Field Measurements to Study the Co-Existence of Geographically Limited Local Industrial Mobile TDD Networks

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***Abstract*—Use of 4G and 5G technologies for local industrial networks has become feasible in recent years. This paper studies the co-existence of two geographically limited adjacent Time Division Duplex (TDD) local networks through a field measurement campaign. The networks have the same or different TDD frame configurations. The test setup developed to conduct the interference measurement campaign can be used to study both 4G and 5G TDD technologies. Measurement results indicate that non-synchronized networks produce interference and significant decrease in data throughput in neighboring networks. Thus, networks using TDD technology are recommended to use synchronized frame configurations to avoid interference. However, local network applications and their requirements may differ between user organizations, and hence the uplink and downlink data rate requirements are different and may need different TDD frame configurations.**

Keywords — private/local wireless network, TDD synchronization, co-existence, LTE, 5G

I. INTRODUCTION

Local mobile networks have recently gained interest in many industrial applications [1]. 3GPP uses the term Non-Public Network (NPN) when it refers to local private mobile networks. Main benefits of local networks are that guaranteed service bandwidth, speed, security, and reliability can be achieved [2], [3]. Term local network means that the network can also offer minor telecommunications services to public. In Finland, local mobile Time Division Duplex (TDD) networks licenses were first granted in June 2020 [4] on a 20 MHz wide band, which is currently shared with temporary Program Making and Special events (PMSE) use for wireless cameras operating in the 2300-2400 MHz band [5].

The field measurement campaign presented in this paper investigates the interference between local geographically limited TDD networks. The main objective of the measurement campaign is to provide results, which can be used to guarantee interference-free operation for local networks and to optimize the spatial usage of spectrum.

Co-existence and interference between wireless systems has been widely studied. Electronic Communications Committee (ECC) of the European Conference of Postal and Telecommunications Administrations (CEPT) has published Reports 15(04) and 172 [6], [7], which describe the scenarios and technical requirements for spectrum sharing in 2300-2400 MHz frequency band between PMSE users and mobile broadband users. Several studies and trials have been conducted on co-existence between wireless systems in [8], [9], [10]. The authors studied local LTE to PMSE interference in a field measurement campaign presented in [14]. ECC Recommendation 15(01) considers cross-border coordination of 4G and 5G Mobile/Fixed Communications Networks (MFCN) to avoid harmful interference and provides guidance for synchronized and unsynchronized MFCN TDD network operation [11]. ECC Report 296 [12] considers co-existence 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) [13].

The authors previously conducted an extensive laboratory measurement campaign to obtain an understanding on how the different frame configurations affect the interference between local networks [15]. Results of laboratory measurements conformed to the possibility of severe decrease in data throughput if the TDD frame configurations of two local networks are not synchronized, which was also noticed in simulations presented in [13]. Link level throughput degradation due to CTI in LTE TDD networks is evaluated also in [16]. This paper extends the previous studies with a field measurement campaign to study the interference in realistic operating conditions.

The paper is organized as follows: Section II describes the interference scenarios and modes in TDD networks, Section III describes the field measurements, Section IV the measurements results, while Section V gives the concluding remarks.

II. INTERFERENCE SCENARIOS AND INTERFERENCE MODES IN TDD NETWORKS

Several radio interface interference mechanisms exist between two independent local networks. Main uplink/downlink

TABLE I. POSSIBLE FRAME CONFIGURATIONS

Config.	Switch Period	0	1	2	3	4	5	6	7	8	9	D	U	S	D/U
1	5 ms	D	S	U	U	D	D	S	U	U	D	4	4	2	1/1
2	5 ms	D	S	U	D	D	D	S	U	D	D	6	2	2	3/1

BS/UE geometries and interference modes are illustrated in Fig. 1. UE to UE interference is not considered in this study because assumption is that UEs are near ground level and in limited geographical area in local networks. Drones could be an exception and are subject to a future study. Mechanisms are different if base stations use the 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. Local LTE networks may use different bandwidths (BW), for example in Finland 5, 10 and 20 MHz, which also affects the level of interference.

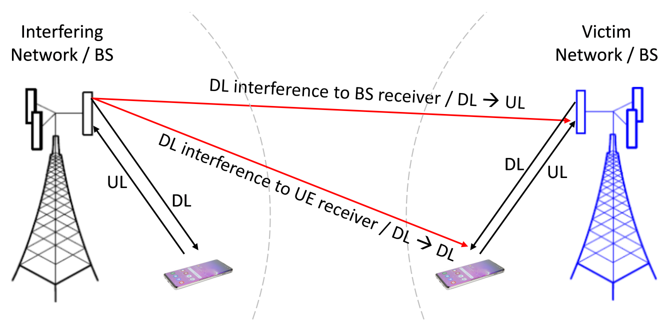

Fig. 1. Interference modes.

Even if the networks are synchronised 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 synchronised 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. Even though the standard defines 7 different frame configurations (0 to 6) the practical implementations include only a few. The base stations used in the measurement were capable to use only frame configurations 1 and 2. Table I reproduces these frame configurations with calculated D/U ratios. As can be seen configuration 1 has the same uplink and downlink capacity and configuration 2 three times more downlink than uplink capacity.

In this measurement campaign the synchronised cases use frame configuration #1 in both base stations and in non-synchronised cases the victim base station use frame configuration #1 and the interfering base station frame configuration #2. This way there are two time slots in the frame where the DL can interfere UL.

III. FIELD MEASUREMENTS

A. Measurement setup

Measurements were done with the field trial setup of the 5G Test Network Turku (5GTNT) of Turku University of Applied Sciences [17]. Fig. 2 shows the general measurement arrangement. General methodology for conducting field measurements to study wireless co-existence is described in detail in [18].

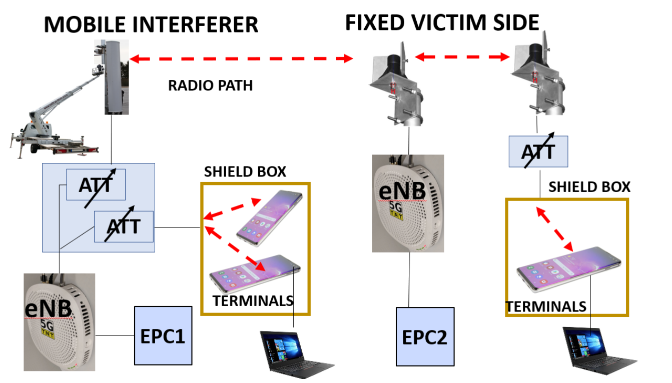

Fig. 2. Measurement set up. Victim base station on the right and interferer base station on the left.

The victim base station was set up at the 6th floor roof of the TUAS ICT building. UEs attached to the victim eNB were inside a shielded box to ensure high RSRP and stable signal and accurate DL/UL speed measurements. Signal for UE was provided by an extra antenna close to the base station antenna and fed via the cabling to 2nd floor and to the antenna inside the shielded box. UE RSRP signal levels were controlled by RF attenuators in the feed cables to the shielded boxes.

The two base stations are using separate core networks to prevent any terminal handovers between base stations. The interferer side downlink was loaded to maintain maximum data speed so that all DL subframes had the same power levels. 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 dBm to +24 dBm. 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, which eliminates any external congestions in speed testing.

B. Interfering base station locations

Field measurements were done in Turku with the victim base station in Kupittaa at the TUAS ICT building 6th floor (roof) and interfering base station in 4 different locations: Kupittaa sand field, Veritas stadion, Retro Dorm and Ilpoinen.

TABLE II. INTERFERING BASE STATION LOCATIONS

Location	Name	Distance [m]
1	Sand field	93
2	Veritas	570
3	Retro Dorm	1600
4	Ilpoinen	2900

Fig. 3. Interfering base station locations 1, 2, 3, and 4

Distances varied from 93 m to 2900 m. Location details are listed in Table II and the locations are shown in Fig. 3.

As interfering base station locations 2, 3 and 4 are more or less in the same direction from the victim base station, a single terrain profile can be shown as Fig. 4. It can be seen that locations 1 to 3 are in line of sight (LOS) conditions, but location 4 is clearly non line of sight (NLOS) condition. Victim base station height at ICT building is estimated to be 50 m above sea level.

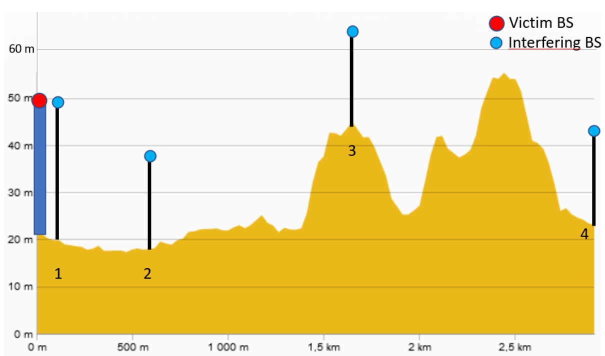

Fig. 4. Terrain profile

IV. MEASUREMENT RESULTS

A. 20 MHz LTE co-channel, frame configurations #1 and #1

First the case where the base stations have the same frame configuration 1 and should in principle cause no interference, was measured. This was studied on the roof because it was possible to have higher power levels due to small separation between the base stations.

Frame configuration # 1, power 24 dBm and frequency 2310 MHz were used for both victim and interfering base stations. The interfering base station was set to 6 m distance from the victim BS. First the victim downlink and uplink speeds were measured as function of UE RSRP without any interference. The results are shown in Fig. 5.

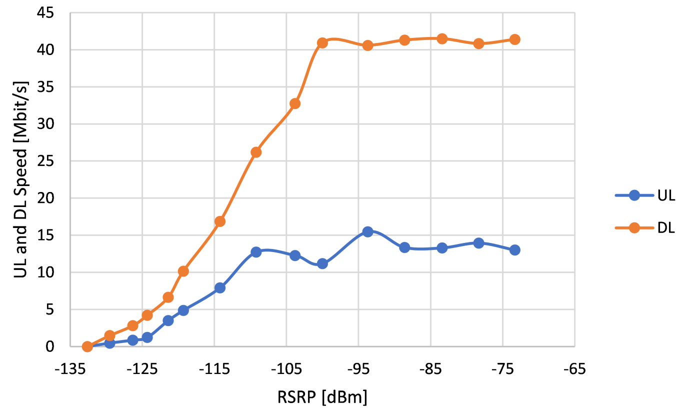

Fig. 5. Victim UE UL and DL speeds as a function of UE RSRP without interference, frame configurations #1 and #1.

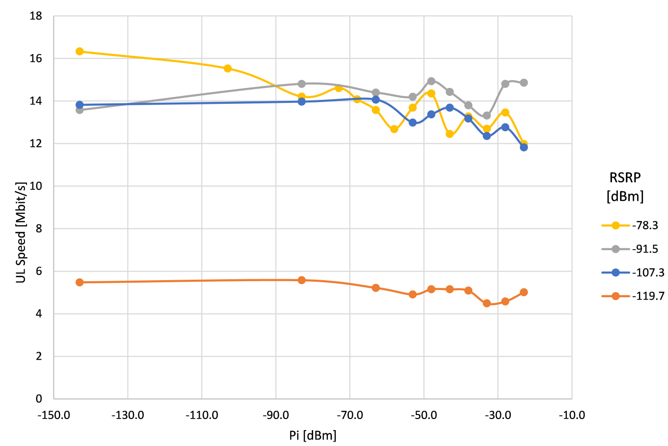

Fig. 6. Victim UE UL speed as a function of interfering power at different UE RSRPs, frame configurations #1 and #1.

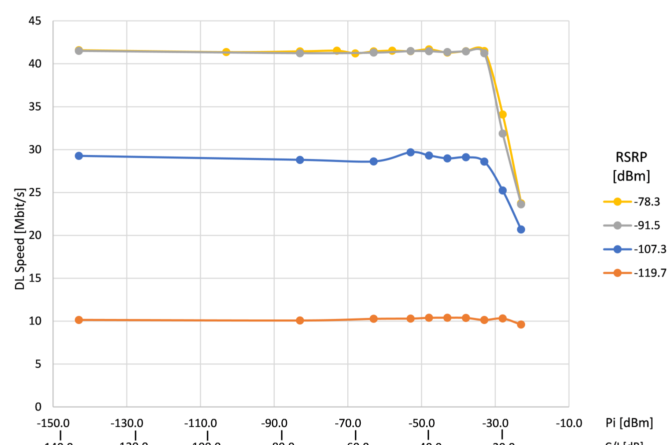

Fig. 7. Victim UE DL speed as a function of interfering power and C/I at different UE RSRPs, frame configurations #1 and #1.

Next, interference was turned on and victim UE UL and DL data throughputs were measured as a function of interfering power at four different victim UE RSRPs, see Fig. 6. The uplink speed has some variations (probably code rate fluctuations), but no real interference is visible as expected.

On the downlink speed, however, there is a clear drop on the three higher RSRPs, see Fig. 7. This due to the DL to DL interference. Fig. 7 has a secondary x-axis for UE C/I. It can be seen that the DL speed starts to decrease at about 25 dB C/I. This is in line with the earlier laboratory measurements.

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

1) Location 1 Sand field: Location 1 was a temporary parking place almost next to the ICT building with approximate distance of 93 m from the victim base station, see Fig. 3 left. The interfering base station antenna was only slightly lower than 6th floor roof antennas. However, it became clear from the path loss measurements that the interfering base station antenna was not optimally tilted vertically. First a signal generator connected to the interfering base station antenna was used to measure the true loss between the antenna feeding points. This was found to be some 16.5 dB lower than calculated with free space loss and nominal antenna gains. This is due to misalignment of both base station antennas. However, as the measured loss was used to calculate the true interfering power, any uncertainties in the antenna alignment do not affect the results.

DL to UL interference was measured at four different victim UE RSRP levels -78.3 dBm, -92 dBm, -107.8 dBm and -119.9 dBm, the highest representing very good signal and the lowest close to the edge of the service area. For each RSRP level the interference level was adjusted with attenuator 1 from the lowest to the highest level with appropriate steps. For each step victim UE UL and DL speeds were measured. Results for the uplink speed are shown in Fig. 8. Upload speed is starting to decrease somewhere between -95 to -100 dBm interference level. This is fairly well in line with the laboratory measurement and can also be compared with the generally used -6 dB I/N criteria, which would give a level of -106 dBm. When DL speed is added to the same graph, we get Fig. 9. The DL speed seems to drop also, but this is not due to DL-DL interference, but rather since at these points the UL speed is close to zero and seems to affect also the downlink. This can be confirmed by calculating DL C/I, which at the -60 dBm interference level is still 35 dB.

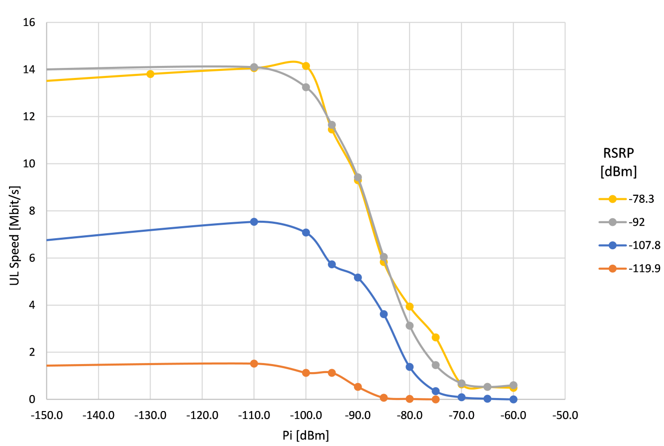

Fig. 8. Victim UE UL speed vs interference power at different victim UE RSRPs, frame configurations interferer #1 and victim #2, location 1.

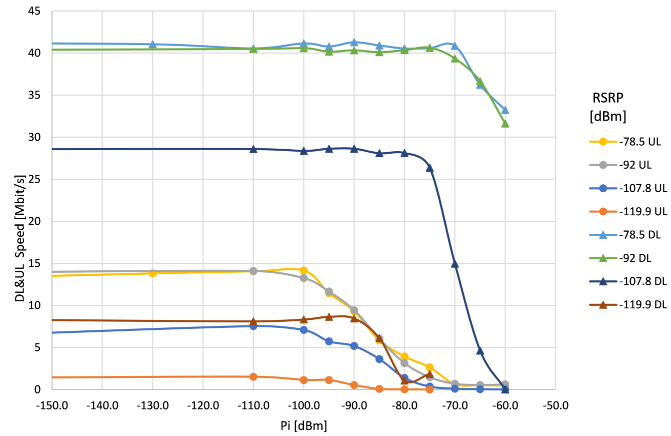

Fig. 9. Victim UE UL& DL speed vs interference power at different victim UE RSRPs, frame configurations interferer #1 and victim #2, location 1.

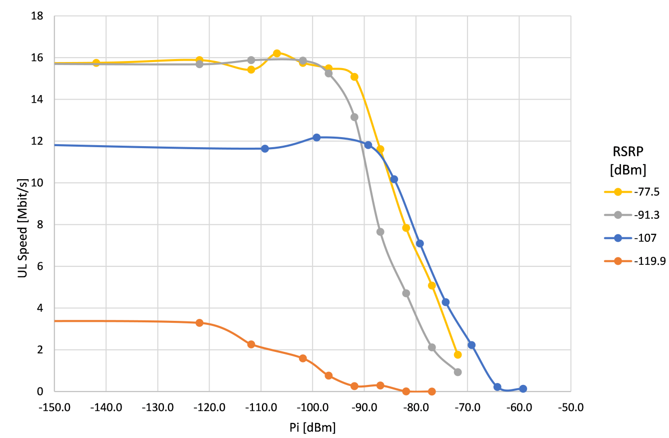

Fig. 10. Victim UE UL speed vs interference power at different victim UE RSRPs, frame configurations interferer #1 and victim #2, location 2.

2) Location 2 Veritas Stadion parking place: Location 2 was parking place in front of Veritas Football Stadion, with approximate distance of 570 m from the victim base station, see Fig. 3 second photo from the left. High gusty winds prevented using the full height of the lift, antenna height remaining to about 20 m. Also, at this location the true loss between antenna feeding points was measured by using a signal generator and spectrum analyser. Assuming LOS conditions the total antenna gain seems to be 12.7 dB less than nominal. At this location, however, the difference is most probably not only due antenna misalignment, but also due to clearly higher path loss than LOS path loss model gives. The true measured loss is used to calculate the interfering power at the victim side. DL to UL interference measurement with four different victim UE RSRPs is shown in Fig. 10.

With the two highest RSRPs the UL speed starts to decrease around -95 dBm. The -107 dBm RSRP curve drops only over -90 dBm interference. In the -119.9 dBm RSRP curve the first drop between -120 and -110 dBm is due to modulation change. Interference drop occurs between -95 and -100 dBm. Victim UE DL speed in shown in Fig. 11. At this location only the two DL curves at the lowest RSRP drop due to the corresponding UL decreasing to almost zero. The curves at the

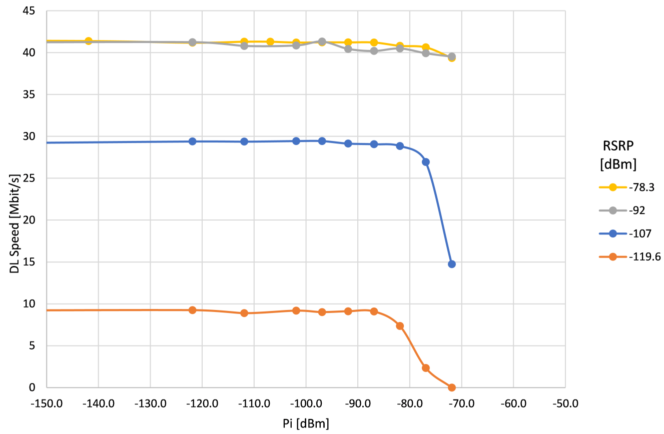

Fig. 11. Victim UE DL speed vs interference power at different victim UE RSRPs, frame configurations interferer #1 and victim #2, location 2.

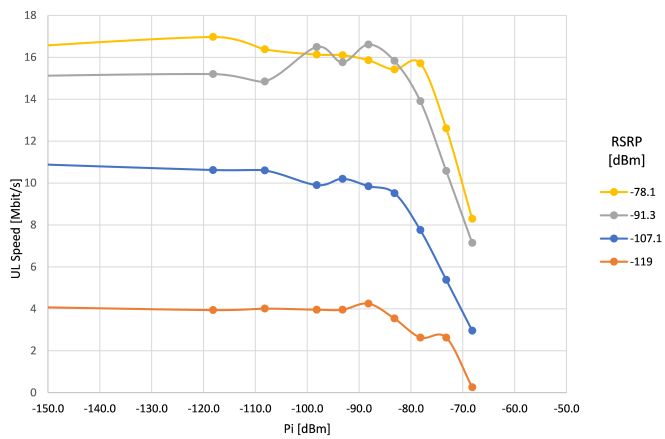

Fig. 12. Victim UE UL speed vs interference power at different victim UE RSRPs, location 3.

two highest RSRP don't have this behaviour as the UL speed remains higher. Nominal C/I is always more than 51 dB so the source is not DL to DL interference.

3) Location 3 Retro Dorm: Location 3 was Retro Dorm, some sort of student dormitory, with approximate distance of 1600 m from the victim base station, see Fig. 3 second photo from the right. Also here high gusty winds prevented using the full height of the lift, antenna height remaining to about 20 m, but just above the trees. Because of the longer distance and higher loss, it was not anymore possible to measure the true path loss due to the dynamic range of the measurement equipment. Calculated LOS and NLOS path losses are 108.4 dB and 136.2 dB respectively. True path loss is between these figures. Antenna tilt is not anymore critical at this distance. All interference power values in the graph are calculated values using LOS path loss of 108.4 dB. This means that the indicated power is higher than true power.

UL interference results with four different victim UE RSRP are shown in Fig. 12. Behaviour is rather similar than in the previous locations, but the corner point for the curves is now around -80 dBm. This is due to the way the interference power is calculated as explained. If we assume that the real corner point would be around -95 dBm, we get an estimation for the

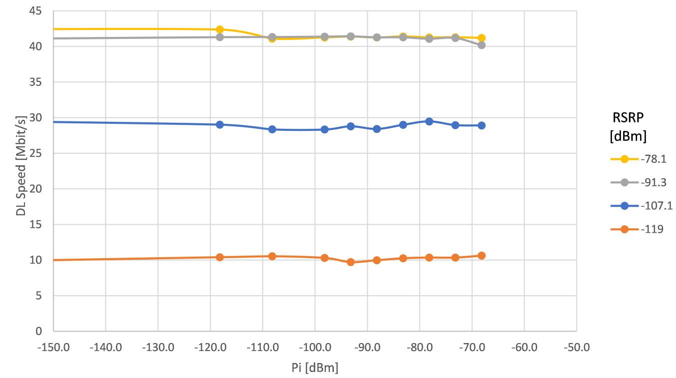

Fig. 13. Victim UE DL speed vs interference power at different victim UE RSRPs, location 3.

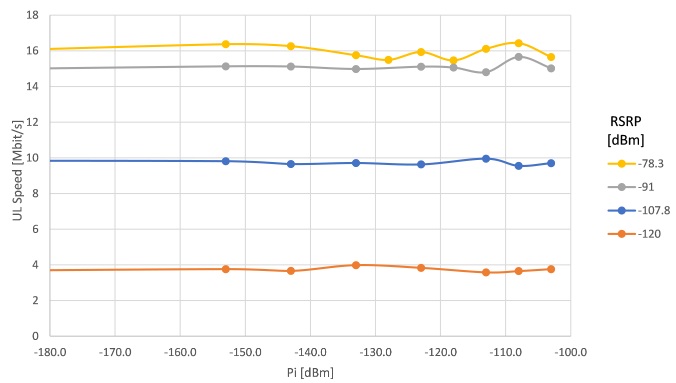

Fig. 14. Victim UE UL speed vs interference power at different victim UE RSRPs, location 4.

path loss to be about 15 dB more than calculated LOS value, resulting 124 dB path loss. Downlink speed, as shown in Fig. 13, does not have any drop, but remains constant. The lowest C/I is about 60 dB with the highest interference power of -68 dBm so DL to DL interference is not possible.

4) Location 4 Ilpoinen: Location 4 was Ilpoinen with approximate distance of 2900 m from the victim base station, see Fig. 3 right. High wind continued and the antenna height was again about 20m. Ilpoinen was clearly a NLOS location as can be seen from the terrain profile Fig. 4. Using NLOS propagation model we get 143.2 dB path loss. This was used to calculate the interfering power as it was not possible to make a direct path loss measurement as in locations 1 and 2. The measured interference curves at different RSRPs are shown in Fig. 14. In this location there was no indication of DL to UL interference. This is fully understandable as the highest calculated interference power is about -103 dBm and typically the interference starts to occur on higher levels than -100 dBm. Fig. 15 shows the DL speed at different RSRPs. As expected, there is no drop of speed due to interference. Calculated C/I is always better than 95 dB.

V. Conclusions

The main objective of the presented field measurement campaign was to confirm that the laboratory measurement results of LTE local network systems using 2.3 GHz TDD technology in [15] and simulations such as [13] are valid in

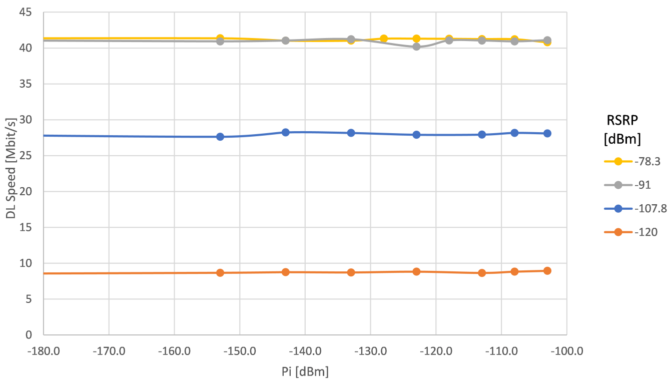

Fig. 15. Victim UE DL speed vs interference power at different victim UE RSRPs, location 4

real operating environments. The field measurements focused on the DL to UL interference using TDD LTE technology.

Severe throughput capacity reduction may occur when base station transmitter DL timeslots overlap adjacent network base station UL received timeslots. On the three closest locations propagation was line-of-sight and DL to UL interference was observed at the victim base station. Interference power level threshold of -100 dBm to -95 dBm in the base station receiver input was observed to cause victim UL speed to start dropping. This is less than -106 dBm with the -6 dB I/N criteria, and would mean that the criteria itself would include a significant margin. On the fourth location, no interference was observed due to clear NLOS conditions and high path loss. Interfered UL speed is decreased by 50 % when interfering power increases 10 dB above the threshold. These levels were in line with the earlier laboratory measurements [15]. On all field locations DL speed decreased, although no DL to DL interference was observed. The reason probably was that the almost zero UL speeds affected also the DL speed throughput when the UL was interfered.

Field trial results confirm that the comprehensive laboratory measurement results [15] can be used as a basis for interference estimations. The results reveal the challenges in the planning of local 4G or 5G networks using overlapping frequencies and TDD technology. Knowledge of adjacent network parameters like: TDD frame patterns, radiated powers, antenna radiation patterns and heights are essential in the planning and site engineering of local networks to reduce interference probability and avoid capacity reduction compared to synchronized TDD networks.

Further, the measurement campaign results can be used in the development of spectrum regulation for local networks, and have already been used in developing the Finnish regulation for local networks. As TDD is the main duplexing scheme in 5G, the results can also be used for 5G local networks.

The future measurement campaigns concentrate on using the developed field trial methodology and measurement setup to study the co-existence of 4G-5G and 5G-5G local networks and drones in local networks.

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