Current Development and Innovations in the Area of Femto Cells

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***Abstract*—This paper gives an overview about current issues with femto cell networks and introduces some of their possible approaches. Due to the technical varieties in means of operating such a network, e.g. private heterogeneous LTE-only networks or public two-tier mixed service networks, different problems may occur. The first main point will cover interference with existing structures and between femto cells. A second point will address handover issues such as streaming (e.g. video calling) while changing from Wi-Fi to a macro cell and subsequently to a private femto cell, which also addresses the problem of seamless continuation of a connection. The paper will conclude with a comparison of existing and similar structures to the introduced ones and give a short overview of still uncovered research fields.**

I. Introduction

Not just since the launch of the iPhone by Apple and precessing smart phones or tablet-computers, demand for higher mobile network availability increased. In the western world, the number of subscribers to mobile data networks have tripled from 2007 to 2011, as shown by the International Telecommunication Union (ITU)[1] The end of the fast-growing development is not in sight, as more different services such as video streaming or calling, online gaming and social networking are likely to become more important.

The connection between a mobile device and the mobile carrier is routed via radio cells of different capacity over the so called air interface[2], meaning the digital data is transferred to electromagnetic waves and send to a cell. Its range chosen by the carrier is ideally based on the expected usage. Conventional macro and micro cells as encountered across the land and in cities cover about $12.5\ \mathrm{km}^2$ or about $1\ \mathrm{km}^2$ [1] accordingly. Due to the increasing amount of GSM and UMTS traffic network carriers tend to distribute femto and pico cells which aim for mobile broadband covering in local areas. Though LTE femto cells are possible, they will not be covered in this paper as LTE technology is just starting to establish, however, several research groups take LTE femto cell issues up. [2], [3] The difference between femto and pico cells[3] is their range; while pico cells cover bigger areas such as a company's premises, a femto cells application is its usage as a hot spot. Those hot spots can be placed either by the mobile carriers or by its customers — the aim for the second model is having a device which can simply be connected (via Ethernet cable) to the internet and start working, hence ensuring its operability for users not skilled in radio routing. [1]

Femto cells have an average radius of 20 m and are therefore used for mobile network coverage in a single flat or on central places in a city. The goal of such femto cells is to increase bandwidth, because while fewer users may actually connect to a femto cell, more femto cells may be distributed, thus allowing high bandwidth mobile usage in areas where macro cells would have to serve too many mobile devices to guarantee a sufficient high bandwidth or provide little or no mobile coverage due to geographic circumstances. They can either be open to every subscriber which is likely for carrier placed femto cells, closed to a particular group, e.g. residents of an apartment in which a femto cell is located or a femto cell can operate in hybrid mode, favoring a particular group by reserving bandwidth especially for them. [1], [4] This paper will mainly focus on user placed femto cells as they suffer most from introduced problems due to their possible great numbers as is shown in section II. Interference in wireless networks and due to their limited radius which is covered in section III. Handover from cell to cell. The differences between user placed and carrier placed femto cells will be pointed out in every section while their problems and impact are compared with each other.

II. Interference in wireless networks

When breaking mobile communications down to its basic physic principles, it is about electromagnetic waves, known to humankind since the 19th century physicists like Hertz and Tesla. The subsequent invention of the radio receiver led to the idea of interference based on the far older Huygens-Fresnel principle: when two or more waves collide, their amplitudes — the absolute values of their oscillation — are either added or subtracted, depending on their wave length. The signal amplification occurs only if the frequency of the two overlapping waves are common natural multiples which is unlikely, as most sources for interference emit waves on a broad spectrum from micro waves up to visible light. Therefore, such sources as competing radio stations of any kind, power plants, a thunderstorm or even common things like domestic appliances diminish the signal. [5] This section will concentrate on interference between macro or other femto

[1] http://www.itu.int/ITU-D/ict/statistics/. Last referenced 01-17-2012.
[2] Vocabulary for 3GPP Specifications, ETSI TR 21.905 V7.2.0
[3] In this paper, the terms pico cell and femto cell will be treated equivalent, as well as the terms macro cell and micro cell.

cells, because they are the only source of interference that can be regulated.

Interference happens to waves of the same frequency only, thus ruling out interference between two mobile operators as they offer their services on different frequency bands. [6] Macro cells of the same operator do interfere with each other so that the carrier is required to carefully plan their positions and signal strength which can be reduced to the graph colouring problem. [7] However, the described distribution model of femto cells may lead to areas with high interference between them as they share the same frequency band not only among themselves but also with the carrier's macro cells. Additionally, femto cells may be installed not just beneath, but also on top of each other, e.g. in a multi-story apartment house. [8]

Possible reasons for interference between femto cells may be a high signal strength, setting up two femto cells too close together or improper frequency usage. This applies especially to user placed femto cells as they are placed by "untrained users" [9] which is also called "Zero-touch installation" [10] , whereas carrier placed femto cells may be planned just as macro cells are, thus ruling out interference with them. [7] Nonetheless, carrier placed femto cells can experience interference problems with user placed femto cell. An example scenario for interference could be a subscriber at the outer limit of the femto cell's covered area. The subscriber has to increase his transmitting power (which is done automatically by the mobile device) in order to be receivable by the femto cell and therefore causing more interference with nearby macro cells, which decreases the signal strength for the subscribers of that macro cell. [1]

As the reasons for interference are known, several concepts for solving interference issues have been presented and will be discussed, separated by interference between femto cells and interference between macro and femto cells.

A. Interference management between femto cells

Once a femto cell is set up, it first searches for free channels or uses channels with low traffic and secondly chooses an appropriate signal level to avoid or at least minimize interference. But as soon as another femto cell is moved in its range or is set up nearby, their two signals may interfere. At that point, those two neighbouring cells have to negotiate for a possible solution. This can be done in three steps: detecting interference, detect the interferer and actual negotiation. Such algorithm can be computed either by a centralized server or between the femto cells themselves. While a centralized server has the advantage of easier implementation since most of the algorithms are graph-based and well known, but especially algorithms like graph colouring are NP-complete, meaning an exponentially increased demand for computation time with increasing numbers of femto cells, [7], [2] the opposing decentralized approach requires more complex algorithms and negotiations which is, however, possible and will be covered here. The principle for a centralized approach would be similar. [11]

1) Detecting interference: Detecting interference from other femto cells is not a trivial problem. The only indicator would be a decreased signal strength which also depends on movement of the mobile device or other emitters of electromagnetic waves mentioned at the beginning of this section. Therefore, a reasonable *interference detection unit* has to interact with subscribed mobile devices, measuring their movement, received signal strength indication (RSSI) plus the signal strength itself and interpreting those metrics.

Interpretation, on the other hand, holds new challenges, as temporary electromagnetic noise emitters or neighbouring channel-searching femto cells do not require any measures from the own femto cell, opposed to permanently interfering devices. Thus, femto cells need to constitute a maximum level of interference, influenced by time and packet loss which, when exceeded, leads to the second step. [11]

2) Detecting interfering cells: Getting the knowledge of neighbouring cells is essential for negotiation, as all reasonable solutions depend on fair participants. In this context, reasonable solutions would be any interference management strategies taking the needs of every participant into account, thus respecting their right to use mobile connections, too.

As an example, increasing the signal strength up to the maximum physical capabilities of the femto cell will solve most interference problems — but only for that cell and its subscribers. Others will suffer from even higher packet loss and decreased receptability.

One possibility for detecting interfering cells is to receive a list of nearby cells from the central backbone when being set up and updates whenever a new cell is installed nearby. That way, a cell can communicate with its known neighbours via the wired backbone and rule out any cell offering its services on a different channel, as they are not possible interferers.

As an alternative, cells can discover each other dynamically, identifying themselves as femto cells by a special discovery message broadcasted periodically. Advantages are the higher accuracy as only cells in actual range are listed and the independence from a central server. [11]

3) Initializing negotiation and possible outcomes: Negotiation best happens via the wired backbone and is easiest done directly between affected femto cells. The algorithm has to take into account that more than one femto cell may be affected, though. A solution with no disadvantages would be to simply switch the channel, if there are free or little used channels available. This requires negotiations with all participating femto cells, since any of them could select a new channel to avoid interference.

As shown in figure 1, if cell A detects an interference and starts negotiating with cell B to switch channels due to their interference, cell B should use another channel instead of cell A, because of cell C, which is unaffected by and therefore unknown to cell A but slightly interferes with cell B. Cell D, which operates on a different channel does not interfere with either cell, but when selecting a new channel, cell B should avoid D's frequency range. [11] The number of such possible constraints is bound to grow with the number of affected cells.

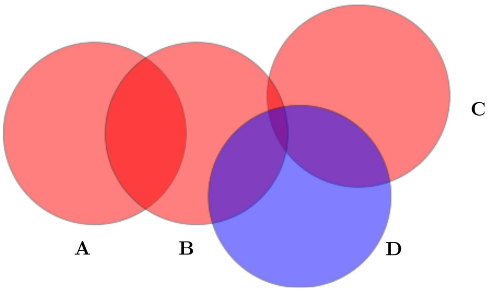

Fig. 1. Four femto cells next to each other, three of them using the same channel, causing interference.

If, maybe due to a dense deployment, no free channels are available, interfering cells have to negotiate power levels. Depending on the circumstances, either femto cell can regulate its maximum up- or downlink power levels, whereas usually all affected cells need to reduce their power to guarantee the highest possible signal strength for their users with a fair algorithm. Additionally, the mobile device itself may reduce its maximum transmitting power when assessed by the femto cell, if supported, to avoid situations like in the aforementioned example of a user on the edge of a femto cell's range. Because reducing the transmitting power for the femto cell or a mobile device always leads to a decreased signal strength and therefore a lower bandwidth and smaller coverage area, this solution may not always be as adequate as switching channels.

To improve the signal strength for subscribed mobile devices and at the same time not reducing the signal quality, the femto cell may also use dynamic power levels, depending on the subscribers position, e.g. when the only subscriber is in the same room as the femto cell, its transmitting power can be reduced to a minimum and still provide sufficient signal strength, though this may prevent other femto cells which are searching for an empty channel from detecting that femto cell, deciding to switch to that channel, thus creating a new source of interference as soon as the first femto cell has to regulate its power levels up. Since this should not happen too much, said scenario is unlikely. [10]

On top of those considerations is the account of the access mode of the femto cell. As shown in [4], the average bandwidth may also depend on whether or not a femto cell operates in closed or public mode. Under laboratory conditions open access femto cells have proven to provide a higher average bandwidth in some test cases. As this definitely is relevant for carrier placed femto cells, the significance for private operated femto cells is unclear, not just because of the laboratory conditions of the researchers' setup but also because the reasons for the higher average bandwidth are the general favouring of higher signal strength by an open access femto cell, which allows a higher bandwidth independently of the operation mode and the more non-restrictive dynamic power diminution which allows a greater range and a higher average signal strength. That paper may however provide high influence on network planning in companies with an own grid of femto cells, as an open access operation mode may prevent dead zones, if no macro cell is available or receptable in that area.

B. Interference management between femto and macro cells

Current distribution strategies show that femto cell infrastructure aims to be running on top of the current macro cell grid, also implying a requirement for interference management between femto and macro cells. As a matter of course, the receptability of the macro cell has a higher priority compared to the femto cell since more users are affected by poor reception of a macro cell's signal. As a result, differing interference management approaches are required. The technical solutions to any interference problems are similar to those introduced for interference management between femto cells so the focus can be laid to the actual management part. It is, however, believed that interference between femto and macro cells will be less important than interference between femto cells, mainly due to the limited range of the base stations and because a strong signal from a macro cell makes setting up a femto cell useless, so interference would be ruled out in the first place. [11]

Opposed to inter-femto interference, a femto cell's interference detection unit cannot tell macro cell interference apart from femto cell interference. However, since the macro cell has a higher priority than any femto cells in its range it can detect interference with an own interference detection unit and solve the conflict by identifying the interferer first and then start negotiating with the femto cell and its neighbours, similar to inter-femto interference. Because macro cells are placed by a mobile operator, interference between them can be kept to a minimum by considerate positioning of separate cells and appropriate choice of available bands. Frequency negotiation between macro cells does not happen and is only necessary between macro and femto cells. In case of interference, appropriate measures can be arranged via the wired backbone between a femto cell and its macro cell and be selected depending on the impact on other participants. [12]

If the number of femto cells within the range of the macro cell is low, interfering femto cells can avoid certain frequency bands used by the macro cell. This may evoke interference with other macro or femto cells and would therefore shift the problem to another base station. As a second point, changing the frequency band does not scale up, as they are expensive for the mobile operator and comparatively narrow, thus limiting the number of femto cells being able to switch their frequency band. [11]

A better solution applicable to more femto cells would be to reduce their power levels, opposed to inter-femto interference where that was the least preferable option with most disadvantages. To minimize interference and at the same time keep an acceptable range, the femto cell's up- and downlink have to be considered separately. The ideal signal strength depends on the level of interference, thermal noise and channel gain. The main problem is to determine the actual transmitting power, since just like inter-femto interference a low power level results in a reduced range whereas a high power level inducts too much interference. The detection of interfering femto cell also requires a different approach than inter-femto interference management strategies. Opposed to a femto cell, a macro cell can evaluate data of every mobile device subscribed to it and therefore detect areas with lowered signal strength. By taking the known positions of femto cells in that macro cell's range into account, an interfering cell can be detected. [10], [11], [12], [8]

III. Handover from cell to cell

If a subscriber switches cells his connections have to be hand over from his old cell to a new one. A handover, also called hand-off, is usually initiated because of the users signal strength and described as a platform independent IEEE standard 802.21 for media independent handover. Handovers may happen in the same network infrastructure which is called horizontal handover or from one network to the other (e.g. from Wi-Fi to UMTS or LAN) which is called vertical handover. In both cases, an algorithm decides whether or not to interrupt the connection before making a new one (break-before-make) or establish a new connection before interrupting the old one (make-before-break). The break-before-make approach is widely used for mobile connections as it is the easiest algorithm from a technical point of view, though it diminishes the bandwidth on a mobile device, as all connections have to be re-established. The opposing make-before-break approach keeps connections alive during a change of the network. In order to make that possible, both the base station and the mobile device have to support a technique called "multihoming" which can generally maintain multiple network interfaces which can keep connections to different service providers via different media at the same time, e.g. one Wi-Fi network and one femto cell grid, thus allowing any connections to continue during and after a handover if applicable. [13] The type of handover determines the seamlessness of the user's connection and may have an influence on the average bandwidth under certain circumstances as it will be shown in this section.

In the city a handover may happen every few hundred meters when moving from one macro cell to another, which is generally sufficient for most subscribers as every handover also means a short drop of bandwidth which does not need to, but can be noticeable or maybe even an interruption of the user's connections. An increasing number or density of femto cells will also lead to an increasing number of handovers for moving subscribers. Since customer placed femto cells may be placed anywhere in an apartment, one cannot predict the exact local coverage outside on the street, which may lead to a sudden drop of network coverage due to interior walls, doors or other obstacles between the femto cell and a subscriber, so a new handover may be necessary very fast, as the usual indicator of a upcoming handover — a slowly decreasing signal strength — is now failing due to said sudden drop of the femto cells signal strength for lack of a clear line-of-sight as apparent in figure 2. [3], [14]

But even without such barriers and obstacles, the actual range of a femto cell is very limited so that moving users

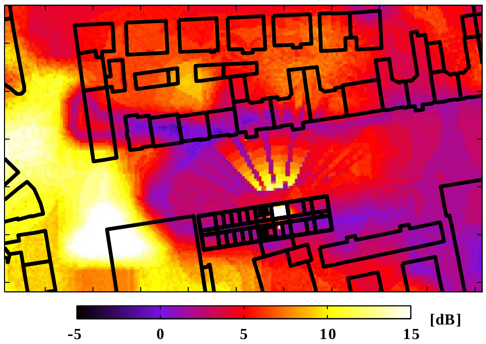

Fig. 2. The setup for signal strength measuring of a femto cell in a complex building from [3]

tend to leave its range quickly and are hand over to either the next available one or a macro cell.

Simulating such a scenario, it has been shown in [3] that a driver with a speed of 50 km/h leaves the femto cells range just after 2.5 s, which leads to a handover and therefore severely reduced bandwidth. This phenomenon is called "ping-pong handover" by the authors. Pedestrians and nearby residents are not affected, though. Thus, a users mobile device has to decide on the basis of its speed (if measurable) and average bandwidth requisition whether or not to use femto cells. As an example, a common driver application like gps navigation and traffic jam avoidance do not need high bandwidth and can connect to a femto cell opposed to media streaming for passengers, who may receive a warning message or decide for connecting to a macro cell in order to receive a connection with a high bandwidth.

As shown in [15] ping-pong handovers between femto and macro cells are not only slowing down already established connections but also increase the load on macro cells dramatically, especially during the hand shake, the initialization of a IP connection, whereas handovers from femto cell to femto cell take the load off a macro cell. Therefore, declining a handover from a macro cell to a femto cell by staying connected with the macro cell may be advisable under such conditions.

This scenario applies to areas with low femto cell density or crowded places in which single femto cells are at their limits and cannot serve another subscriber, as a result they are forcing the subscriber to connect to the macro cell again. The situation is exactly the same for customer placed femto cells and those mounted by a network service provider. The authors describe an algorithm, which "reduces unnecessary handovers up to 40% compared to the normal handover decision algorithm." Based on the time connected to a femto cell and the velocity, a server can predict a users moving pattern and declare him a "temporary femtocell visitor" or not, thus declining connections to femto cells or allowing them accordingly. A major advantage of this algorithm is not just a cutback of the macro cell's load but also offering higher bandwidth and a better mobile connection to subscribers who are barely moving, such as visitors in a café or residents of nearby apartments, who are more likely to use high bandwidth applications such as media streaming than pedestrians. As a disadvantage, this algorithm's design requires a central server calculating the movement patterns of cell phone users, which not just only shifts the load from the macro cell to said server but may also become a huge privacy problem, as this server is not just calculating with but also storing the subscribers movement data.

The mentioned advantage of a femto cell's higher throughput for applications needing more bandwidth also leads to the idea of doing a handover not just based on signal strength but also on factors like peak bandwidth reception, energy efficiency or lower cost as described in [16]. Because talking to someone over the telephone (64 kb/s[4]) is not the only function a telephone has, therefore becoming less important from a bandwidth point of view and mobile devices are capable of offering high bandwidth services like media streaming, a seamless handover grows more attractive. The specified smart handover trigger — as opposed to the standard handover which constantly measures the signal strength of the own and neighbouring cells — aims to reduce interruption by an early decision to switch cells or the network in order to give the mobile device's network manager more time to e.g. reserve channels or reroute connections if necessary. The trigger itself consists of three parts which constitutively decide about initiating a handover:

1) The first step contains the actual trigger, deciding *when and why* a handover might be necessary. Data like critical energy levels requiring an energy saving connection, ongoing processes needing higher bandwidth or of course the overall signal strength can be taken into account. This trigger is also highly depending on the mobile devices purpose in terms of their expected behaviour.
2) Based on the indicators from step one, available target networks are compared with the preferred networks and their saved properties, such as energy efficiency, bandwidth availability or signal strength, thus deciding *where* to connect to.
3) As a last step before the actual handover, the algorithm has to decide *how* to hand over the connections. Depending on the decision of step two, a vertical or horizontal handover is initiated and, based on the mobile devices and target networks capabilities, the algorithm may decide between a make-before-break or break-before-make handover.

After those decisions, the actual handover may be initiated that is, if possible, interruption free due to its early triggering. [16]

IV. Outlook

Femto cells are a new technology which still has great potential for growth, as their distribution areas, fields of application and feature sets are still limited. This section will introduce some ideas and yet proposed approaches.

A scenario imaginable for future research could be the replacement of macro cells by femto cells in certain areas. According to [14], the installation and operation of a macro cell "causes huge operational costs that amount easily to more than 75% of the total expenses." On the other hand, femto cell networks as self-configuring and self-managing systems can not just help to reduce those costs but also help increasing the maximum possible throughput, as shown in sections II and III. Possible areas for a replacement would be cities with high population density, where the risk of areas uncovered by femto cells is low, but also can be covered subsequently by carriers as soon as they learn of said uncovered areas by additional femto cells.

But femto cells are neither the first nor the only low range radio cells. Especially the widely used Wireless LAN (Wi-Fi) shares a lot of features with femto cells, e.g. they both connect mobile devices to a greater network via the air interface, they can either be operated in closed or public access mode and need little or no configuration by the user if user placed but they also scale up for companies and both support seamless handover. [9], [17]

Just like femto cell networks, Wi-Fi networks have to deal with interference issues, particularly in companies with Wi-Fi grids, as they tend to increase the density of Wi-Fi access points to gain more overall signal strength and decrease handover related bandwidth drops. [17] Opposed to femto cell networks, Wi-Fi networks do not have an underlying macro cell grid of any kind, which greatly delimitates interference problems and it support higher bandwidths, which makes a bandwidth drop appear less significant in general.

Contrary to femto cells, such Wi-Fi cells and their subscribers tend to maximize their transmitting power, thus causing high interference with access points on the same channel. It has been shown that static power reduction lead to "starving" cells as they are overlapped by stronger cells near them. So comparable to the introduced algorithms for femto cells, the researchers in [17] proposed an algorithm that generally allows higher signal power for cells with more users or users with bad reception. As an advantage to femto cells, such algorithms can usually be centralized as Wi-Fi networks do not cover whole cities, which is well possible for femto cells. Interference is quite possible to become an issue for Wi-Fi, though. As it has been shown, future work can base on interference management research which focused on femto cells.

Other still open fields are mobile femto cell access points, e.g. on trains, airplanes or even cars. Key points are uplink considerations in terms of bandwidth and stability of the connection and of course, interference issues especially for cars, as they may have no time [3] to do interference negotiations with static cells. The advantage of such technologies would be mobile ubiquity even in moving vehicles and those mobile femto cells could replace Wi-Fi [5] on said vehicles.

[4] ITU standard G.711

[5] e.g. Delta Airlines: http://www.delta.com/traveling_checkin/inflight_services/products/w
or Deutsche Bahn: http://www.bahn.de/p/view/service/zug/railnet_ice_bahnhof.shtml.
Last referenced 01-19-2012

As a last open point, issues like privacy or security are barely addressed. While user placed femto cells do have the option to operate in closed access mode, thus apparently guaranteeing its users privacy and security, any data send or received by a mobile device passes not just through its subscribed femto cell, but also through the internet to the femto cell's backbone. Neither the internet nor the firmware (once shipped) of the femto cell are under control of either the user or the mobile carrier in general, thus adequate precautions like strong encryption and digital signatures for system updates have to be made. [14] This has been a problem before[6] and cannot be ruled out for the future.

A scenario imaginable for future research could also be the replacement of macro cells by femto cells in certain areas. According to [14], the installation and operation of a macro cell "causes huge operational costs that amount easily to more than 75% of the total expenses." On the other hand, femto cell networks as self-configuring and self-managing systems can not just help to reduce those costs but also help increasing the maximum possible throughput, as shown in sections II and III. Possible areas for that would be cities with high population density, where the risk of uncovered areas is low.

V. Conclusion

This paper has given an overview about current techniques and research ensuring high receptability with femto cells. The first part describing interference management methods will become most important when high density femto cell grids, i.e., multi-story apartments and company buildings, establish. Research concentrated on interference avoidance or minimizing it by intelligent signal strength adoption algorithms. The second part, handovers, has its use for passing a connection of a mobile device on from e.g. a Wi-Fi network to a macro cell or vice versa but will become more important when especially public femto cells starting to have an influential part in the field of mobile network coverage, however, the general availability for femto cells is not in sight. The research on that topic concentrated on either making smart handover decisions in order to accelerate a handover and keep a bandwidth diminution to a minimum or avoiding handovers in general, thus circumventing a possible bandwidth drop.

The still ongoing research on both of these topics is not the reason for the mobile operator's slow-going process of launching femto cells to their customers, since existing[7] femto cell devices do have a build-in update manager[8]. Thus, any interference management or handover algorithms can be upgraded into the femto cell's operating system, even after distribution to customers. Therefore, their establishment is hopefully scheduled in the near future.

[6] http://heise.de/-1279576l. Last referenced 01-19-2012

[7] e.g. http://shop.vodafone.co.uk/shop/mobile-accessories/vodafone-sure-signal or http://www.t-mobile.de/shop/handy/0,4855,2963-_8439-1982-8631;CNC-1,00.html. Last referenced 01-20-2012

[8] see footnote 7.

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List of Figures