Radio Resource Management Considerations for LTE Femto Cells

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ABSTRACT

Femtocell access points (FAPs), also popularly known as Home Base Stations, are small base stations for use within indoor environments to improve coverage and capacity. FAPs have a limited range (e.g. limited to a home or office area) but offer immense capacity improvements for the network due to the ability to reuse a frequency more often as a result of smaller coverage areas. Because there may be thousands of these devices and since the nature of deployment is *adhoc*, it may not be possible to carry out elaborate frequency planning like that in the traditional cellular network. This paper aims to outline the radio resource management considerations within the context of femto cells, the broader objective being to initiate a discussion and encourage research in the areas highlighted.

Categories and Subject Descriptors

C.2.1 [**Network Architecture and Design**]: Wireless Communications; C.2.3 [**Computer-Communication Networks**]: Network Operations

General Terms

Management, Algorithms, Design

Keywords

Femtocells, Radio Resource Management (RRM), interference management, algorithms, survey, LTE

1. INTRODUCTION

Femtocell access points (FAPs), also popularly known as Home Base Stations or NodeB or evolved NodeB (eNB), are small base stations for use within indoor environments to improve coverage and capacity. FAPs have a limited range (e.g. limited to a home or office area) but offer immense capacity improvements for the network due to the ability to reuse the frequency more often as a result of smaller coverage areas. The main benefit of femtocells to the end user is that they help to plug the coverage holes (dead zones) in the home. This solution is especially attractive for those homes where the signal from the macrocell cannot penetrate the home due to difficult radio propagation conditions. Thus, in situations like these, the user equipment would use the femtocell base station instead of a macrocell base station thereby achieving a superior connection. This not only helps to off-load traffic off the macrocell but also creates more capacity on top of what the macrocell has to offer. Reducing load on the existing macro network by offloading traffic to femtocells also helps to improve performance of the macrocell users at the same time reducing the capital and operating expenditure of the network operator. Moreover, the capacity improvements in the home can assist the operator in rolling out competitive pricing plans e.g. unlimited usage at flat rates to compete with fixed line telephones. The cellular operator can provide incentive e.g. reduced/zero call charges to the customer for using femtocells as this will result in better performance (huge capacity) at a cheaper price (lower usage charges). This translates into a win-win situation for both the customer and the operator. However several challenges need to be met before this can be realized in practice.

FAPs are designed to be customer premises equipment. There may be thousands of these devices, and since the nature of deployment is *adhoc*, it may not be possible to carry out elaborate frequency planning as in traditional cellular networks. These devices are likely to be installed by end users[1] as the cost associated with the installation process involving skilled technicians is prohibitive. Thus, these devices are expected to be plug and play type whereby the device will self configure and self optimize itself during setup and operation. Once a femtocell powers on, there are several tasks that it needs to perform. It first needs to discover the operator's network and register itself. The registration process involves the femtocell sending its credentials to the network's authentication server which then authenticates the femtocell. Subsequent to successful authentication, the operator's network sends initial values for configuration parameters. To speed up deployment, the time-tested standard TR-069 [2] titled "CPE WAN Management Protocol" from the Broadband Forum had been adopted 'as is' to be used within the context of femtocells [5]. While this takes care of the initial configuration, the operational aspects related to Radio Resource Management (RRM) remain to be addressed.

One of the outstanding issues with deployment of FAPs

[1] most of whom may not appreciate the technical aspects

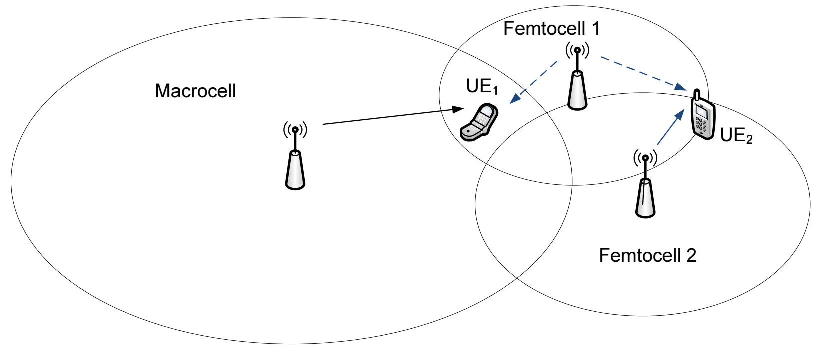

Figure 1: Inter-macro-femtocell and Inter-femtocell interference.

is the problem of interference between cells. Due to the nature of FAP deployments, femtocells are likely to interfere with neighbouring cells since they will be utilizing the same frequency resources. An illustration of intercell interference scenarios is shown in Figure 1. A study carried out by the Femto Forum titled "Interference Management in UMTS Femtocells" [1] investigated the effect of interference using simulations in scenarios defined by the 3GPP RAN4 study group in document TR25.820 [3]. Following are the three important conclusions from this study:

- Femtocells should have appropriate transmit power. If the transmit power is too high, they may cause interference to the neighbouring macrocell and femtocells. On the other hand if they are too low, this may limit the coverage which they can achieve.
- Femtocells should have a smaller receiver gain. This stems from the need to prevent passerby/neighbouring User Equipments (UEs) from camping onto the femto. This can cause increase in the number of signalling messages in the operator's core network if UEs try to handover to the femto unnecessarily.
- An upper limit must be configured on the transmit power of the User Equipment (UE). This is to ensure that the UE will handoff to the macrocell rather than increasing transmit power to reach the femtocell access point.

Whilst these have provided valuable insights in the macro-femto interference problem, the femto-femto interference aspects remain unaddressed. The discussion in this paper outlines this problem and points in the direction of potential solution strategies.

2. BACKGROUND ON RADIO RESOURCE MANAGEMENT IN FEMTO CELLS

Femtocell access points are likely to be deployed as an overlay on top of the existing cellular infrastructure. This dictates that there should not be a need to change the way resources are allocated in the existing infrastructure. Unlike the macro network, it may not be possible to carry out an elaborate frequency planning of the femtocell network so they are expected to have self-configuring ability *i.e.* automatically detect/negotiate resources[2] that can be used and resolve conflicts arising from use of overlapping resources that result in interference problems. The main question to be answered here is *What resources should the femtocell use so as to achieve acceptable performance with little/no interference to others?* This in essence is the RRM problem - detection / negotiation of resources and resolution of conflicts (if any) arising from the resource allocation process.

There are two possible deployment paths for the operator as highlighted in the existing literature [1]. One approach is to set aside a chunk of the spectrum for deploying femtocells and use the remaining for the macro network. This is well-known as the 'dedicated channel' deployment approach. The other approach is to deploy femtocells on the same spectrum as existing macrocells. This is well-known as the 'co-channel' deployment approach. The advantage of the former approach is that interference effects of the femto network to/from the macro network can be isolated. However, this is not a cost effective solution as the licensed spectrum is not only scarce but also expensive. Additionally, this also reduces the spectrum utilization efficiency. Nonetheless, it may be possible that operators may consider this option given that they want to ensure that the capacity gains facilitated by the deployment of femtocells do not come at the cost of degradation in the macro network performance. Having said this, it does not necessarily mean that the same cannot be achieved with the co-channel deployment approach. The advantage of this approach is that it is cost effective and improves spectrum resource utilization in comparison to the dedicated channel approach. However, deployment on a co-channel may not isolate the interference effects of femtocell transmissions to/from the macro-cell/other femtocell transmissions. Careful engineering is required to minimize (if not eliminate) these effects.

3. DESIGN CONSIDERATIONS

The design choices that can be exercised are brought forward by raising relevant questions and trying to answer them subject to the constraints of the underlying scenario.

What are the typical deployment scenarios?

These could be categorized as home deployments or enterprise deployments. In the home deployment case, the potential scenarios could be those of dense urban deployment or sparse sub-urban deployment. The former scenario can be visualized as a crowded group of multi-storey apartments in a dense city centre each comprising of several flats. Such a scenario is typically characterized by a short coverage

[2] The term resource and frequency is used interchangeably throughout this document

area with potential for high interference from neighbouring[3] femtocells e.g. flats on either side and the one above and below the flat. The other scenario can be thought of as a row of houses adjacent to each other having reasonable separation between each other in a sparsely populated suburban setting e.g. bigger and more spread out houses as we move towards the outskirts of the city. In contrast to the former scenario, this scenario is very likely to be characterized by a need for a much larger coverage area due to much bigger houses with less potential for interference from the neighbours. Clearly, the solution space in each scenario is different e.g. the resource management approach for the dense deployment scenario is likely to require co-ordination amongst neighbours in real time for resolving interference issues. On the other hand, a simple solution may suffice in the other scenario as there may be little or no interference amongst the neighbouring femtocells.

What are the typical applications envisaged to use the femtocells and what would be the usage patterns?

This would be largely governed by the location e.g. users at home may tend to use the femto network early in the morning before heading to work and later in the evening after returning from work. Similarly, users at work may tend to use the enterprise femto network during the day whilst in the office. The nature of applications may vary depending on the location/time of the day e.g. users in an office environment may generally tend to use voice as most of their other traffic might be carried by the high bandwidth internet connection available at work. On the other hand, users at home may use anything from basic voice to more diverse applications such as mobile TV/video streaming/file transfer/peer-to-peer/instant messaging/online social networking web applications etc. An important consideration here is the effect of traffic dynamics on the resource management policy. Depending on the application requirements, different amounts of resources may be required on different timescales e.g. a user doing FTP may require a large amount of resource for a short period of time until the transfer completes while a user watching a video may need certain minimum resource over an extended period of time. It may be necessary to factor this in the resource allocation process so as to ensure that this does not lead to starvation of some users. Addressing fairness is a difficult problem but needs careful consideration especially amidst users that may have different levels of subscription (which may require prioritizing traffic).

How to allocate resources to satisfy application requirements?

In an LTE system, the spectrum is divided into fixed sized chunks called 'Resource Blocks (RBs)'. One or more RBs can be assigned to service an application request subject to the availability of the resource and network policies. Unless stated otherwise, the ensuing discussion is based on the assumption that the underlying system under consideration is LTE.

One approach could be to use scanning. This entails scanning the entire spectrum (within which the device is operating), identify the loud transmissions and avoid using the frequency chunks that these transmissions are using. If choosing a certain set of frequencies results in interference, then the scanning can be repeated to move to some other frequency. Such a simple solution is desirable and practical in scenarios where there is little/no contention for the resources e.g. in the sparse deployment scenario. This is because, in such scenarios, there is a high likelihood that once discovered, a resource can be used without any interruption for a long period of time. On the other hand, this may not be a practical approach in dense deployment scenarios that are likely to be characterized by significant amount of contention for resources. In these scenarios, scanning is not only energy in-efficient (drains power) but also time consuming. It may lead to delays either until a usable resource is found or while looking for an alternate resource in the event of interference (conflicting use of resource by more than one communicating entities). Moreover, if this involves switching the operating frequency several times during the lifetime of an application, then this may have adverse impact on the application performance e.g. effect of variable delays on voice/video performance. This limits the applicability of such an approach.

Another issue with using the scanning approach is whether to use a dedicated radio for scanning or use a single radio for both scanning and communication purposes. The former approach has the advantage that it provides the ability to keep track of the spectrum usage patterns in real time. This can be of help to make quick decisions on what part of the spectrum to use/switch to. While this approach is technically superior, it may not be desirable from an economic perspective as this increases the cost of the user equipment due to the need for an additional radio. In contrary, the latter approach helps to eliminate the cost associated with an extra radio. However, this limits the functionality as the device cannot do both sensing and transmission/reception at the same time. It has to either sense or transmit/receive at any given time. Thus, adaptation based on usage patterns may not always be possible in real time. There exists a trade-off between cost and flexibility which needs to be investigated.

One other simple approach could be for the femto cell to allocate any available RB(s) that it has not already allocated to somebody else concurrently. In the event that there are interference problems, the resource could be negotiated with whoever is interfering with the UE. Such an approach could be fast and efficient when there is little or no contention for the resources i.e. in a sparse deployment scenario or when the traffic volume is low e.g. a few voice calls. This is because, once allocated, there may not be a need to renegotiate resources. However, in a dense deployment scenario and under heavy traffic levels, there are likely to be interference issues due to the use of overlapping resources e.g. when identical RB(s) (subset/all) are assigned by neighbouring femto cells within the transmission range of each other. In such a situation, negotiation of resources may be necessary. This leads us to some important questions:

- How to ascertain that a UE is interfered with?
- How to identify who is interfering with the UE?
- Are neighbours already known? If not, how to detect them?

[3]Only neighbouring femtocells operating on the same operator's network may cause interference to each other. Those operating on different operator networks will not cause any problem to each other as they will be operating on different frequencies altogether

- Once identified, how to exchange information with these neighbours so as to resolve the problem?

The ensuing discussion is an attempt to seek answers to these questions. Some of the underlying practical issues are also highlighted.

How to ascertain that a UE is being interfered with?

Interference issues are largely topology dependent. UE movement or change in the position of the FAP within a room may greatly influence the amount of interference caused/suffered. In such situations, it may not be trivial to identify the cause of interference i.e. who is causing interference and who should be notified of the problem. The UE that is being interfered with may be able to distinguish the signal from the interfering node using some sort of spatial diversity technique. However, this may be governed by the movement patterns of the interfering nodes and may not always solve the problem. The other alternative could be to use the periodic measurement reports sent by the UE to the FAP. Based on these reports, the FAP could deduce that a UE is being interfered with. To cite a simple example, if the BER performance reported by the UE shows a decline in conjunction with no decrease in RSSI, then the FAP can infer that the UE is experiencing interference. It should however be noted that this is not the only way to infer interference and other metrics may also be employed. In fact there is a need to identify performance indicators which can clearly and concisely capture interference situations e.g. what should be a trigger threshold - threshold when the interference suffered by a UE reaches unacceptable level.

How to detect who is interfering with the UE?

It is clear that the neighbouring femtocell(s) who have allocated identical (subset/all) RB(s) as the one allocated to the affected UE and within transmission range of this UE are responsible for the interference[4]. However, macrocell base stations could equally allocate the same frequency resources to their UEs. While it is impossible to accurately identify the exact source of interference, it is possible to short list the possible aggressors using the identified neighbour list. Any mitigation action would therefore involve some form of coordination with the responsible neighbour(s). This entails identifying the neighbouring femtocells. Subsequently, communication could be initiated with these neighbouring femtocells to resolve the issue. It may be reasonable to assume that the list of neighbouring femtocells is passed on as a configuration parameter to each femtocell during initial configuration by the centralised Network Management System (NMS) of the mobile operator. Alternatively, this list could be populated by dynamically discovering the neighbouring femto cells.

Mechanisms such as the cognitive pilot channel (CPC) [4] can be used to identify the possible interferers and also provide information on the occupied frequencies. The CPC is the concept of a control channel where information on nearby transmitters can be attained. The CPC will provide critical information on the frequencies currently being used in a particular geographical area and the radio access technologies using them. They could also provide information on the operator using these frequencies to enable vertical handovers or even spectrum trading. Consequently, this information can be used by femtocells to plan frequency allocation so as to avoid causing interference to other users and also avoid interference from other users.

How to negotiate resources so as to mitigate/avoid interference?

Once the neighbours are identified, the next step would be to collaborate with them so as to resolve interference issues. In the ensuing discussion, several solution strategies are highlighted and their pros and cons are analysed.

Approach 1, Transmit power control: This approach involves adapting the transmit power in a collaborative manner. Once the neighbour responsible for interference is identified, the suffering femto/UE could negotiate on the transmit power to be used with this neighbour(s). If both the parties drop transmit power then this may solve the problem albeit compromising the range. This may not be a desirable solution. Rather it may be an inconvenience, as the UE may have to move closer to the FAP to get meaningful service. Nonetheless, in the worst case scenario where there is a high level of contention for the scarce spectrum, such a solution can at least ensure service availability/continuity by sacrificing the range. However, to have a meaningful effect, this solution has to be realised in a collaborative manner e.g. if one FAP (say F1) drops power and the other (say F2) doesn't then the performance of F1 may further degrade (if the transmissions of F2 are still within the range of F1).

Approach 2, Randomize frequency use: This is one of the solutions advocated within LTE. Recalling from the earlier discussion, the operator's spectrum is divided into fixed number of RBs. If the allocation of certain RB(s) to service an application request result in bad performance as evident from the UE's periodic reports to the FAP, the FAP can randomly reallocate some other RB(s). If none of the neighbours are using the newly allocated RB(s), then this will most likely solve the interference problem. However, this type of solution will work best in scenarios with low traffic levels or in less dense deployments as the likelihood of availability of free resources is high in such scenarios. In contrary, in a dense deployment scenario or in a scenario with heavy levels of traffic where resources may not be free, such a solution strategy may cause instability e.g. during the reallocation process, there may be a danger of femtocells jumping from one set of resources to other only to find that the reallocated resource is in use concurrently by other femtocells thereby resulting in an unstable condition. In such a case, it may be more appropriate to employ a coordinated approach as opposed to this adhoc standalone solution.

Approach 3, Deduction based resource allocation: In this approach, the femto tries to learn the resource usage patterns and based on this synchronize to exploit the "gaps" (free slots). Clearly, such an approach would work only when the traffic is predictable (e.g. Constant Bit Rate type traffic or ON/OFF traffic with well known ON/OFF intervals) which may not be a commonly observed case. Moreover, time synchronisation is not trivial to achieve in a distributed environment. These difficulties limit the applicability of this approach.

Approach 4, Collaborative Resource Negotiation: In this approach, frequency to be used is negotiated with the neighbours (potential interferers). This could be realised either in a centralized or a distributed manner. A

[4]As per one of the conclusions of the study in [1], it is highly unlikely for a macro cell to cause interference to femto cells in the downlink. This is because, if a strong macro cell signal is received indoors, there may hardly be a need for installing a femtocell in the first instance

simple way to realize this is to have a centralized entity that could coordinate the resource management. The advantage of this approach is that it is simple and the operator retains control. However, a single centralised network management entity won't be able to cope with the resource management of hundreds/thousands of femtocells. This will not only lead to scalability issues, but will also introduce significant delays in the resource management decisions being conveyed to the femtocells. A distributed approach on the other hand is generally fast and accurate as localised decisions are made. This comes at the cost of increased complexity and the operator may lose some control. Additionally, there may be an issue with stability (especially when nodes act independently without coordination) as it is difficult to prove that the proposed solution will always behave in a predictable manner. There may be situations where it may not be possible to guarantee stability e.g. if an interference notification results in all nodes transiting to another frequency (which ends up being same) then this will not solve the problem but may further compound it. Ideally, in a situation like this, it may be more desirable to take coordinated action. However, achieving this in a distributed manner is not trivial. Thus, the centralised v/s distributed trade-off should be investigated.

Some hybrid solution (a mix of both centralised and distributed) may bridge the gap between the two extremes discussed above. A distributed approach to sharing local information and a locally centralised approach for decision making may be an attractive alternative. For example, in the Long Term Evolution (LTE) system, there is provision for evolved NodeB (eNB) to communicate a high interference indication [6] to neighbours subsequent to which action needs to be taken to mitigate this. Instead of neighbours acting on their own in response to this notification, they could send a message to the central manager within the locality who then takes the appropriate action. Ideally, a simple solution that can guarantee stability of operation and where the operator can enforce some control is desirable.

Another approach could be to exchange information using the wired backhaul. Having identified the neighbours and whether they could potentially interfere, femtocells could coordinate resource management via the wired backhaul e.g. decide on who takes turns, who grabs how much resource and for how long etc. However the backhaul IP network has to meet the tight demands of reliable and low latency communication as it may be necessary to exchange information and reach a resource allocation decision in near real time.

4. SUMMARY

This paper provided an overview on the deployment aspects of femto cells with a particular emphasis on outlining the radio resource management challenges. Different design considerations, which mainly revolve around issues such as potential deployment scenarios, type of traffic, resource allocation and potential solution strategies for resolution of conflicts arising therefrom (interference detection/avoidance) were discussed in detail. The suitability of the potential solutions with respect to the constraints of the underlying scenario were also elaborated upon. It appears from this discussion that the underlying scenario is likely to drive the choice of a particular RRM solution. In sparse deployment scenarios and those characterised by little/no contention (low levels of traffic), simple randomisation solutions may be effective. However, in dense deployment scenarios and those with heavy levels of traffic, there may be merit in considering solutions based on collaboration. An example of such an approach could comprise of a simple strategy, which, based on the scenario identified through context information, could decide which solution to adopt e.g. use randomisation if low traffic/sparse deployment scenario and use collaboration if high traffic level/dense deployment scenario. Alternately, this could also employ some form of learning to determine the trigger thresholds to select different algorithms/modes/approaches etc. However, prior to adopting collaborative solution strategies, it is necessary to carefully consider whether the benefits arising from collaboration outweigh the overheads involved. In conclusion, radio resource management in femto cells is a nascent area that has thrown up several interesting problems which offer immense opportunities for contributing both from a research as well as an engineering perspective.

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