu} + N_{bs}) & \text{if } \theta_{lte} \geq 0.4 * C_{max} \\ 10 - N_{mu} & \text{otherwise} \end{cases}. \quad (1)$$

The main goal of the coexistence scheme is to maximize the spectrum efficiency and fairness. Spectrum sharing fairness is maximized by using the TRTC-based Wi-Fi COT estimation. The spectrum efficiency can be maximized by assigning resources such that the capacity of resources allocated to LTE (C_{lte}) is close to θ_{lte} while keeping fairness into account. C_{lte} is the capacity of resources allocated to LTE within multicast channel scheduling period (M_{sp}) which is given by:

$$C_{lte} = \left(\frac{1}{P_{mu}} * \frac{N_{lte}}{10} + \frac{P_{mu} - 1}{P_{mu}} \right) * b_s * M_{sp}. \quad (2)$$

where b_s is the total number of bits scheduled in an LTE subframe, which depends on the Modulation and Coding Scheme (MCS) and the configured bandwidth. The value of b_s for a given MCS and bandwidth is selected based on the 3GPP standard [10]. The spectrum efficiency is calculated based on the LTE frame configuration used in the M_{sp}, as the configuration is updated in every M_{sp} frames.

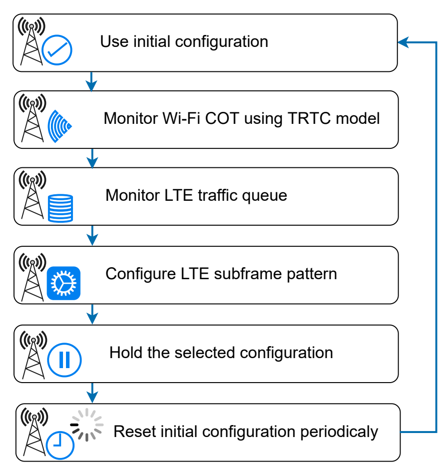

Fig. 1: Proposed resource allocation process.

Fig. 1 shows the process of the adaptive MBSFN resource allocation algorithm that chooses the MBSFN frame pattern based on the LTE traffic queue and COT of Wi-Fi transmissions. Initially, the LTE eNB determines the COT of the channel using the TRTC model in [8]. Initially, the system starts with 5 muted MBSFN subframes, giving an almost equal spectrum share to the two technologies. The LTE then uses the LTE traffic queue information and the Wi-Fi COT to select an LTE frame pattern that maximizes the spectrum efficiency and fairness. After that, the frame configuration is periodically updated based on the aforementioned metrics.

[1] https://gitlab.ilabt.imec.be/mgirmay/adaptive-mbsfn/-/tree/DSS

III. Proposed coexistence Scheme Process

Algorithm 1 shows the procedures of the proposed resource allocation scheme. In the *monitoring phase*, the LTE eNB initially selects a $N_{lte} = 5$, $P_{mu} = 1$ configuration, which results in 5 muted MBSFN subframes in each frame. Using this configuration, the eNB senses the Wi-Fi COT (Ω_{wi}) using the TRTC model. In the *update phase*, the eNB selects an LTE frame configuration (L_{con}) that gives a capacity closest to the LTE traffic queue (θ_{lte}). The eNB uses stored reference capacity values computed using eq. 2 for all combinations of bandwidth, MCS, M_{sp}, N_{lte}, P_{mu} values. If this frame configuration gives at least five muted subframes in each frame, this configuration will be used until the next M_{sp}, as it guarantees fairness by giving at least 50% of the spectrum to Wi-Fi.

If, on the other hand, the configuration chosen based on θ_{lte} results in $N_{lte} > 5$, the configuration is tuned accounting the estimated Ω_{wi}. In this case, the LTE selects a configuration that gives a capacity value closest to the LTE traffic queue θ_{lte}, while keeping a certain number of muted subframes that cover at least Ω_{wi} percentage of the total duration. For example, if the estimated Ω_{wi} is 40%, at least 4 subframes will be muted in every frame while the rest of the 6 subframes are available for the LTE traffic.

Algorithm 1 : LTE resource allocation scheme

Input: LTE queue length (θ_{lte}), Wi-Fi COT (Ω_{wi})
Output: Optimal frame configuration $L_{con} = (P_{\text{mu}}, N_{\text{lte}})$

```
while true do
    if F_c % M_SP = 0 then
        Use P_mu = 1, N_lte = 5          ▷ monitoring phase
        Monitor Ω_wi using TRTC
        Monitor θ_lte in eNB Scheduler
        Update L_con based on θ_lte      ▷ update phase
        if (N_lte ≤ 5) ∩ (P_mu = 1) then
            Use selected L_con
        else
            Update L_con based on θ_lte and Ω_wi
        end if
    end if
end while
```

Based on the θ_{lte} of LTE and Ω_{wi} of Wi-Fi sensed in the previous window, the LTE eNB updates its frame configuration every M_{sp} frames i.e. when eNB's frame counter (F_c) modulo M_{sp} is zero. The LTE eNB sends SIBs to exchange relevant information with the LTE UE. Particularly, MBSFN configuration parameters are conveyed from eNB to UE via SIB2 and SIB13 every 160 ms [7]. Hence, the proposed solution doesn't require any modifications on the UE side.

IV. Experimentation Setup

To implement the proposed adaptive eNB resource allocation, we used srsRAN [11] eMBMS SDR solution as a baseline. We extended the srsRAN eNB by including the resource scheduling process presented in Algorithim 1. Fig. 2 shows two host machines, each connected to a USRP b200mini, which are used to run the LTE eNB and LTE UE. An additional USRP b200mini, connected to the LTE eNB host machine, is used to collect I/Q samples for TRTC. For the Wi-Fi network, openwifi [12], which is an open-source SDR IEEE802.11n-based solution, was used. Both Acess Point (AP) and station run over the Xilinx ZC702 boards and use Analog Devices FMCOMMS4 as front-ends.

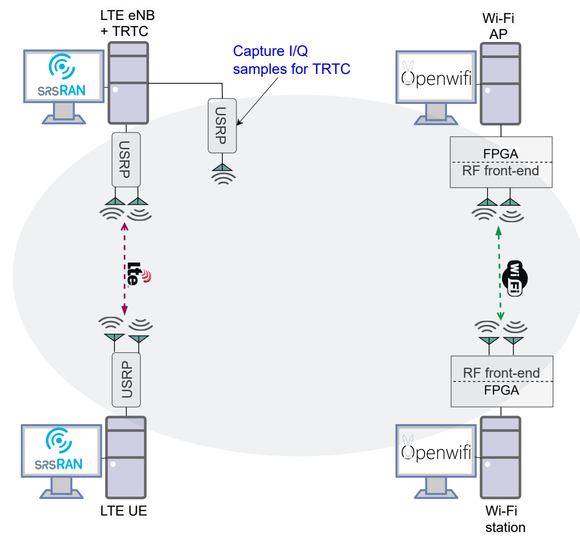

Fig. 2: Experiment setup topology.

V. Experimentation Results

For the performance evaluation, we used 20 MHz of bandwidth, a center frequency of 5.18 GHz, and a SISO mode for both technologies. To evaluate the performance of the proposed scheme, random traffic loads were generated between 0 and 43 Mbps for the LTE network and between 0 and 25 Mbps for the Wi-Fi network. The range of traffic loads is selected based on the maximum saturation throughput [13] obtained in standalone experiments for both technologies. For each randomly selected traffic load, LTE throughput, Wi-Fi throughput, and aggregated throughput values are stored. The analysis was made based on 10 runs for each considered case, where each run had a dynamic traffic load with a run time of 200 s.

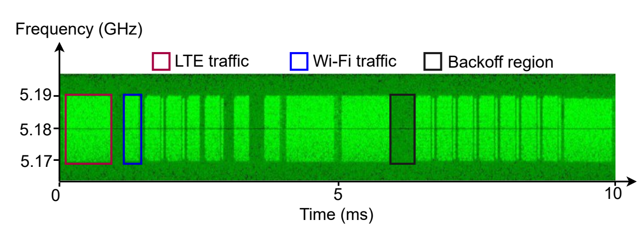

Fig. 3: Spectrogram of LTE and Wi-Fi signals in a frame.

Fig. 3 shows the spectrogram of the LTE and Wi-Fi signals in a single LTE frame. It can be observed that the Wi-Fi senses

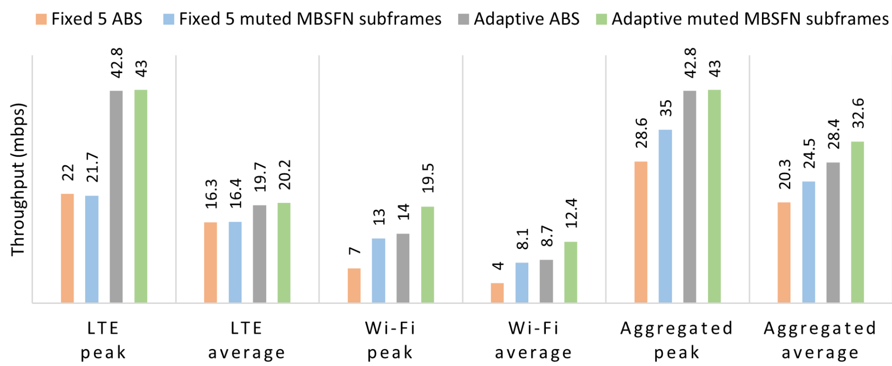

Fig. 4: Throughput of LTE and Wi-Fi networks using different coexistence schemes.

and exploits the muted MBSFN subframes. Fig. 4 shows the peak and average throughput of LTE and Wi-Fi networks, as well as the respective aggregated values considering, 5 fixed ABS LTE subframes, 5 fixed muted MBSFN subframes, adaptive ABS, and adaptive muted MBSFN subframes. ABSs refer to subframes with active PDCCH and CRS, and muted PDSCH, while every symbol of a muted MBSFN subframe in the MBSFN region is muted. For the adaptive ABS-based and muted MBSFN subframes-based coexistence schemes, the LTE frame configuration is selected based on the procedures described in Algorithm 1 with a monitoring periodicity of 640 s. This monitoring period can be an integral multiple of 160 ms (SIB2 periodicity) and can be adjusted based on the traffic dynamics of the applications.

The results show that using a spectrum-inefficient fixed configuration leads to lower throughput as compared to the two corresponding adaptive configurations. It is also observed that using ABS-based coexistence leads to lower Wi-Fi throughput due to interference from the LTE CRS. Fig. 4 also shows that muted MBSFN subframe-based coexistence gives a 15% improvement in aggregated LTE and Wi-Fi throughput compared to ABS-based coexistence.

VI. Conclusion

An adaptive LTE and Wi-Fi coexistence scheme based on muted MBSFN subframes is proposed in this work. The LTE eNB utilizes information from a convolutional neural network-based technology recognition and traffic characterization system to determine the optimal MBSFN configuration, based on the current state of the LTE traffic queue and Wi-Fi spectrum occupancy. The results show that the proposed coexistence technique can be used to ensure efficient coexistence between LTE and Wi-Fi networks without requiring any changes to the standard MBSFN-compliant LTE UE. The results also reveal that, compared to using ABS for coexistence, employing muted MBSFN subframes improves the average aggregated LTE and Wi-Fi throughput by 15%.

In the near future, it is expected that open and sufficiently stable 5G MBMS platforms will become available. The proposed coexistence scheme can be adapted and validated using the MBMS feature of 5G-NR, instead of the MBSFN feature of LTE, for an efficient coexistence of 5G-NR, LTE, and Wi-Fi networks.

VII. Acknowledgements

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