Mobility management in heterogeneous networks

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Abstract

In this report, an overview of mobility management in heterogeneous networks and intercell interference coordination in heterogeneous networks is written. Initially the need for deploying heterogeneous networks and elements in a typical heterogeneous network are discussed. Deployment of heterogeneous networks introduces a few challenges. In this report two of the key challenges handover and interference are addressed. Handover process with respect to 3GPPLTE is explained. The effect of a few parameters on handover like TTT and techniques like range expansion are also discussed. Intercell interference coordination and an algorithm for eICIC implementation in 3GPP LTE is explained. The effects of range expansion with eICIC on handover failures and ping-pong rates are discussed. A mobility based eICIC technique is discussed and hence the need for mobility state estimation techniques and algorithms in heterogeneous networks is emphasised for effective implementation of mobility based eICIC schemes.

Introduction

The number of wireless and mobile users is increasing rapidly and hence wireless data traffic is increasing exponentially. Also there is a demand for higher bandwidth and higher data rates due to advanced applications like mobile TV, cloud storage, video conference etc. It is a challenge to cater to rapidly increasing users and providing sufficient bandwidths and data rates they demand.
Traditional homogeneous networks with macrocells and microcells need significant network enhancements that can boost the performance of the network to cater to the needs of users. A few enhancement techniques like carrier aggregation where multiple frequency carriers are utilised concurrently to provide users with larger bandwidth, MIMO systems- Multiple antennas or antenna arrays used at transmitter and receiver, co ordinate multipoint transmission and reception where multiple cells coordinate and schedule their transmission to serve users at cell edges can serve the need to certain extent. But these do not provide significant enhancements to the network. Thus we need a technology that can significantly enhance the network and deploying heterogeneous networks (HetNets) can be considered as a solution to enhance the network performance significantly.

In a homogeneous cellular network all the cells are identical and are served by identical base stations or eNBs in case of macrocells. But in a heterogeneous network, as the name says, there are cells served by base stations of different transmission power and using different radio access technologies, cells of different coverage area (cell size) etc. A typical architecture of heterogeneous networks consists of macrocell network overlaid by small cells (picocells, femtocells) that have less coverage served by low power nodes or low power base stations. A heterogeneous network uses low power nodes or small cells to bring the network closer to user and hence enhances radio link. Also by using small cells having less coverage area, the spectral reuse is enhanced and thus improving the spectral efficiency of the network. Also small cells overlaid over macrocell network offload traffic from macrocells which otherwise will be overloaded due to increasing traffic of users.

Heterogeneous networks typically have the following elements: Macrocells, picocells, femtocells, relay and remote radio heads as shown in figure 1.

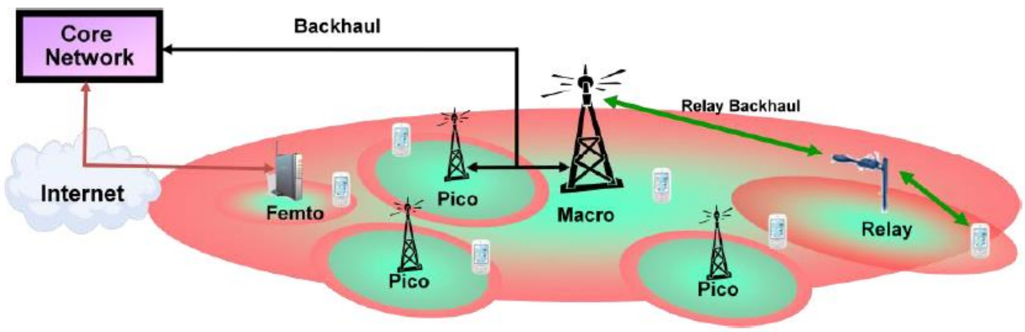


Figure 1 HetNets utilizing macrocells, picocells,femtocells and relay
Source: "LTE Advanced: Heterogeneous network", Qualcomm, February 2010

Macrocells form the skeleton of network with eNBs placed as in a homogeneous network. Picocells and femtocells are cells with smaller coverage area served by low power nodes and are overlaid on macrocells. Femtocells have even lesser coverage area than picocells and are typically deployed by users while the macrocells and picocells are deployed by operators. Relays are also deployed by operators to enhance signal quality at cell edges or in tunnels. Remote radio heads (RRH) are placed at remote places like rural areas and are connected to a base station through optical fibre cables. RRH are used to extend the coverage of the network. The following table gives the specifications of different elements in a typical heterogeneous network.

Types of nodes	Transmit power	Coverage
Macrocell	46 dBm	Few kilometers
Picocell	23-30 dBm	< 300 meter
Femtocell	< 23 dBm	< 50 meter
Relay	30 dBm	300 meter
RRH	46 dBm	Few kilometers

Table1 Specifications of different elements in HetNets
Source: "Enhanced intercell interference coordination challenges in heterogeneous networks", David lopez perez et al., IEEE Wireless communications June 2011.

There are a few technical challenges that we come across while deploying heterogeneous networks. Here we look into two of the key challenges handover challenges and interference.

Handover

Handover (HO) is a process by which the mobile user equipment (UE) connected to a cell in the network is transferred to another cell in the network to maintain quality of service and stay continuously connected in the network. HO process depends on various system parameters like time to trigger, hysteresis margin, velocity of UE etc. In case of homogeneous networks, UE uses same set of HO parameters for all cells. Using the same set of HO parameters in heterogeneous networks may lead to more number of handover failures as each cell has different coverage area and transmission power etc.

Overview of Handover process in 3GPP LTE

Handover process could be performed between different radio access technologies, carriers, cells. Here we consider intra RAT, intra carrier handover in a 3GPP LTE network. In 3GPP LTE network, the UE disconnects from source cell before connecting to target cell i.e. 3GPP LTE handover is a hard handover.
3GPP LTE handover process consists of 4 phases: measurements, processing, preparation and execution.

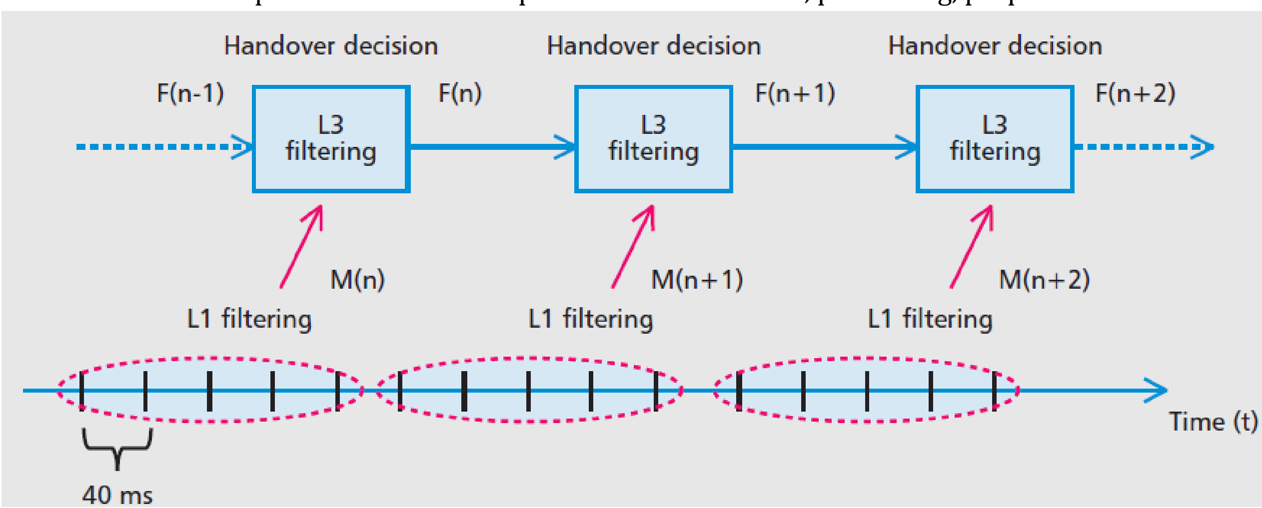


Figure 2 Handover measurements and processing

Source: "Mobility Management Challenges in 3GPP Heterogeneous Networks", David lopez perel et al., "IEEE communications Magazine, December 2012

Measurement and processing are done by UE. Measurements are based on downlink reference signal received power (RSRP) while processing is done to remove the effects of fading on estimations. UE performs measurement in layer1 (physical layer) and processing in layer3. For measurements, UE takes the RSRP estimations of all cells in its neighboring cell list. Each RSRP sample is measured as the linear average of power from all resource elements that carry reference signal in the given bandwidth within one sub frame (1ms). Each RSRP estimate is obtained by taking linear average of few RSRP samples in layer1. Figure 2 shows typical measurement scheme. It is shown that each RSRP sample is measured at an interval of 40ms and the average of 5 such RSRP samples is taken and linearly filtered in layer1 (L1 filtering). This L1 filtered measurement is updated at UE every HO measurement period and a moving average is taken in layer3 through a 1st order IIR filter. This averaging performed in layer3 is called L3 filtering.

In LTE 3GPP, handover takes place if the L3 handover measurement output meets one of the handover event entry conditions. There are eight types of handover event entry conditions:

Event A1: Server becomes better than threshold.
Event A2: Server becomes worse than threshold.
Event A3: Neighbor becomes offset better than server.
Event A4: Neighbor becomes better than threshold.
Event A5: Server becomes worse than threshold1 and neighbor becomes better than threshold2.
Event A6: Neighbor becomes offset better than secondary server.
Event B1: Inter RAT neighbor becomes better than threshold.
Event B2: Server becomes worse than threshold1 and inter RAT neighbor becomes better than threshold2.

Intra RAT, intra carrier handovers are triggered by handover event entry condition A3: The RSRP of target cell is better than RSRP of source cell plus hysteresis margin. As soon as A3 is met, the UE starts TTT (time to trigger) timer. Only if the condition A3 is satisfied throughout the TTT, UE alerts source cell for handover process with report of handover measurements as shown in figure 3 and initiates handover process.

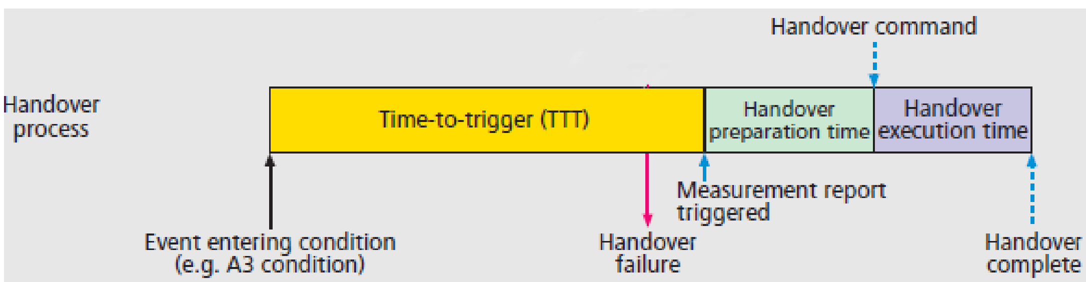


Figure 3 Handover preparation and execution phases

Source: "Mobility Management Challenges in 3GPP Heterogeneous Networks", David lopez perel et al., "IEEE communications Magazine, December 2012

In the preparation phase, source cell sends a handover request message to target cell. Based on quality of service requirement of UE, the target cell decides whether it should serve UE and sends a handover request acknowledge to the source cell. After receiving handover request acknowledgement, the source cell forwards data of UE to target cell. Simultaneously, source cell also sends HO command to UE.

In the execution phase, UE synchronizes with target cell and sends handover complete message to target cell. Target cell then sends message to network to indicate that UE has changed its serving cell. Network in turn sends markers to the source cell to release allocated resources for the UE that was handed over to another cell.

Handover failure and ping-pongs

When the SINR (signal to interference plus noise ratio) or channel quality indicator (CQI) of UE falls below a threshold Qout, it is said to be out of synchronization. It is said to be back in synchronization when its wideband SINR is above threshold Qin. UE starts a timer T310 when its SINR falls below threshold Qout. The timer T310 stops as soon as the SINR of UE is above Qin. A radio link failure (RLF) is declared when the SINR of UE goes below threshold and remains below threshold Qin until the timer T310 runs and expires (figure 4).

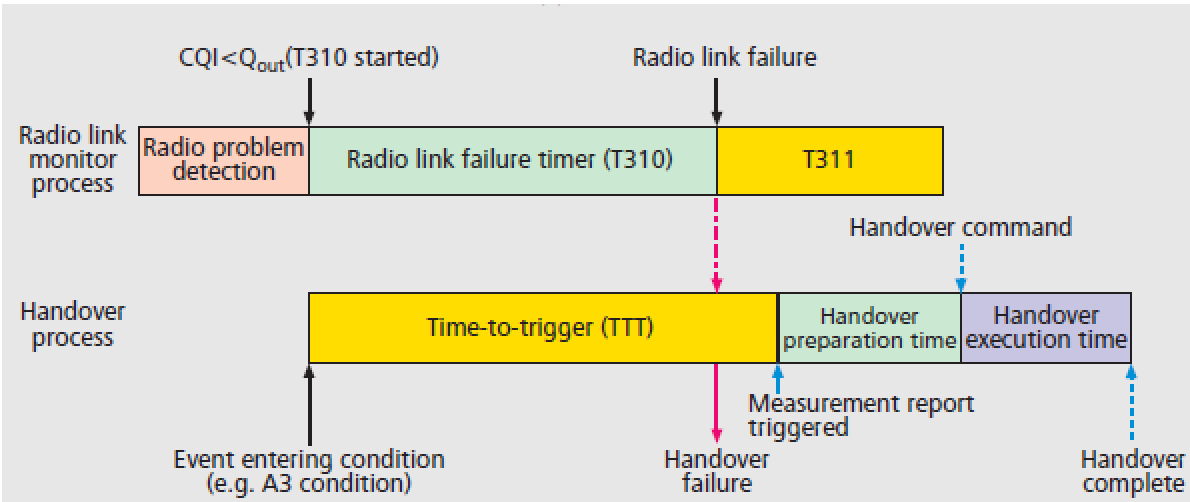


Figure 4 Events indicating radio link failure and handover failure

Source: "Mobility Management Challenges in 3GPP Heterogeneous Networks", David lopez perel et al., "IEEE communications Magazine, December 2012

In 3GPP LTE, HO failure is considered when one of the 3 conditions are met

1. RLF happens during the time between satisfying the event A3 condition and receiving a handover command.
2. T310 timer is triggered and still running when a handover command is sent.
3. The UE wideband SINR Qout,u is lower than Qout when a handover complete message is sent.

The time of stay of an UE in a cell starts from the time it sends HO complete message to the cell to the time it sends HO complete message to another cell. Ping-pong is said to occur when the UE stays in a cell for duration less than threshold Tp and the new cell is the same cell that was the source cell in earlier handover process.

In heterogeneous networks, handovers is from macrocell to picocell or picocell to macrocell. If TTT is large then while handing over to picocell from macrocell, the macrocell UE (MUE) may run deep into picocell before TTT expires as picocell has lesser coverage area (smaller transmission power). Thus SINR of MUE may be significantly degraded before handover process is completed and hence HO failure may occur. The handover from picocell to macrocell is not an issue due to TTT. Thus a large TTT would increase the rate of HO failure in heterogeneous networks. But we see that ping pongs increase with smaller TTT. There is a tradeoff between HO failures and ping-pongs and TTT is to be carefully chosen to minimize both handover failures and ping-pongs or either HO failures or ping-pongs which ever problem is significant in the network. HO failures occur usually with high mobility UEs as they run deep into picocells faster and before TTT expires. Ping-pongs affect low mobility users at the cell edge sites.

Interference

Interference problems in heterogeneous networks are complex compared to interference problems in homogeneous networks. Few cells like femtocells are typically deployed by user and can be deployed very near to another macrocell eNB. Thus the femtocell users may face a strong interference from the macrocell. Few userlaid femtocells may have access only to a closed user group. A UE that is near femtocell but doesn't have access to the femtocell, may still be connected to the macrocell far away and may face interference from the femtocell. Unplanned deployment of cells from users makes the interference problems more complex in heterogeneous networks.

Picocells, femtocells have low power transmitters (hence called low power nodes). So in a handover scheme that uses strategy to connect to the cell that provides strongest downlink RSRP, a UE very near to a picocell or a femtocell still connects to macrocell with large transmission power that is far away. Thus the purpose of picocells and femtocells to offload traffic from macrocell is not served. In order for UEs to connect to near by picocells, femtocells range expansion technique is used.
In range expansion, a bias or a offset is added to picocell , femtocell RSRP measurements at UE to determine the target cell to which the UE is to be handed off.
Though range expansion may balance the load in the network, it increases the interference or degrades SINR of UEs connected to picocells. This is because the UEs are not connected to cell that gives strongest RSRP and may face severe interference in the downlink path. The interference problems degrade the network performance sufficiently and hence in heterogeneous networks, use of intercell interference coordination schemes is required to guarantee minimum quality of service.

Enhanced ICIC (eICIC) schemes

In order to address heterogeneous network interference problems, enhanced intercell interference coordination (eICIC) schemes are developed in 3GPP LTE release 10.
They are grouped under three categories:
1. Time domain techniques
2. Frequency domain techniques
3. Power control techniques

In time domain techniques, macrocells and picocells coordinate with each other to schedule their victim UEs in time subframes where no data or control signals are transmitted by the other cells and hence mitigating interference.

In frequency domain techniques, channels of different cells are scheduled in reduced bandwidth to have totally orthogonal transmission of the signals at different cells and hence mitigate interference.

In power control techniques, different cells coordinate to adjust their transmission power to accommodate users and reduce interference at other cells.

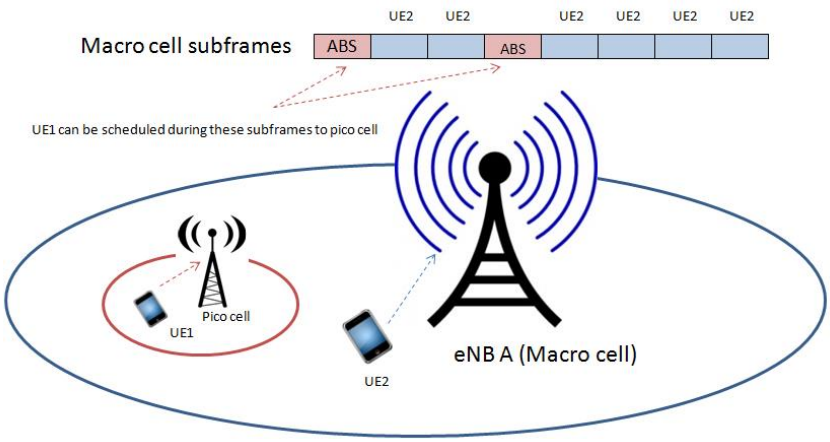


Figure 5 ABSFs in eICIC scheme Source: 3GPPLTE blogspot

In one of the time domain eICIC schemes, as shown in figure 5 macrocells configure almost blank subframes (ABSFs) in which only reference signals are transmitted and no data or control signals are transmitted. The range expanded UEs in picocell that experience interference from macrocells are scheduled in these subframes to mitigate the interference. The subframes in picocells corresponding to ABSFs in macrocells are called protected subframes as UEs in scheduled in thses subframes are protected from intercell interference.

[3] proposes one such time domain eICIC scheme that takes into account the number of ABSFs configured at macrocell and UE partition scheme at picocell and maintain a balance in the performance of macrocell as well as picocell. UE partition scheme or UE scheduling scheme divides the UEs of picocells into two groups, one which require to be scheduled in protected subframes or subframes corresponding to ABSFs in macrocell and the other group that are not subjected to strong interference. Generally, the worst UEs are arranged in the protected subframes to enhance the performance. More the number of UEs to be protected, more is the number of ABSFs to be configured in the macrocell. Thus the UE partition scheme and number of ABSFs are interdependent. But increasing the number of ABSFs will reduce the performance of macrocells as the number of subframes available for transmission in macrocells will reduce. Thus a allocation scheme should balance the performance of both picocells and macrocells.

The resource allocation scheme proposed here adjusts the number of ABSFs in macrocell and UE partition in picocell in turns to achieve a performance balance i.e. each time the number of ABSFs is updated, the UE partition scheme is assumed as fixed and each time UE partition scheme is updated, the number of ABSFs is assumed to be fixed. The assumptions made here are that all macrocell eNBs deploy same ABSF pattern and the picocells employ range expansion to offload traffic from macrocell. Nash bargaining strategy (NBS) is used to partition UEs into two groups. Nash bargaining strategy is a strategy for distributing resources among K competing players. UE partitioning scheme is considered a two player game with protected subframes and uprotected subframes as two players competing for UEs.

Let i denote the type of subframe. If i=1, subframe is of type normal or unprotected and if i=2, subframe is of type protected. Let n denote the nth small cell eNB considered. Let Rni denote the data volume of nth small cell eNB for type-i subframe. The bargaining goal is to maximize transmitting data at both types of subframes. When detailed scheduling information is not known, we can assume that each UE receives a

fraction of $1/Nn$ of resource from the small cell where Nn is the number of UEs in the nth cell. In 3GPP LTE, wideband SINR of all UEs are available at eNB side.
Thus the transmitted data of nth small cell in normal and protected subframes can be approximated as below

$$\begin{aligned} R_{n1} &= \frac{W}{\sum_{j=1}^{N_n} a_{1j}} \sum_{j=1}^{N_n} a_{1j} \log_2\left(1+\mathrm{SINR}_{wb,1j}\right) T(1-\beta) \\ &= R_{n1}^{T}(1-\beta) \end{aligned}$$

$$\begin{aligned} R_{n2} &= \frac{W}{\sum_{j=1}^{N_n} a_{2j}} \sum_{j=1}^{N_n} a_{2j} \log_2\left(1+\mathrm{SINR}_{wb,2j}\right) T\beta \\ &= R_{n2}^{T}\beta \end{aligned}$$

(I)

Where W is the bandwidth of the channel, β is the ratio of the number of ABSs to the number of all available subframes, aij denotes whether UE j is arranged in subframe type i. SINRwb,1j and SINRwb,2j represent the wideband SINR of UE j in the normal subframe and the protected subframe, respectively. T is the ABS pattern period, therefore, $T(1-\beta)$ denotes the time duration of the normal subframes and $T\beta$ denotes the time duration of the protected subframes.
The equation below gives the marginal benefit difference of normal and protected subframes, when UE j is arranged in them. If the equation yields positive value, UE should be arranged in normal frames, else it must be arranged in protected subframes.

$$f\left(\frac{\alpha_{1j}^{\rho_{n1}}}{\alpha_{2j}^{\rho_{n2}}}\right) = WT\log_2\left(\frac{\alpha_{1j}^{\rho_{n1}}}{\alpha_{2j}^{\rho_{n2}}}\right) - \frac{R_{n1}}{\gamma_{n1}N_{n1}} + \frac{R_{n2}}{\gamma_{n2}N_{n2}}$$

where

$$\rho_{n1} = \frac{(1-\beta)}{(R_{n1}-R_{n1,min})N_{n1}}$$

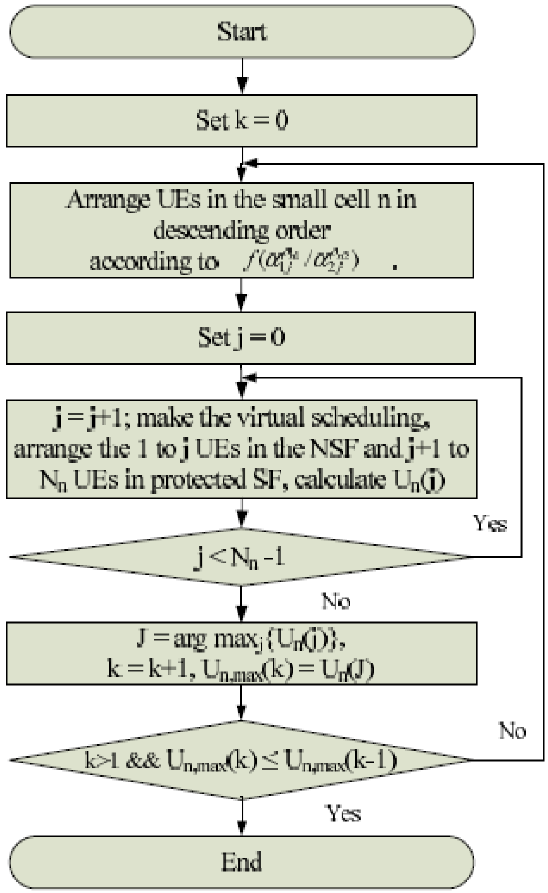
and

$$\rho_{n2} = \frac{\beta}{(R_{n2}-R_{n2,min})N_{n2}}$$

(II)

Where $Nni = \Sigma aij$, αij = (1+ SINRwb,ij) and $\gamma ni = Rni - Rni,min$.

During each UE partition procedure, β is fixed, and hence ρni is also fixed in each update. The flowchart below explains the UE partition algorithm.
1. At the start point, we set a variable $k = 0$
2. Arrange the UEs in the small cell n in decreasing order according to marginal benefit of arranging UE j in normal subframe. The ρni is determined based on the initial β and UE partition.
3. Then arrange the first 1 to j, $j \in [1, Nn - 1]$ UEs in normal subframes and (j +1) to Nn UEs in the protected subframes, calculate $Un(j)$,
4. Select the partition J = argmax<j> $Un(j)$. set $k = k + 1$, and $Un,max(k) = Un(j)$.
5. Repeat the UE partition process with the updated ρni according to the new partition J until no more improvement can be achieved for Un.



Flowchart UE partition algorithm

Source: "Resource allocation for eICIC scheme in heterogeneous networks", Lei Jiang and Ming Lei, IEEE 23rd International symposium on personal, indoor and mobile radio communications, 2012

After UE partition is done, we have to decide on ABSFs. For nth cell $Rtn1$ is the data transmitted over time t in normal subframe, $Rtn2$ is the data transmitted over time t in protected subframe. Then, the utility function of nth cell is given by

$$Un = (Rtn1\ (1 - \beta) - Rn1,min)(Rtn2\ \beta - Rn2,min)$$

We select a β which maximizes the product of utility functions of all eNBs. This β is used to determine the UE partition in the next iteration.

The entire algorithm may be summarized as follows

1. At the start of algorithms, an initial β is broadcasted to all eNBs and the small cell enBs arbitrarily partition their UEs.
2. At the beginning of each ABSF pattern period, all small cell eNBs partition their UEs according to algorithm described earlier and the UE partition obtained is applied for this ABSF period.
3. At the end of ABSF period all the small cell eNBs report their $Rtni$ control center that will determine a new β to maximize the utility functions of all eNBs.
4. The new β is broadcasted to all eNBs and the step 2 is repeated.

Handover failures and ping-pongs in eICIC range expanded heterogeneous networks

Handover failures are reduced in range expanded picocells implementing eICIC techniques. Due to expanded range of picocells, the A3 condition for handover is met and TTT timer starts at greater distance from range expanded picocell base station compared to picocell with no range expansion. Also due to eICIC, there is no significant degradation in SINR as the UE runs deep into the picocell. There is sufficient time TTT to expire and for handover to start before the macro UE runs deep into the picocell. This reduces handover failure. However ping pong rate for UEs increases due to range expansion of picocells. This is because the cell selection oscillation due to fading increases as the range of the picocell is increased without increasing the transmission power (fading in larger area).

Conclusion

There is a tradeoff between handover failures and ping-pong rates with respect to time to trigger as well as range expansion with eICIC. Hence the range expansion bias, eICIC schemes and TTT have to be decided carefully. In [1] a mobility based ICIC technique is proposed that combines HO parameter optimization with eICIC to reduce handover failures and ping-pongs. The paper proposes that ABSFs be configured at picocells, where the macrocell can schedule their high mobility users to reduce chances of handover failure and ping-pongs for low mobility users are reduced by increasing TTT sufficiently using handover parameter optimization.

Here we see that the scheduling of UEs in protected subframes or Handover parameter optimization depends on the mobility of UEs. Thus to decide on whether the UE is high mobility UE or low mobility UE we need mobility estimation techniques. In a homogeneous network, number of handovers within a given period can be used to determine the mobility of the user. But in heterogeneous networks, this technique doesn't serve the need as the cells are of different sizes. Mobility state estimation using above technique can be adapted to heterogeneous networks by taking average handover count proportional to the cell size or taking weighted average. Larger the cell larger is its weight in calculating weighted average. Also Doppler frequency measurements along with cell reselection count may be used to estimate the the mobility of UE effectively. However more effective mobility state estimation techniques are to be proposed and implemented to determine the mobility state of UE more precisely

References

[1] "Mobility Management Challenges in 3GPP Heterogeneous Networks", David lopez perel et al., "IEEE communications Magazine, December 2012

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