TDD Synchronization Testing Over Neighbouring 5G Networks in a Cross-Border Corridor

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***Abstract*— The 5G New Radio (NR) specification proposes flexible spectrum usage using Time Division Duplexing (TDD), and caters for many frequency bands in low, mid and high frequency ranges. Currently, the combination of the 3.5 GHz range and 5G NR is becoming the first major rollout of TDD cellular networks in many countries. While radio synchronization has always been a key issue for mobile networks, the use of TDD frames inherently mandates time and phase alignment that needs to be further evaluated. This paper summarizes the TDD synchronization aspects and considerations for neighbouring TDD networks, with special focus on the cross-border aspects. Exploiting the cross-border deployment of the European Innovation project, 5G-MOBIX, in the Greece-Turkey cross-border corridor, initial measurements are presented, and early insights are drawn regarding the impact of the different TDD patterns and operation of neighbouring TDD networks.**

Keywords—5G network, CAM, cross-border corridor, trials, TDD synchronization;

I. INTRODUCTION

5G, the cornerstone of future communications, offers ubiquitous, super-fast, reduced-latency connectivity and seamless service delivery in all circumstances, paving the way for revolutionary applications, such as Connected and Automated Mobility (CAM). These do not come with a simple upgrade from the previous LTE generation, and mandate Radio Access Network (RAN) and core network transformations to optimize performance and reliability. In terms of RAN, the 5G New Radio (NR) specification proposes flexible spectrum usage using Time Division Duplexing (TDD). While it is foreseen that the business requirements will drive the utilization of the appropriate band, currently [1] the majority of 5G commercial networks have been deployed at the 3.5 GHz frequency band (3.300-4.200MHz) as a cost-effective balance between coverage, capacity and network investments. The combination of the 3.5 GHz range and 5G NR is thus becoming the first major rollout of TDD cellular networks in many countries [2].

While radio synchronization has always been a key issue for mobile networks, the use of TDD frames that inherently mandate time and phase alignment between radio base stations (gNBs), add complexity in the process to prevent interferences and related loss of traffic. At a national level, alignment between operators can be orchestrated through policy makers and National Regulation Agencies (NRAs) that typically regulate the spectrum utilization and can propose guidelines to facilitate the necessary synchronization. However, in cross-border network deployments, such as the European Transport Network (TEN-T) [4] corridors, achieving network synchronization across countries is a cumbersome task, since a common framework may not be possible.

This paper presents the initial work carried out as part of the 5G-MOBIX EU-funded research project [6] addressing cross-border CAM services provisioning over 5G. The paper focuses on assessing in practical terms the operational issues of neighbouring TDD networks and the impact of different TDD patterns, using real-life measurements from the 5G networks comprising the Greece-Turkey Cross-Border Corridor (GR-TR CBC). The insights gained are discussed on the basis of the recommendations provided by the GSM Association (GSMA), regarding TDD network operation. The remainder of this paper discusses the GSMA recommendations relevant to cross-border operation, provides an overview of the Greece-Turkey CBC and presents early measurements and insights.

II. 5G NETWORKS TDD SYNCHRONIZATION ASPECTS

TDD, which is widely employed in mobile networks with the advent of 5G, is considered the prevailing technique to optimize spectrum use and allow for flexibility in bandwidth allocation between uplink (UL) and downlink (DL). Opposite to its frequency Division Duplexing (FDD) counterpart, where the DL and UL use different frequency channels, in TDD, transmission and reception occur in the same frequency channel, with different time slots assigned to UL and DL respectively [3]. By changing the duration of these slots, and selecting the appropriate transmission pattern, network performance can be tailored to meet the emerging UL-heavy applications needs, and balance uplink and downlink capacity as necessary. However, to avoid interference and subsequent deterioration of performance, any adjacent TDD network – either 5G or LTE- need to be synchronized, neighbouring base stations must transmit at the same fixed time periods and all devices should only transmit in dedicated time periods [2]. According to ECC report 296 [5], the optimal separation distance between two unsynchronized macro base stations/networks is up to 60 km for a co-channel configuration and up to 14 km for adjacent channel operation.

In TDD operation, different frame structures may be used, meaning that a different combination of DL and UL slots may be allocated per frame. Different frame structures correspond to different trade-offs relatively to key performance aspects. For example, the more frequent the DL/UL and UL/DL switching, the lower is the RTT (Round Trip Time). A short latency improves the channel estimation quality (CQI) using TDD channel reciprocity properties and also enables fast HARQ retransmissions. More frequent switching therefore has a positive impact on spectrum efficiency in high mobility conditions, which is ideal for CAM use cases. The frame structure also impacts coverage performance. The guard period (GP) between DL and UL must be large enough to compensate the propagation delay for large cells [3].

GSMA for 3.5GHz TDD Synchronisation

GSMA has investigated the importance of TDD synchronization in the 3.5 GHz range in [2] with the aim to inform policymakers and mobile operators on relevant aspects, and has provided recommendations [2], including proposals on the preferred frame structure, for initial 5G launches in 3.5 GHz. These recommendations address key aspects such as default parameters and frame structure for TDD synchronization at national level, localized arrangements among Mobile Network Operators (MNOs), common clock reference and more. However the most important recommendations from the perspective of our work are the ones addressing international and cross-border synchronization. Those recommendations are:

- **Recommendation 4 [Synchronization at International Level]**: Networks should be synchronized at an international level whenever possible, which may be difficult, due to the number of countries involved, the different migration and implementation timescales and the difficulty of negotiating per MNO and neighbouring country. It is anticipated that the preferred frame structures are (D= DL slot, U=UL slot, S=Special):
  - DDDSU (3+1), 30 kHz Sub-Carrier Spacing (SCS);
  - DDDSUDDSUU (4+1+3+2)
  - DDDSUUDDDD (4+2+4), both only to be considered where LTE is present at the band.
- **Recommendation 5 [Cross-border Coordination]:** To manage cross-border coordination, even though the use of a common frame structure is favoured, it is considered unlikely due to the domino effect which may affect a large number of countries. Alternatives to find localized solutions are proposed:
  - In the border areas where neighbouring countries have selected the same frame structure, all the synchronized base stations can be used on either side of the border with limited coordination efforts.
  - In the border areas where neighbouring countries have not selected the same frame structure operators will need to engage in additional coordination efforts. Discussions and agreements of operators on bilateral or multilateral and in respective industry forums are necessary and the involvement of policymakers and/or administrations can be a useful complement.
- **Recommendation 6 [Co-existence of non-synchronized networks]**: Where no agreements on the frame structure can be reached, in order to identify practical solutions to coexistence of networks, the following options are proposed (subset of recommendations):
  - Network optimization (such as base station location, antenna, direction, and power limits);
  - Downlink blanking where operators, on both sides of the border, agree to stop the use of some of their downlink slots when the other operators are using an uplink slot;
  - A step-by-step migration based on the regional timings of 5G deployments and 4G migrations;
  - Migrate 4G networks to a different band or to 5G technology;
  - Avoid co-channel use and aim to have operators only using adjacent channels;

Besides the above, the GSMA suggests that countries also agree on acceptable signal strength levels at borders (on a bilateral, multilateral or regional level).

The GR-TR 5G-MOBIX partners, have used the initial network test measurements for the recently installed 5G networks at either side of the GR-TR Kipoi-Ipsala border, to assess the impact of the different TDD patterns on performance, to investigate potential impact from neighbouring TDD network operation in adjacent bands and to put to the test some of the above GSMA recommendations.

III. 5G-MOBIX GR-TR Cross-Border Corridor

In the context of the European H2020 ICT-18-2018 5G-MOBIX Innovation project [6], a cross-border corridor (CBC) has been constructed at the borders between Greece and Turkey, in order to perform real-life trials of cross-border operation of CAM services using autonomous FORD trucks (automation level 3-4) [8]. The CBC, which is located between Kipoi (GR) and Ipsala (TR), comprises hard borders and customs checks and is covered with 5G connectivity provided by the COSMOTE and Turkcell Non Stand-Alone (NSA) 5G networks respectively, based on Radio and Core equipment of 3GPP Rel.15, provided by Ericsson. The largest part of the CBC, on the Turkish side, is a 6 km stretch of road covered by three gNBs with six New Radio (NR) cells (plus LTE anchors), while the GR side of the CBC is covered by a single gNB/cell, located 3.2 km away from the nearest Turkcell gNB, as depicted in Figure 1. All cells operate in the 3.5 GHz band, while Active Antenna Systems (AAS) are used on both sides of the border with a NR carrier of 100 MHz Band-Width with a maximum transmission power of 200 W.

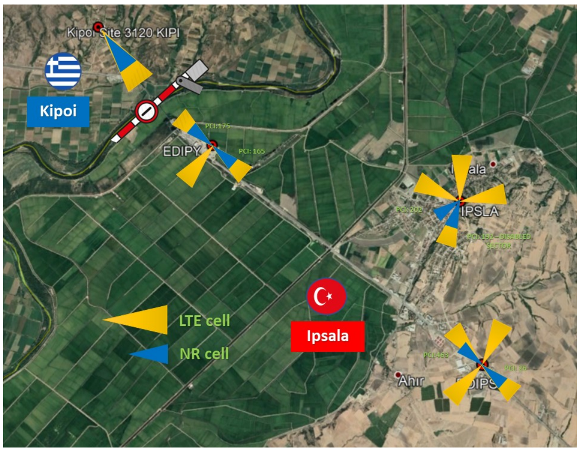

Figure 1: GR-TR Cross-border Corridor layout

In Greece, as of December 2020, COSMOTE commercially operates 5G in the awarded frequency bands, including the 3400-3800 MHz band. Given that incumbent legacy systems operate in the 3.5GHz range, the Greek NRA [7] provided some guidelines in terms of synchronised and non-synchronised / semi-synchronised operation that are in alignment with GSMA Recommendation #3. Specifically, for synchronised operation, it has been decided to utilise the 4+2+4 TDD pattern. In Turkey, no auction has taken place yet for the commercial allocation of the 5G bands, but Turkcell has reserved a test license for the 3.5 GHz band, for the purpose of the 5G-MOBIX trials, where different TDD patterns may be applied.

Generally, in neighbouring TDD deployments, base stations are in a close proximity and even if they are phase synchronized, they can interfere each other. To avoid interference at least 25 MHz of guard band between operators is recommended [9]. Following, such insights from previous research and based on the GSMA recommendations, a guard band of 50 MHz has been selected for the GR-TR deployment, as depicted in Figure 2. This selection guarantees minimal to zero interference, between the two networks, irrespective of the TDD pattern (to be confirmed by the measurements).

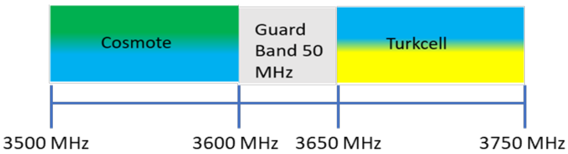

Figure 2: Spectrum Allocation at the GR-TR CBC

IV. INTER-PLMN TDD MEASUREMENTS

As part of the final verification and integration tests performed in the 5G networks of the GR-TR corridor, and before the official CAM trials begin, extensive measurements were taken on both sides of the border to verify the proper functionality of the two networks and to investigate the impact of the usage of different TDD patterns under varying conditions. The measurements focused on the experienced DL and UL throughput using TCP and UDP protocols i) with the neighbouring network activated and deactivated, ii) for different TDD patterns, and iii) with Carrier Aggregation (CA) ON and OFF. All measurements took place from static locations close to the actual border (one location for the GR side measurements and one for the TR side), which translates to an approximate distance of 2.5 km from the COSMOTE gNB for the GR side measurements and 250 m from the Turkcell gNB for the TR side measurements. The measurements results are presented in the rest of this section.

Performance with neighbouring PLMN ON/OFF

In order to assess the impact of potential TDD interference from the neighbouring network, the throughput at the Turkcell network was measured with COSMOTE network activated and deactivated, while both networks use the same TDD pattern, i.e., the 4+2+4. The UL throughput was selected as the most suitable metric, as most networks are UL limited.

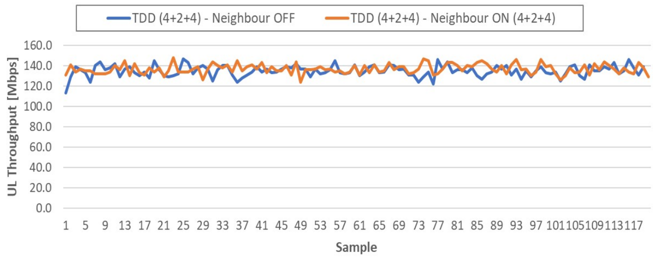

Figure 3: UL Throughput @ Turkcell network with COSMOTE network ON and OFF (same TDD pattern)

Figure 3 depicts the measured throughput at the TR side measurement point under the Turkcell network which was steadily measured around 140 Mbps with UL CA activated. As this measurement verifies, the operation of the neighbouring (COSMOTE) network has practically no effect on the measured performance, which was expected due to the large guard band used between the two MNOs (50 MHz).

Performance under different TDD patterns

To investigate the potential impact on performance of the different TDD patterns for TCP and UDP traffic, a series of measurements were performed using the two most common TDD patterns described in recommendation #4, namely the 4+2+4 and the 4+1+3+2. Figure 4 depicts the UL throughput measured at the GR side measuring point under the COSMOTE 5G network. It can immediately be observed that the 4+1+3+2 clearly outperforms the 4+2+4 pattern by up to ~60% (avg. 40 Mbps vs 64 Mbps). This observation is in line with the used frame structure as the 4+1+3+2 pattern allocates 30% of the frame to UL slots, while the 4+2+4 pattern only allocates 20% of the frame to UL slots. The use of TCP or UDP traffic does not seem to affect the experienced data rate at all (almost identical performance), while a comparison with the Turkcell network measurements for the 4+2+4 with UL CA deactivated (Figure 3) indicates that the average UL throughput is lower at the GR side. This is due to the much larger distance of the GR measurement point from the serving gNB (see beginning of Section IV).

Due to space limitations, the TR side measurements for different TDD patterns are not analytically presented here, however it is interesting to note that the UL performance measured for the two patterns was almost identical, as depicted in Figure 6, in contrast to the GR side measurements which showed the expected differentiation. This could be the result of a number of reasons (configuration, measurement set-up, end-device, etc.) which are currently under investigation.

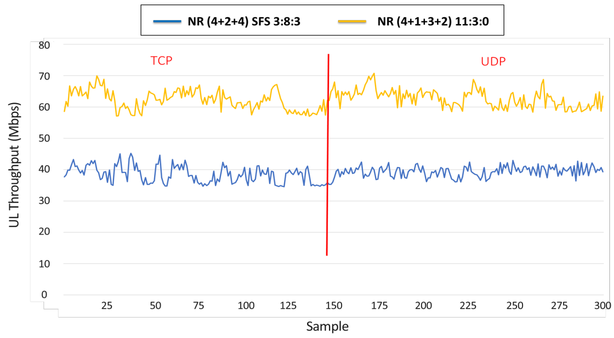

Figure 4: UL Throughput @ COSMOTE with two TDD patterns for TCP and UDP traffic (CA OFF)

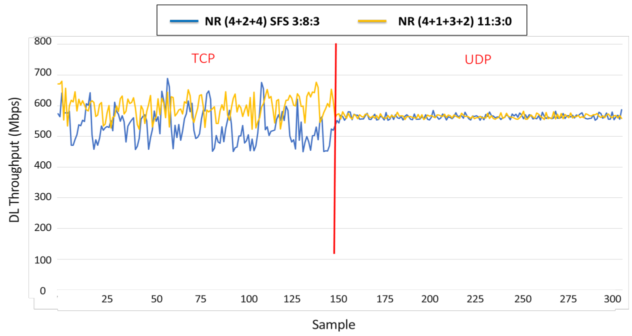

Figure 5: DL Throughput @ COSMOTE with two TDD patterns for TCP and UDP traffic (CA OFF)

Regarding the DL throughput measurements (Figure 5), the average DL throughput at the GR measuring point (2.5 km from the serving gNB) was found to be around 560 Mbps, while the used TDD pattern did not seem to have any significant impact on the experienced DL data rate, despite the different DL slot allocation. This is especially true for UDP traffic where the data rate showcased less variations.

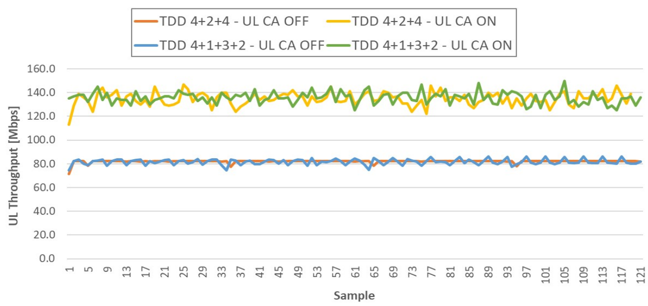

Figure 6: UL Throughput @ Turkcell for two TDD patterns and CA ON/OFF

Performance with Carrier Aggregation (CA) ON/OFF

The effect of UL LTE and NR Carrier Aggregation (CA), i.e., the combined use of different spectral resources from LTE and NR to increase the user data rate, was also tested at the TR side and the Turkcell network by taking different measurements with the CA activated and deactivated. Figure 6 depicts the UL experienced TCP throughput for the two different TDD patterns and with CA ON and OFF. In both cases a significant increase of the experienced UL throughput is observed when CA is activated, from an average data rate of about 80 Mbps to an average of 136 Mbps. The use of different TDD patterns did not seem to have any effect on the received CA performance boost.

V. Conclusions

This paper presented the preliminary work carried out at the GR-TR CBC of the 5G-MOBIX project, where advanced CAM trials will take place within the next year. As part of the GR-TR corridor deployment and verification process, some early field measurements on the effect of TDD network synchronization were performed, to investigate the impact of neighbouring 5G networks operating in adjacent bands and the effect of the different TDD patterns. Early results indicate that the use of significant guard bands (as also recommended by GSMA) protects neighbouring networks from interference, while some significant variation in UL performance can be expected by the use of different TDD patterns, according to their slot allocation. NR and LTE carrier aggregation was also shown to significantly improve UL performance.

Acknowledgement

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