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Measurements to Study the Coexistence of Private LTE TDD Networks in 2.3 GHz Band

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Abstract—Private wireless networks have recently gained interest in many business applications. Use of 4G and 5G technologies for private network deployments has become feasible recently. Finnish Transport and Communications Agency Traficom began to grant licenses for private mobile Time Division Duplex (TDD) networks on frequency band 2300-2320 MHz in 2020. In this study, the coexistence of two 4G TDD networks is investigated through an extensive measurement campaign. The laboratory test setup developed to conduct the interference measurement campaign can be used to study 4G and 5G TDD technologies in frequency bands below 4 GHz. Networks using TDD technology are recommended to use synchronized frame configurations to avoid interference. Private network applications and requirements differ between user organisations and hence the uplink and downlink data rate requirements are different and may need different TDD frame configurations. This paper studies interference between adjacent private networks, which have same or different TDD frame configurations. Measurement results indicate that non-synchronized networks produce interference and significant decrease in data throughput in neighboring networks.

I. INTRODUCTION

Private mobile networks using LTE technology have recently gained interest in many business applications. Main benefits of a private network are guaranteed service bandwidth, speed, security, and reliability [1].

The Finnish regulator Finnish Transport and Communications Agency Traficom began to grant licenses for private mobile Time Division Duplex (TDD) networks on frequency band 2300-2320 MHz in June 2020. This 20 MHz wide band has the status of a secondary allocation in the 2300-2400 MHz band, which is currently primarily allocated in Finland for Program Making and Special events (PMSE) use for wireless cameras [2,3]. In Finland, many of the existing private LTE networks have been deployed on the 2600 MHz band and use frequency division duplex (FDD).

Electronic Communications Committee (ECC) of the European Conference of Postal and Telecommunications Administrations (CEPT) has studied shared spectrum access in 2300-2400 MHz band. ECC Reports 15(04) and 172 [4,5] describe the scenarios and technical requirements for the sharing of this frequency band between PMSE users and possible mobile broadband users. Several studies and trials have been conducted on spectrum sharing using Licensed Shared Access (LSA) and coexistence between PMSE and LTE systems [6,7,8]. ECC Recommendation 15(01) considers cross-border coordination of 4G and 5G Mobile/Fixed Communications Networks (MFCN) to avoid harmful interference and provides guidance in case of synchronized and unsynchronized MFCN TDD systems operation [9]. In ECC Report 296 [10] considers coexistence of MFCNs in synchronized, unsynchronized and semi-synchronized operation in 3400-3800 MHz band. Simulation results show that the throughput degrades significantly due to the Crossed Timeslot Interference (CTI) [11].

Measurements campaigns were initiated in the 5G Vertical Integrated Industry for Massive Automation (5G VIIMA) project to study coexistence and interference in 2.3 GHz band if 4G, 5G and PMSE technologies are used simultaneously. The first measurement campaign studied interference between LTE and PMSE. The results from this campaign have been published in [12].

This paper studies the coexistence between two LTE TDD private networks. A measurement test bench was developed to conduct measurements with commercial base stations, packet core networks and user equipment.

These measurements will also serve 5G TDD private network deployments, as the secondary allocation of 2300-2320 MHz band in Finland is technology neutral. This allows 5G to be used in the band in the future.

II. INTERFERENCE SCENARIOS

Two independent LTE networks which include core elements, base stations and SIM cards were deployed to demonstrate two Private LTE Networks. In the measurements described in this paper two LTE indoor base stations (BS) were used with their own dedicated evolved Packet Core (ePC). ePC specific SIMs are used in the user equipment (UE) which means that UEs are not able to register into the neighboring network. This results to following research questions:

- What are the interference mechanisms if the networks are TDD synchronized with the same frame structure?
- In private LTE networks there could be a demand for higher uplink capacity than in commercial networks resulting different frame structures. What are the interference mechanisms in this case?
- How different bandwidths affect the interference?
- Can results obtained in laboratory be utilized with the network planning software tools?

A. Interference modes in TDD networks

Several radio interface interference mechanisms exist between two independent LTE networks. Main uplink/downlink BS/UE geometries and interference modes are illustrated in Fig. 1. UE to UE interference is not included in this study because assumption is that UEs are near ground level. Mechanisms are different if base stations use same frequencies which is the co-channel case or adjacent/alternate frequency channels. Interfering signal power in the victim BS receiver depends on interfering BS Equivalent Isotropic Radiated Power (EIRP) and BSs antennas radiation patterns. The worst case is when the base station antennas main lobes are pointing towards each other. Interference can be minimized utilizing antenna back or side lobes or even side lobe minimums. Private LTE networks may use different bandwidths (BW), for example in Finland 5, 10 and 20 MHz, which also affects the level of interference.

Even if the networks are synchronized with the same frame structure, the interfering DL will interfere the victim network UE with simultaneous DL from both networks. Between base stations the interfering BS downlink transmitter signal will interfere the victim BS uplink receiver, but this is the case only if the networks are not synchronized with the same frame structure. In case of co-channel operation, the interfering power will be the in-block power of the BS and in case of adjacent channel operation the out of band power is defined by the Adjacent Channel Leakage Ratio (ACLR) of the BS.

Interference from interfering network UEs at ground level to victim BS is not considered in these measurements because in private LTE networks the UEs are typically within the geographically restricted service area and UE uplink interference to neighboring BS receiver is not very likely. However, drones may be an exception, as the drone UE uplink may be even in line of sight for the neighboring base station. Drone application is a special case, which will be studied in a separate measurement campaign.

Fig. 2 reproduces the various downlink/uplink frame configurations with calculated D/U ratios. As can be seen configuration 0 has the highest uplink capacity, three times of the downlink. Configuration 5 on the other hand has the highest downlink capacity, 8 times more than uplink.

Two interference comparisons between configurations 0/5 and 1/2 are presented in the lower part of the table in Fig. 2. Assuming full synchronisation, it can be seen that the downlink subframes in the interfering base station will override uplink subframes of the victim base station. Therefore, it can
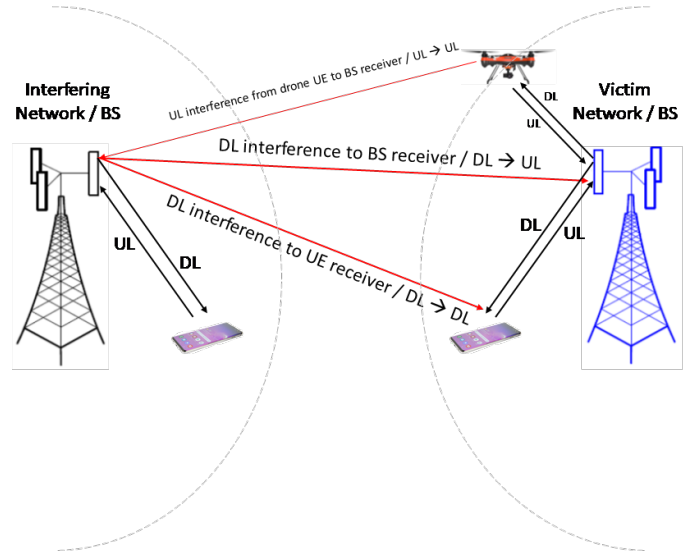

Fig. 1. Interference modes.

Fig. 2. TDD uplink and downlink frame configurations.

be concluded that if two adjacent private LTE networks would like to take full advantage of synchronisation, they should have the same D/U configuration, otherwise the configuration which have more downlink will dominate and destroy additional uplink capacity of the other configuration. In commercial base stations, especially in lower power micro and pico base stations, number of implemented TDD configurations are reduced to 1 and 2. In case different configurations are needed other measures (different frequencies, antenna patterns, separation etc.) to avoid interference should be considered.

III. LABORATORY SETUP

Setup for the laboratory measurements test bench is shown in Fig. 3. The interfering network is on the left side and victim network on the right side. Interfering base station and other related equipment are situated in another room to prevent direct interference to the victim network. Terminals in both networks are inside shielded boxes so that the signal levels can be controlled with an attenuator. Directional couplers are used to increase isolation from the terminal uplink to the other network. Some fixed attenuators are used in signal paths to adjust the signal levels to appropriate range. Attenuator 1 (Att 1) is used to adjust the interferer signal level to the victim network. Deploying the setup shown in the Fig. 3. It is possible to adjust the interference level at the input of the victim base station receiver input between -135.3 dBm and -22.8 dBm.
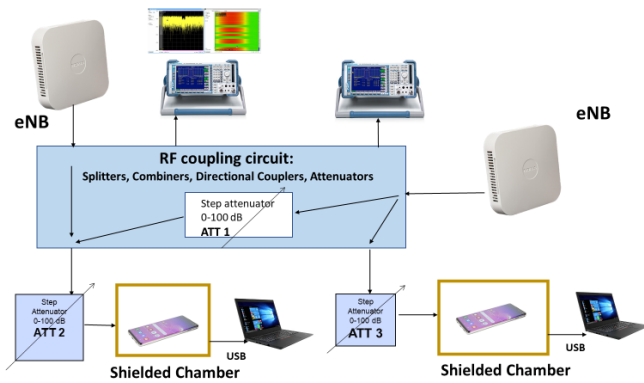
Fig. 3. Laboratory measurement test bench.

Fig. 4. UE RSRP vs. setup attenuator 2 setting.

Attenuators 2 (Att 2) and 3 (Att 3) are used to adjust the path loss to terminals. Nominal levels at the antenna ports of the shielded boxes are between -22.7 dBm / -102.7 dBm (interferer) and -15.8 dBm / -115.9 dBm (victim). Downlink signal levels can be monitored with terminal RSRP information. RSRP is the power of a single reference carrier in one symbol at the antenna connector (test port). For 20 MHz LTE there are 1200 carriers, so theoretically it gives log(1200) = 30.8 dB lower value than the total received power (nominal). In addition there is a coupling loss between the antenna in the shielded box and the terminal antenna. Assuming this to be 30 dB would give RSRP range of -177 dBm to -77 dBm. However, RSRP values below -130 dBm are not usable for the terminals.

The two base stations are using different core networks to prevent any terminal handovers between base stations. The interferer side downlink should be loaded as much as possible so that all DL subframes will have the same power. This was achieved with sequential downloads of large files from a FTP server. Selected phones (UEs) for the tests were Essential PH-1s. Base stations are Nokia type Flexi Zone Indoor Pico operating in 2300-2400 MHz, bandwidths 10/15/20 MHz and output power adjustable in the range of 17-24 dBm (50-250 mW).

Link reception parameters were monitored with Keysight Nemo Handy test SW and DL/UL link speeds with Speedtest SW. TUAS has its own highspeed inhouse Speedtest server connected in the inhouse core network, so any external effects are minimized.

IV. MEASUREMENT RESULTS

A. 20 MHz LTE co-channel downlink to uplink with frame configurations #1 and #1

This measurement studies the case where the base stations are TDD frame synchronized both networks using frame configuration #1. First the signal path losses between different points were measured with the measurement setup. Next the RSRP was measured as a function of attenuators 2 and 3 at interfering and victim sides. The resulting graph is shown in Fig. 4.
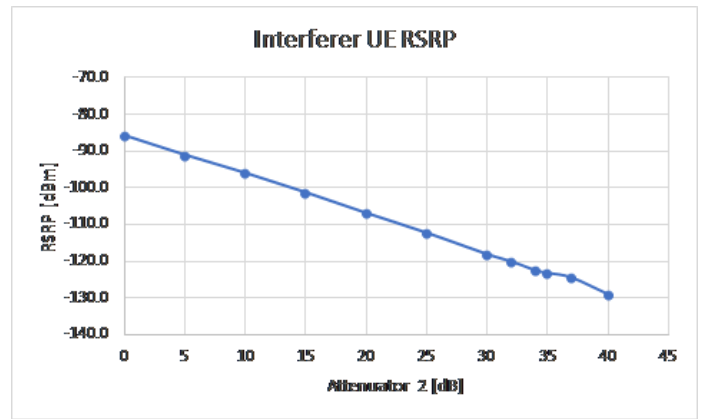
RSRP on both terminals is changing linearly as expected and differences between UEs are very small. Only in very low RSRP values there can be seen some non-linearity due to leaking power to the shielded boxes. However, values below -120 dBm are not practical as these are out of the service area. Next the victim side uplink (UL) and downlink (DL) speeds were measured without any interference as a function of RSRP. The results are shown in Fig. 5. Maximum DL speed is just above 40 Mbit/s and UL speed about 15 Mbit/s. The steps in the graphs in -88 dBm to -86 dBm RSRP are due to modulation and code rate changes done automatically by the LTE system when the path loss changes and received power changes. Note that in the basic measurement system the maximum RSRP was -77 dBm, but with some temporary modification some points between -65 and -70 dBm were obtained. The maximum speed, however, remained the same. As can be seen the practical service limit is around -120 dBm RSRP resulting already very low DL & UL speeds. Also, the terminal may easily loose the service i.e. drop from the network. Note, that the maximum speeds measured are characteristic for the tested terminal and base station and the selected parameters.

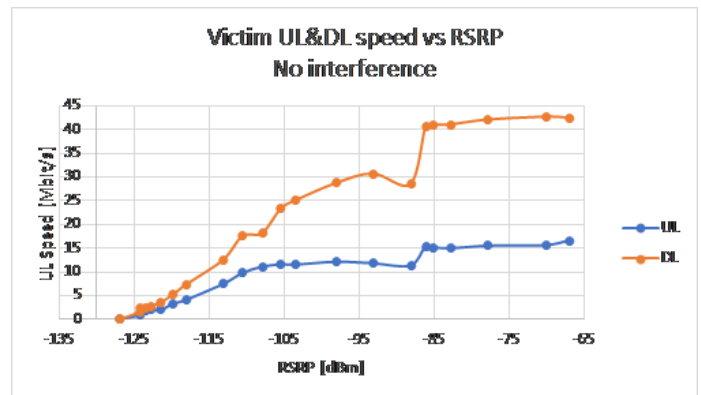In the next phase the interferer side UE was set to operate

Fig. 5. Victim side UL & DL speeds as a function of RSRP.

RSRP [dBm]	UL [Mbit/s]	DL [Mbit/s]	Att 1 [dB]	Pi [dBm]
-122.8	1.26	2.66	0	-28.8
-118.1	3.73	7.87	0	-28.8
-107.9	10.5	19.98	0	-28.8
-88.1	11.88	30.85	0	-28.8
-77.9	15.28	41.15	0	-28.8

at RSRP -91.1 dBm (att3 5 dB) and downlink interference power level to victim Base station receiver was increased by decreasing the attenuation in the attenuator 1. Result was that only the highest possible interference power level with this setup -28.8 dBm (att1 = 0 dB) could cause noticeable 5-10 % decrease in the UL speed as shown in Table 1.

A few more points were measured with RSRP -118.1 dBm and at RSRP -107.9 dBm. But only the maximum interference level -28.8 dBm could cause a slight decrease in the UL speed. This could be due to overloading of the receiver or uncertainties in the measured uplink speed.

B. 20 MHz LTE co-channel downlink to uplink and downlink to downlink with frame structure configurations #1 and #2

This measurement studies the case where the interfering and victim base stations have different frame configurations interfering #2 and victim #1 as shown in Fig. 6.

The interferer side UE was RSRP -91.1 dBm and downlink interference power level to victim Base station receiver was increased. As expected with different frame structures interference was seen in the victim side uplink. Measurements were taken with 5 different victim side UE RSRPs to cover signal conditions from strong -77.6 dBm to weak -118 dBm. Results for the uplink speed as a function of interfering power are shown in Fig. 7.

It can be estimated that the interference free operation is up to roughly -96 dBm interfering power, with the highest RSRP even slightly higher. Note also that the decrease of UL speed is not very steep. If the non-interfering limit is calculated with the ECC report 172 values (N = -96 dBm, I/N=-6 dB), the criterion would be -102 dBm, so in practice we seem to get about 6 dB "better" values.

Downlink to downlink interference was also measured and the results are presented in Fig. 8.

The result was that the DL speed is not affected. This can be seen in Fig. 8. which presents the corresponding DL speed graphs. The result could be expected because DL slots are synchronized in both networks.
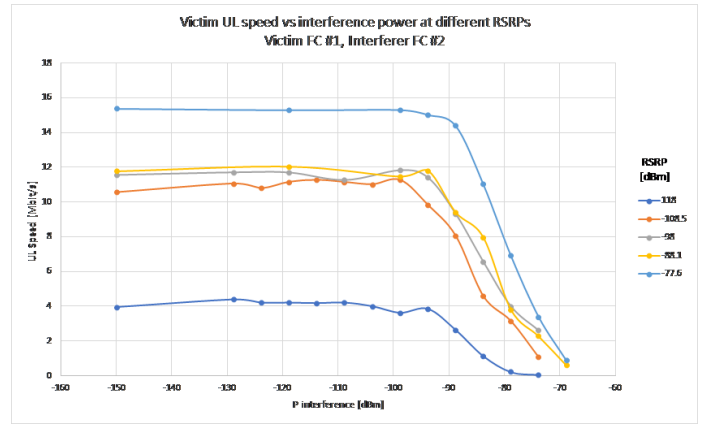

Fig. 7. Victim UL speed with different RSRPs, frame configurations #1 and #2.
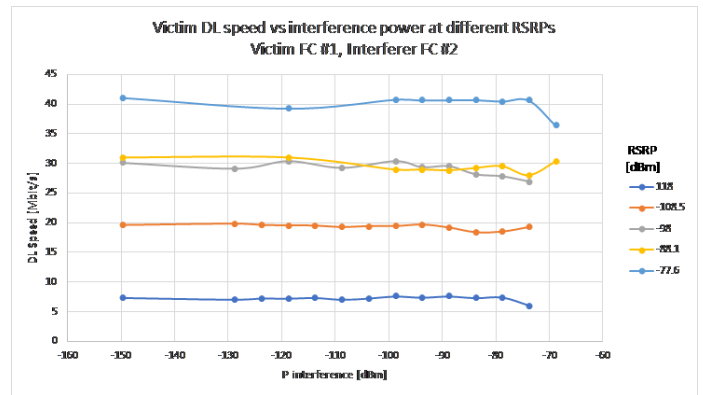

Fig. 8. Victim DL speed with different RSRPs, frame configurations #1 and #2.

C. 10 MHz LTE adjacent channel with frame configurations # 1 and # 2

The third measurement was studying the case, where two adjacent 10 MHz LTE base stations are operating with different frame configurations. The LTE base stations are operating at 2305 MHz and at 2315 MHz. The victim side uplink (UL) and downlink (DL) speeds were measured without any interference as a function of RSRP. Result is very similar to curves in Fig. 5, except that DL and UL speeds are about half of the 20 MHz LTE speeds. The interferer side UE was now set to operate at RSRP -91.1 dBm (att3 5 dB) and downlink interference to victim BT receiver was turned on with attenuator 1. As expected with different frame configurations interference was seen in the victim side uplink although at much higher nominal interference power levels because the true interference power is lower by the ACLR of the BS. Resulting graphs at various RSRP values are shown in Fig. 9.

D. Measurements with delayed frames

As the number of frame configurations was limited to only two (#1 and #2) it was decided to use base station user interface parameter "Air frame time for 1pps reference" to
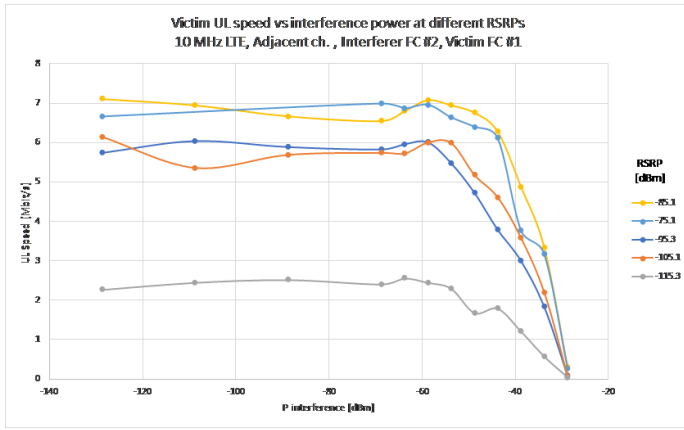

Fig. 6. Victim and interferer TDD configurations.

Fig. 9. Victim UL speed at different RSRP, 10 MHz LTE.

	Config.											Delay [us]
Victim	1		D	S	U	U	D	D	S	U	U	D	0
Interf.	1		D	S	U	U	D	D	S	U	U	D	0
Interf.	1		U	U	D	D	S	U	U	D	D	S	3000

Fig. 10. Delayed frame with configuration #1.

adjust the frame delay. The range for this parameter is -4900 μs to +4900 μs meaning almost ± half of the frame length (10 ms). For frame configuration #1 the worst delay seemed to be 3 subframes (3 ms), which would put two interfering DL subframes over the victim side UL subframes, see Fig. 10. Similar test as the first measurement with synchronized frames with configuration #1 was performed, but now with 3 ms delay on the interferer side.

Results are shown in Fig. 11. For comparison, graphs from the first measurement without any frame timing delay are shown in the same figure. As can be seen, introducing 3000 μs delay will destroy the frame synchronisation and the non-interference free power limit will change to about -95 dBm like in the case with different frame configurations.

Next interferer side frame configuration was changed to #2 and both +3000 μs and -3000 μs delays were tried. These are
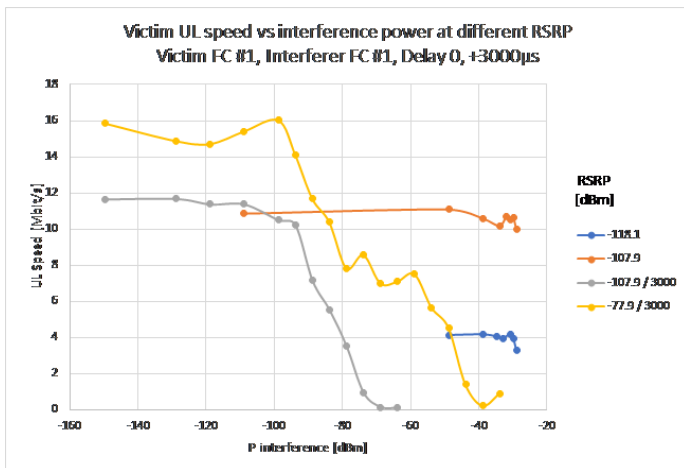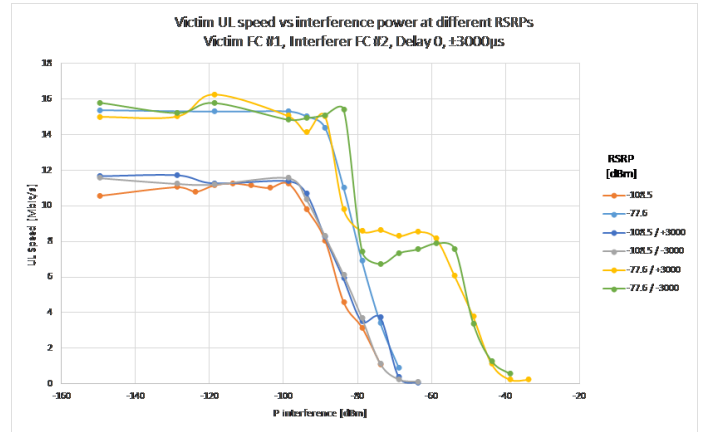

Fig. 11. Victim UL speed, frame configuration #1 and #1, delay 0 / 3000 μs.

illustrated in Fig. 12.

In this case it would also look like the 3000 μs is the worst case theoretically as DL subframes from the interferer would destroy both UL subframes and S subframe on the victim side.

Measurements were done with two victim RSRP values, -77.6 dBm and -108.5 dBm. Results are shown in Fig. 13.

E. Downlink to downlink interference for frame configuration #1

Measuring downlink interference in the UE will require modification to the basic measurement setup. The victim side directional coupler is turned over and the attenuator 3 is moved between the BS and directional coupler. This way both the wanted downlink and interfering downlink can be controlled. Frame configuration was set to #1 on both sides, so that the frames are synchronized, see Fig. 14.

Victim side DL and UL speeds were also measured without any interference, see Fig. 15.

Interferer side was set to RSRP of -87.7 dBm. The victim side DL speed was measured as a function of the attenuator 1 between the network alternating the DL interference from the interferer network. This was done at five different victim side RSRP values, -77.9, -88.3, -98.2, -108.7 and 118.7 dBm representing different signal conditions. From the calibration measurements and attenuator settings both absolute DL interference power and C/I values at the victim side UE was calculated. Results are shown in Fig. 16. and Fig. 17. From the graphs we can assess that with high -77.9 dBm RSRP level

	Config.											Delay [us]
Victim	1		D	S	U	U	D	D	S	U	U	D	0
Interf.	2		D	S	U	D	D	D	S	U	D	D	0
Interf.	2		U	D	D	D	S	U	D	D	D	S	3000
Interf.	2		D	D	D	S	U	D	D	D	S	U	-3000

Fig. 12. Delayed frame configurations #1 and #2.

Fig. 13. Victim UL speed, frame configuration #2 and #1, delay 0 / ±3000 μs.

Config.													Power [dB]	Freq [MHz]	Delay [us]
1	Victim	D	S	U	U	D	D	S	U	U	D		24	2310	0
1	Interferer	D	S	U	U	D	D	S	U	U	D		24	2310	0

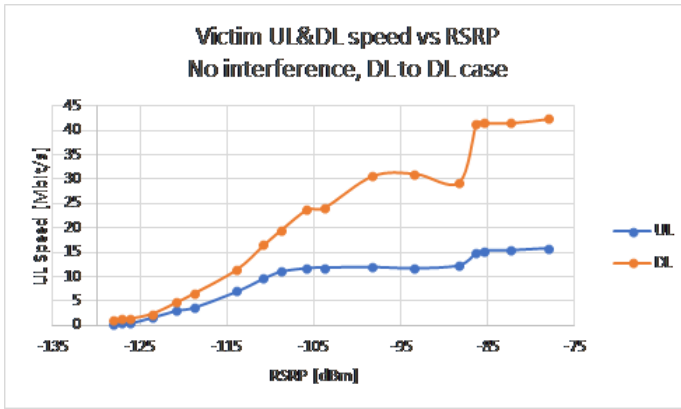Fig. 14. Frame configurations used for the DL to DL case.

Fig. 15. Victim UL&DL as function of UE RSRP, no interference, DL to DL case.
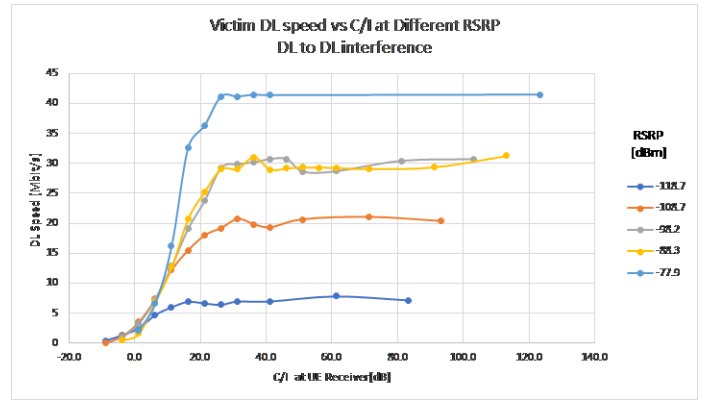

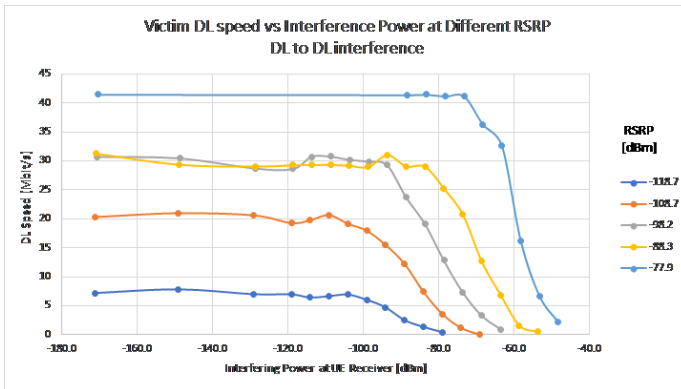Fig. 17. Victim DL speed as function of C/I, DL to DL interference.

Fig. 16. Victim DL speed as function of interference power, DL to DL interference.
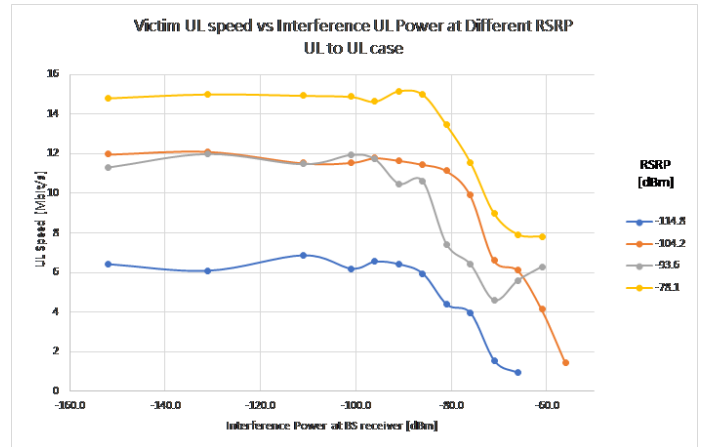

Fig. 18. Victim UL speed as function of interference power, UL to UL interference.

the interferer power is about -70 dBm and with lowest RSRP level -100 dBm. In terms of absolute interference power it is understandable that with higher RSRP the UE can tolerate higher interference than with low RSRP.

When the curves are drawn as a function C/I, the maximum data rate threshold is in the 20 dB +/- 5dB C/I region depending on RSRP levels.

F. Uplink to uplink interference for frame configuration #1

Measuring uplink interference from the UE to BS receiver required modification to the basic measurement setup. The interferer side directional coupler is turned over and the attenuator 2 is moved between the BS and directional coupler. This way both the wanted uplink and interfering uplink can be controlled. The interfering power is this time the UE transmitter, with a power of +23 dBm. The RSRP at the interferer UE is maintained low in the measurements as this will ensure that the UE transmits with maximum power. Both base stations have frame configuration #1. Effect of the UL interference was measured with four different victim UE RSRP levels, 78.1, 93.6, 104.2, and 114.8 dBm. Results are shown in Fig. 18.

Limit for interference is around -90 dB, slightly higher nominal power than in the base station DL interfering UL

(measurement 2, -96 dBm), but this is probably since the UE uplink is SC-FDMA.

V. CONCLUSION

The main objective in this measurement campaign was to produce knowledge on coexistence between two LTE Private Networks using 2.3 GHz band and TDD technology. TDD Frame configurations and synchronization between the networks were in focus. Private network applications and requirements differ between user organizations and hence the uplink and downlink data rate requirements are different and may need different TDD frame configurations. Results presented here are based on laboratory measurements, where commercial network products and user equipment were used. The developed laboratory measurement setup, with variations to different interference cases, proved to be functional and gave consistent results.

In co-channel 20 MHz bandwidth and equal TDD frame configuration scenario the interfering power in the Base Station receiver input should be higher than -28.8 dBm to cause uplink throughput degradation. This high power level is reached in the distance of 100 meters to 1 km of base station depending on transmitter power, antenna gain and radiation sector. In

nonequal TDD configuration scenario, when interfering BS has pattern 2 and the victim base station pattern 1, the non-interfering power level is up to -96 dBm. 10 dB stronger interfering power decreases the throughput by 30 % in higher receiver RSRP power levels and 50 % on the lowest RSRP level. This power level is reached in the distance of several hundred of meters to several kilometers depending on base station radiated power, antenna height and propagation conditions. Downlink throughput is not affected, because interfering pattern 2 uplink slots do not overlap with the victim downlink slots. When bandwidth is decreased to 10 MHz and networks use adjacent channels, the interference-free operation is up to -54 dBm and adjacent channel interference ratio (ACIR) is 42 dB, which means that interfering distance is reduced by factor of 1/100 compared to co-channel situation.

When TDD frame time delay of 3 ms, which results in the victim uplink slots to overlap with interfering downlink slots, was introduced to the interfering TDD frame, the uplink non-interference operation was achieved at -95 dBm level. Hence, introducing a delay of milliseconds between otherwise similar frame structures deteriorates the synchronization. Thus the interference behaviour is similar to the scenarios where different frame structure configurations were used.

Throughput degradation depends on the delay time and hence the overlapping between uplink and downlink slots. Measured case was the worst case when the delay was adjusted to cause full overlapping. Downlink to downlink interference threshold is -100 dBm to -70 dBm depending on the received RSRP. Lower interfering power is needed to decrease throughput at lower received power levels.

The measurements will be extended to study the interference between private LTE and 5G New Radio (NR) networks and between two 5G NR networks. This will give additional understanding on what kind of protection areas and minimum separation distances (MSDs) are required between private 4G/5G networks.

The measurement data and results have been used in the development of radio regulation for private networks in Finland.

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