Joint Macro and Femto Field Performance and Interference Measurements

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Abstract **– In this paper macro performance in a co-channel macro and femto setup is studied. Measurements are performed in a live Universal Mobile Telecommunication System (UMTS) network. It is concluded that femto interference does not affect macro downlink (DL) performance as long as the macro Received Signal Code Power (RSCP) is stronger than femto RSCP. We also conclude that a macro escape carrier is a robust DL interference management solution. In uplink (UL) direction it is shown that a single femto UE close to macro cell can potentially cause a noise rise of 6 dB in the surrounding macro cell. In order to limit the noise rise from femto UEs, femto UE power capping and lowering femto common pilot channel (CPICH) power is recommended. The consequence is less uplink interference towards the macro, but also decreased femto coverage. Measurements close to macro cell centre showed femto coverage radius smaller than 5 meter – with realistic power settings. This makes co-channel femto deployment less promising in dense macro environments with good macro RSCP coverage.**

I. INTRODUCTION

In the next couple of years mobile data traffic is expected to increase by 92% per year between 2010 and 2015 [1]. To cope with such an increase network operators are required to upgrade the current mobile networks. One potential solution to increase the capacity in existing networks is femto cells. Femto cells are low powered and low priced access points intended for indoor deployment. The low price of femto cell deployment is a consequence of femto cells being self configuring allowing for uncoordinated mass deployment. Furthermore the femto backhaul is expected to be the end user's own fixed internet connection. The fact that femto cells are meant for indoor deployment gives certain advantages over macro cells, namely that the femto cells are inside the same building as the UE being served. This means that there is no additional outdoor to indoor building penetration loss – a factor which could worsen the link budget by some 20 dB or more.

Femto cells can operate in open access or in closed subscriber group (CSG) mode [2]. In CSG mode only a certain group of UEs are allowed to connect to the femto cell. This can potentially limit the performance of macro cell users that do not belong to the CSG list. In this case the femto cell is a severe source of interference – potentially creating a coverage hole in the macro cell. If not dealt with, a dense femto deployment can have a strong impact on macro cell performance. Therefore, interference management schemes are fundamental if femto cells are to become a success in the future.

Today the open literature includes many performance studies for co-channel deployment of macro and femto cells. Various interference management solutions have been extensively studied for such cases for both HSPA and LTE; see [3-6]. However, the majority of these existing performance and interference management studies rely solely on theoretical models and simulations, and therefore the validity of the conclusions depends on the underlying assumptions. Contrary to those previous studies, we here present field measurements for both co-channel deployed macro and femto cells, as well as cases with the availability of a macro escape carrier, free of femto interference.

Our objective is to show representative results from a co-channel macro and femto deployment scenario. As a case study, we present results for HSPA, but many of the results presented can be extended to LTE as well. In this paper, we investigate the interference caused by femtos and femto UEs. Thus, several femto locations are chosen for interference measurements, including femto locations at macro cell edge and macro cell centre, as these locations cover the extremes in terms of path losses to the macro site. It is expected that the interference from femtos in DL is stronger at macro cell edge, whereas interference from femto UEs in UL is worse at macro cell centre, as a consequence of the path loss relations. We also measure the performance of the escape carrier scenario.

The rest of the paper is organised as follows. Section II describes the measurement locations and the macro and femto deployment scenario. In Section III the measurement procedure and equipment are presented. Section IV covers co-channel interference measurement results while Section V includes the escape carrier findings. Finally, Section VI concludes the paper.

II. MEASUREMENT SETUP

The measurement campaign was carried out at the campus area of Tampere University of Technology (TUT). A Nokia Test Network (NTN) macro cell base station provides macro coverage to the entire TUT campus area and has been utilised during the measurements campaign. The sector antenna of macro cell base station was mounted on top of a nearby 4-storey office building. The femto cell was deployed in offices, lecture rooms and hallways at TUT. Basically the only constraint for femto deployment is available power and network plugs. The locations of macro and femto cells together with the measurement routes are shown in Figure 1. There are no buildings between the macro site and location 3

978-1-4673-1881-5/12/$31.00

(line of sight propagation conditions), while a single 4-storey building is located between the macro site and both location 1 and 2. The distance between the macro site and the femto cell locations varies between 250 meter (Location 3) and 600 meter (Location 1).

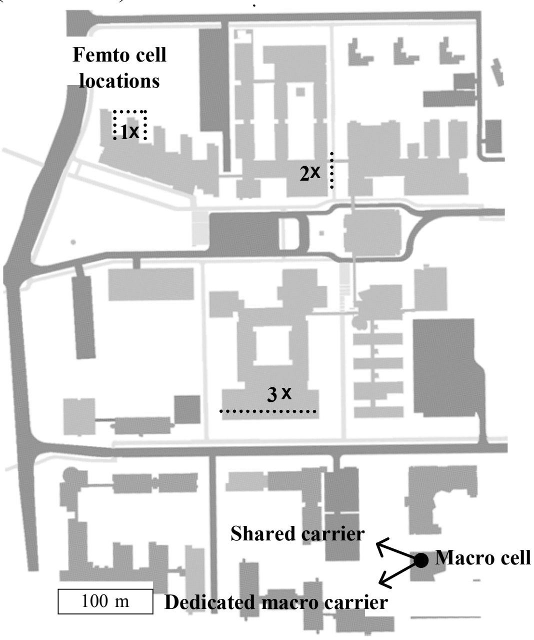

Figure 1 – Femto cell locations and macro cell sector direction. Dashed lines are the DL interference measurement routes.

All 3 femto locations were used for DL interference measurements while only location 1 (macro cell edge) and 3 (macro cell centre) were used for the UL interference measurements. Location 2 was used for the escape carrier scenario [5]. The main parameters of the femto and macro cells are gathered in TABLE I.

TABLE I MAIN PARAMETERS OF FEMTO AND MACRO

Parameter	*Unit*	*Femto*	*Macro*
Total Tx power	dBm	{0; 5; 14; 20}	43
Antenna gain	dBi	0	17
Antenna height	m	–	20
Cable loss	dB	0	3
UARFCN		10662	{10662; 10638}
3GPP Release		8	6
HS-PDSCH codes		max. 15	max. 15
P-CPICH Tx power	dBm	{-10; -5; 5; 10}	33
Max UE Tx power	dBm	{-13; 0}	24

Throughout the measurement campaign a single femto access point [7] was deployed at the measurement location and the femto backhaul was an internet connection at the TUT network. The backhaul capacity was measured to be more than 40 Mbps. Most measurements were performed after office hours to minimise the possibility of having other active UEs in the network and reduce the disturbance from people in the measurement area.

III. MEASUREMENT EQUIPMENT AND PROCEDURES

The DL interference and escape carrier measurements were performed with a UE dongle [8] connected to a laptop with measurement software [9]. Measurements are performed outdoor while moving along the pre-planned measurement routes outside the femto buildings. Four sets of measurements are conducted:

1. Femto is turned off, and outdoor UE is kept in CELL_DCH state measuring macro RSCP and E_C/I_0.
2. Femto performing a High-Speed Downlink Packet Access (HSDPA) data transmission and outdoor UE is kept in CELL_DCH state measuring macro RSCP and E_C/I_0.
3. Femto is turned off, and outdoor macro UE is performing an HSDPA data transmission while measuring macro RSCP, E_C/I_0 and DL throughput.
4. Femto performing HSDPA data transmission and outdoor macro UE is performing an HSDPA data transmission while measuring macro RSCP, E_C/I_0 and DL throughput.

By comparing the different sets of measurements it is possible to determine the interference caused by the femto, as well as the corresponding effect on the macro UE throughput.

For the macro escape carrier measurements a neighbouring macro site sector was configured to a dedicated macro carrier. In an ideal escape carrier scenario both the shared carrier and the dedicated carrier would be configured on all three macro site sectors. In our setup the consequence of using two different sectors is that the dedicated carrier RSCP is 7 dB lower than the shared carrier RSCP. In the ideal escape carrier setup the dedicated and shared carrier RSCPs would be similar assuming similar frequencies. This configuration was chosen because of the required time to configure the macro site. Inter-frequency measurements are triggered when the serving cell E_C/I_0 goes below -15 dB. If a neighbouring inter-frequency cell E_C/I_0 is above -13 dB, an inter-frequency handover is started. Time to trigger is 100 ms [10].

The UL macro interference measurements were conducted at location 1 and 3. During these measurements, the femto UE was performing a High-Speed Uplink Packet Access (HSUPA) transmission while transmitting at maximum transmitting power. In order to cause maximum possible UL noise rise in the macro cell the UE is going to the femto cell edge area, thus increasing the UL transmission power. Macro cell measurements of the uplink noise rise are reported to the Radio Network Controller (RNC). The RNC stores those measurements for later data analysis.

IV. CO-CHANNEL INTERFERENCE MEASUREMENTS

This section covers the co-channel interference measurement results. It is investigated how indoor femto deployment affects macro DL performance and contributes to noise rise in the surrounding macro cell.

A. DL Interference Measurements

For the DL interference measurements one femto cell is deployed in a building at macro cell centre and at macro cell edge. Only the results from macro cell edge are presented due to page constraints. Macro cell edge results are chosen because of larger path loss from the macro site to cell edge location, and therefore they represent the worst case in terms of propagation. Maximum femto transmission power is 20 dBm, and femto CPICH power is 10 dBm. The measurements were repeated 10 times, and the figures in this section show the average of all measurements.

Figure 2 shows macro RSCP and femto RSCP when measuring at location 1. It is shown that the macro RSCP varies from -90 dBm to -80 dBm.

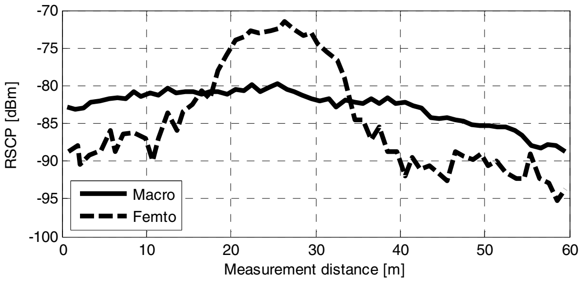

Figure 2 - Macro and femto RSCP measurements, location 1.

More interesting are the femto RSCP measurements. At the first 10 meter and the last 20 meter the femto RSCP is around -90 dBm, thus lower than the macro RSCP. From 18 to 35 meter the femto RSCP is better than macro RSCP. After 25 meter femto RSCP peaks and reaches -73 dBm, 7 dB above the macro RSCP. At this location the femto and measurement UE are only separated by a solid outer wall with metal coated windows.

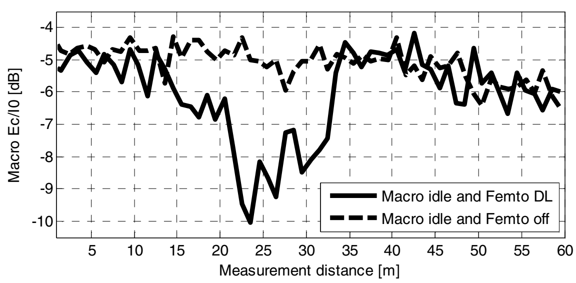

Figure 3 - Femto interference effect on macro E_C/I_0, location 1.

Figure 3 shows how much the macro E_C/I_0 is affected by a fully loaded femto. At the first 10 meter and last 25 meter the femto has no effect on the macro E_C/I_0 as there is no significant difference in macro E_C/I_0 when the femto is turned on with full load and when the femto is turned off. At the middle part of the measurement route the macro E_C/I_0 drops to -10 dB (5 dB smaller than in non-interfered locations) caused by femto interference. Comparing Figure 2 and Figure 3 reveals that the macro E_C/I_0 is only degraded when the femto RSCP is better than the macro RSCP.

Figure 4 shows how the macro UE throughput in DL is affected by the femto. As expected the only significant difference between the fully loaded femto scenario and femto off scenario is when measuring close to the femto, from 20 to 35 meter. At this part of the measurement route the macro throughput is reduced by more than 2.5 Mbps compared to when the femto is switched off, but still achieved almost 3 Mbps on average. On the remaining part of the route there is no noticeable difference between the loaded femto and switched off femto measurements.

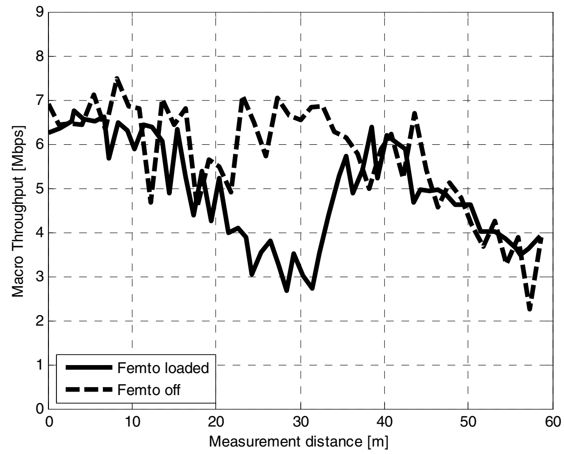

Figure 4 - Macro cell throughput, location 1.

Based on the measurement results from all locations, the general conclusion is that if the macro RSCP is better than femto RSCP, then the macro throughput is not affected by the femto presence, regardless of the femto load. Also, if the macro RSCP and femto RSCP is at the same level or femto RSCP above macro RSCP, then the femto cell makes the macro performance worse. However, in the most interfered locations the outdoor macro throughput keeps staying around 3Mbps on average.

B. UL Interference Measurements

The objective of the UL macro interference measurements is to determine the noise rise from a single femto UE. UL interference measurements were conducted with the femto deployed at macro cell edge and cell centre. At macro cell edge the measured femto UE to macro path loss equals 120 dB and 100 dB for the macro cell centre location. From the RNC recordings the macro cell noise floor is measured to -105.5 dBm. At macro cell edge this implies a noise rise of 0.2 dB, when assuming femto UE transmission power of 0 dBm. At macro cell centre the noise rise contributed by the femto UE is estimated to be 6.6 dB. Measurements confirm the estimated noise rise. TABLE II compares the estimates with the measured noise rise values at macro cell edge and macro cell edge.

TABLE II MACRO NOISE RISE FROM SINGLE FEMTO UE

	Macro cell edge	Macro cell centre
Estimated	0.2 dB	6.6 dB
Measured	0.0 dB	5.9 dB

The small differences between estimated and measured values can result from measurement accuracy, fading channels and the difficulty of forcing the femto UE to constantly transmit at 0 dBm during the measurements.

In network planning a total noise rise in the order of 3 dB is considered [11]. Hence, a 6 dB noise rise from a single femto UE is too large as it would compromise the macro coverage and, in worst case, leave areas without macro coverage. In practice multiple femto UEs would contribute to macro noise rise and worsen the problem. Therefore, it is paramount that a single femto UE cannot cause a noise rise of 6 dB. Potential solutions to limit the noise rise are power capping the femto UEs lower than 0 dBm, reducing the femto CPICH power, or a combination of both.

Additional measurements with reduced femto CPICH power and power capping the femto UE at -13 dBm were therefore performed. The femto CPICH power was reduced to 5 dBm, -5 dBm, and -10 dBm. When lowering the femto CPICH power the femto coverage shrinks – due to more dominating macro CPICH – and less transmission power is required by the femto UE, thus reducing the contribution to macro noise rise. By applying the new power settings no noise rise contribution from the femto UE was measured at the macro site. Also the femto coverage with the updated power settings was measured. Femto coverage is defined as the area where the femto UE is able to camp on the femto. Measurements were performed by connecting to the femto in CELL_DCH state and then walking away from the femto. Then the distance to the end of the coverage was measured. Femto and femto UE were at all times in the same room/building without any indoor walls in between. This procedure was repeated 3 or more times.

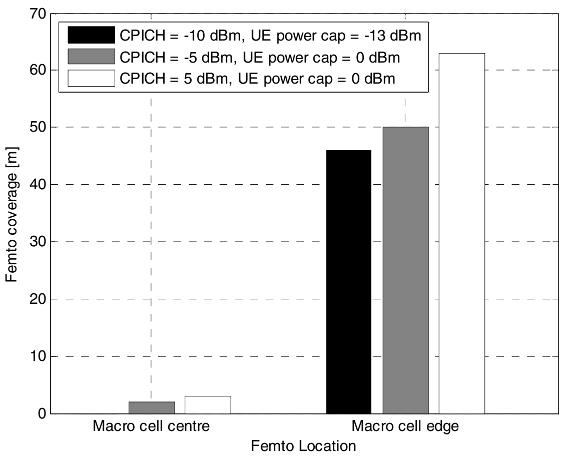

Figure 5 - Femto coverage at macro cell centre and edge for varying CPICH power.

Figure 5 shows the average femto coverage measurement results. At macro cell edge the femto coverage is larger than 45 meter for all CPICH powers. More interesting is the measured femto coverage at macro cell centre. The measurement results show that at macro cell centre the femto coverage is less than 5 meter. The reason for such a small femto coverage is a very good macro coverage. The macro RSCP is -65 dBm at the measurement location. In general it proved very difficult or nearly impossible just connecting to or camping on the femto due to dominating macro CPICH.

These results indicate that femto co-channel deployment close to macro cells becomes less attractive due to the limited effective femto coverage. In dense macro locations the probability of dominant macro RSCP over femto RSCP is high. Therefore, femto deployment is more attractive in areas with less dominant macro RSCP, such as e.g. macro cell edge, residential, or rural areas. At these locations the femto can provide coverage of up to 60 m depending on power settings.

V. MACRO ESCAPE CARRIER SCENARIO

All previous measurements were performed in a co-channel macro and femto setup. In this section the so-called macro escape carrier scenario is studied. This means that an additional dedicated, femto-free macro carrier is available. The idea is that macro UEs, on the shared carrier, can hand over to the dedicated macro carrier if the macro UE experiences strong interference from a CSG femto, thus avoiding potential macro coverage holes. All escape carrier measurements are performed at least 6 times, and the following figures show the averaged measurement results.

Figure 6 shows the femto RSCP and co-channel macro RSCP on the measurement route. When walking on the measurement route at location 2 you walk towards the femto and away from the macro; see Figure 1. This is also visible as the femto RSCP increases and co-channel macro RSCP decreases.

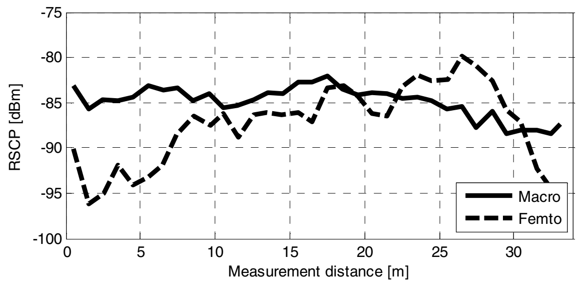

Figure 6 – Co-channel femto and macro RSCP on measurement route.

In Figure 7 the macro E_C/I_0 is shown. We measured back-and-forth on the measurement route, thus "Start of route" is shown twice. Both a femto UE and a macro UE are performing a HSPDA download during the measurements.

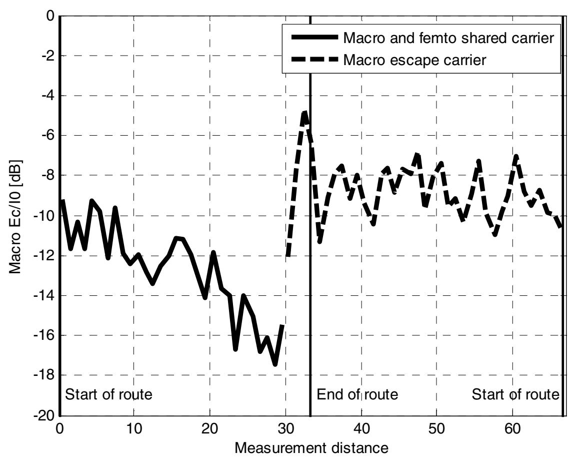

Figure 7 - Macro E_C/I_0 on co-channel carrier and on dedicated carrier.

At the start of the measurement route the macro E_C/I_0 is -11 dB on the co-channel carrier. As the macro UE gets closer to the femto, the macro E_C/I_0 deteriorates because of femto interference. Right before the end of the measurement route an inter-frequency handover to the dedicated carrier is completed. After the handover the macro E_C/I_0 is -9 dB. Close to the femto, the measured E_C/I_0 decreases by almost 8 dB with reference to the level at the start of the route, but the macro UE is able to recover from the femto interference by handing over to the macro escape carrier. During the measurements the HSDPA session always continued on the escape carrier, except for a HSDPA transmission break for a couple of seconds during the inter-frequency handover, as illustrated in Figure 8.

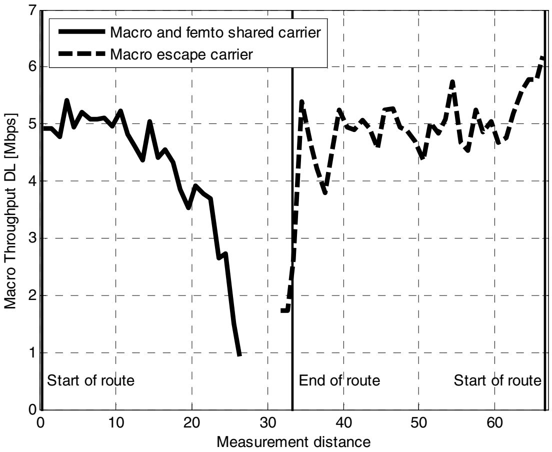

Figure 8 - Macro throughput on co-channel and on dedicated carrier.

Prior to the measurements, no inter-frequency mobility optimisation was performed. Macro UE throughput dropped to 1 Mbps before the handover was triggered. With optimised mobility parameters the handover might be triggered earlier. However, handover optimisation is out of the scope of this paper, and the default mobility parameters are considered reasonable.

Based on the measurement results the macro escape carrier scenario proved a good, robust interference management solution in DL direction. The main drawback of the solution is the obvious requirement of two carriers. Also, the escape carrier scenario only resolves femto interference in DL. For additional UL interference management solutions, see Section IV.B.

VI. CONCLUSION

This paper studied the consequences of co-channel macro and femto deployment from an interference point of view and also suggests potential solutions in case of strong femto interference.

Based on our results we conclude that as long as the macro RSCP is better than femto RSCP, the macro UE DL performance is most likely not being degraded. Basically this means that as long as the femto is deployed indoor, and macro UEs are located outdoor, an acceptable macro performance is guaranteed. Our worst case result showed that an outdoor macro UE was still served with almost 3 Mbps in DL.

In situations where strong femto interference is inevitable, e.g. macro UE entering buildings with one or more femtos deployed, the macro escape carrier proved a good interference management solution. Whenever the serving macro E_C/I_0 dropped below the threshold for inter-frequency handovers, due to femto interference, an inter-frequency handover was triggered and executed. And we never experienced any dropped connections. The drawback of this interference management solution is the need of two or more available UMTS carriers.

What is more critical is the UL noise rise towards the macro when the femto is deployed at macro cell centre. A UL noise rise of 6 dB was measured. This is clearly unacceptable. Reduced femto CPICH power and femto UE power capping was investigated, but the outcome was very small femto coverage area. The consequence is that co-channel femto deployment is only an option in locations with no dominant macro, e.g. rural areas.

Considering both the DL and UL findings the concluding femto co-channel deployment guidelines are: indoor co-channel femto deployment is most useful at macro cell edge, and furthermore, a network operator should always deploy a femto-free macro escape carrier in order to guarantee reliable macro coverage.

ACKNOWLEDGMENT

We would like to thank Jarno Niemelä for fruitful discussions and troubleshooting of the femto setup, Jari Kossila for macro network configuration, NSN Femto Support in Wroclaw, Rajadurai Subramaniam and Rohit Ahuja for helping out with femto measurements, and Anite for providing the necessary measurement equipment.

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