Abstract— 3GPP Release 9 has introduced a proximity detection feature where the User Equipment (UE) when so configured is able to determine its proximity to a Closed Subscriber Group (CSG) or hybrid cell. The proximity is determined for CSG or hybrid cells whose CSG Identity (CSG ID) is in the UE’s CSG whitelist. The UE sends an “entering” or “leaving” proximity indication to the Serving Radio Network Controller (SRNC) whenever it is entering or leaving respectively the proximity of one or more such cells. This helps the network to take the necessary actions for handover preparation viz. configure or take away handover measurements at the UE. The proximity detection feature is based on UE implementation and this paper proposes a macro cell based fingerprint method for proximity detection. This method offers reliable triggering of proximity indication but may not be very precise. Additionally an enhanced method is proposed using the out–of-band (OOB) radio integrated with the Home NodeB (HNB). In the enhanced method, OOB equipped UEs start searching for the HNB over the OOB link when the macro cell based fingerprint match occurs and “entering” proximity indication is sent only after the HNB is detected over the OOB link. The enhanced method offers higher precision and better network performance due to less measurement gaps being configured.

Keywords— Femtocells; HNB; CSG; proximity detection; proximity indication; measurement gaps, UE; OOB; WiFi; Access Point

I. INTRODUCTION

In 3GPP [1], [2], [3], [4], CSG cells and hybrid cells are defined as those which broadcast CSG ID to provide restricted and preferential access respectively to member UEs. The member UEs are those UEs which have the CSG ID broadcast by CSG or hybrid cells present in their CSG whitelist. Residential or enterprise femtocells i.e. HNBs could be deployed as CSG or hybrid cell, providing restricted or preferential access to their member UEs. Since member UEs typically get better quality of service (QoS), billing rates, enhanced location services etc. at their CSG/hybrid cell, it is desirable to offload these UEs as soon as possible from the macro network to their CSG/hybrid cells even in good macro channel conditions. This offload also helps relinquish bandwidth for other UEs on the macro network. When the HNB is on a different frequency or Radio Access Technology (RAT) than the serving macro network, then macro channel condition based triggers for offload might not always work. To enable offload of connected mode UEs, 3GPP introduced CSG proximity detection feature in Release 9.

Using CSG proximity detection feature, a UE is able to determine that it is near a CSG or hybrid cell whose CSG ID is in the UE’s CSG whitelist. Based on this determination the UE provides to the SRNC an indication of its proximity to the CSG or hybrid cell. 3GPP defines the following CSG proximity indication related parameters to indicate whether the UE supports proximity indication for intra-frequency cells or/and inter-frequency cells or/and E-UTRAN cells
a) Support of intra-frequency proximity indication
b) Support of inter-frequency proximity indication
c) Support of E-UTRA proximity indication

Fig 1. Inter-frequency Measurement Procedure of CSG and Hybrid cells

Fig. 1 shows the inter-frequency measurement procedure for UMTS CSG and hybrid cells. This is similar to the inter-RAT measurement procedure used for inter-RAT mobility from UMTS cell to Home eNodeB (HeNB). In step 1, the SRNC configures the UE with a measurement having "CSG Proximity detection" as measurement type thereby configuring....
the UE to report proximity to its member CSG and hybrid cell. In step 2, the UE sends an "entering" CSG proximity indication when it determines it may be near its member CSG and hybrid cell. The CSG proximity indication includes the RAT and frequency of the cell. Step 2 may not be performed for CSG/hybrid cells that the UE has not previously visited.

In step 3, the SRNC configures a measurement on the reported RAT and frequency to measure CSG/hybrid cells. Compressed mode (CM) gaps if required by the UE are also activated to allow the UE to perform measurements on the reported RAT and frequency. In step 4, the UE sends a measurement report including the measured Primary Scrambling Codes (PSCs). If subsequently the UE determines that it is no longer near its member CSG/hybrid cell after sending an "entering" CSG proximity indication in step 2, the UE sends a "leaving" CSG proximity indication to the SRNC. Upon reception of this indication the SRNC may reconfigure the UE to stop measurements on the reported RAT and frequency.

In step 5, the SRNC configures the UE to perform System Information (SI) acquisition and reporting of a particular PSC. In step 6, the UE performs SI acquisition using autonomous gaps i.e. the UE may suspend reception and transmission with the SRNC within the limits to acquire the relevant SI from the target HNB. In step 7, the UE sends a measurement report including cell identity, CSG ID and CSG membership indication. In step 8, the SRNC proceeds with the handover processing.

The focus of this paper is CSG proximity detection in connected mode for inter-frequency or/and inter-RAT scenarios. The proximity detection is an optional feature and based on UE implementation. It is also to be noted that there is no conventional CSG proximity detection method. The rest of the paper is organized as follows. Section II discusses the proposed baseline CSG proximity detection method; Section III discusses the details of the proposed enhanced CSG proximity detection method using OOB link; Section IV compares the baseline and the enhanced methods while Section V concludes the paper.

II. BASELINE CSG PROXIMITY DETECTION

In the proposed baseline macro cell based fingerprint method for CSG proximity detection, the UE stores the fingerprint information corresponding to each member HNB when it visits the HNB for the first time. The fingerprint information contains cell identities of one or more neighboring macro cells on each RAT/frequency. In Fig. 2, HNB fingerprint = union (Cell-1, Cell-2, Cell-3). The UE also stores HNB related information e.g. frequency, RAT etc. The first visit to the CSG cell can be through user-triggered manual CSG selection [4]. During subsequent visits the UE considers itself to be in proximity of the HNB if it happens to be in the HNB fingerprint i.e. in any one of the neighboring macro cells of the HNB as stored in the fingerprint.

The baseline CSG proximity detection method is similar to the baseline reference implementation being considered in 3GPP RAN Working Group#4 for testing CSG proximity detection feature [9]. The baseline method is not always very precise. For example, let us consider 2 UEs viz. UE 1 and UE 2 that are both members of the HNB. Both UE 1 and UE 2 are within the HNB fingerprint = union (Cell-1, Cell-2, Cell-3).

Hence as per the baseline method both UE 1 and UE 2 send “entering” CSG proximity indication to SRNC indicating proximity to member HNB that is on a different frequency. The SRNC configures both UEs for measurement gaps to perform measurements. As UE 1 is in the HNB coverage UE 1 will detect the HNB. However UE 2 is not in the HNB coverage and hence will not be able to detect the HNB until it moves within the HNB coverage. Therefore the measurements gaps configured for UE 2 triggered by the proximity indication sent while it is outside the HNB coverage are unnecessary. The SRNC would not know when UE 2 would move within the HNB coverage and hence for how long it should configure UE 2 with the measurement gaps. It is to be noted that continuation of the measurement gaps would impact the macro cell’s capacity while taking away the measurement gaps would prevent the handover of the UE 2 to its member HNB. Thus the baseline method offers reliable triggering of proximity indication but may cause some loss of macro capacity due to measurement gaps if the HNB discovery is delayed.

III. ENHANCED CSG PROXIMITY DETECTION

Integrating an OOB radio e.g. Bluetooth or WiFi to the HNB had been proposed by us earlier; [6] talks about our proposal of using the OOB link in facilitating active hand-in from macrocell to femtocell. HNBs integrated with OOB radio are becoming reality and. Integrated Femto WiFi (IFW) i.e.
HNB integrated with WiFi has been taken as a study item by the small cell forum earlier known as femto forum [7]. Also most of the phones nowadays have WiFi or Bluetooth. In the remainder of the paper, WiFi is used as an example of the OOB link; and WiFi and OOB are used interchangeably.

In the enhanced method once the UE considers itself to be in the HNB fingerprint, the UE does not send “entering” CSG proximity indication to the SRNC. Instead the UE starts searching for HNB WiFi based on prior information stored about the HNB WiFi as discussed in the section below. Thus the UE WiFi does not need to be ON always for CSG proximity detection. When the HNB is detected over WiFi, the UE sends “entering” CSG proximity indication to the SRNC. Similarly when the UE no longer detects the HNB over WiFi, it sends “leaving” CSG proximity indication to the SRNC. For HNBs or UEs not equipped with WiFi, the CSG proximity indication is sent as per the baseline method discussed in Section II.

The WiFi coverage is almost matched to the HNB coverage and hence the enhanced method offers very precise and reliable mechanism for triggering proximity indication to the SRNC. Revisiting Fig. 2, both UE 1 and UE 2 are within the HNB fingerprint = union (Cell-1, Cell-2, Cell-3). UE 1 detects HNB WiFi and sends “entering” CSG proximity indication to the SRNC. The SRNC configures UE 1 for measurement gaps to perform measurements and UE 1 detects the HNB as it is in the HNB coverage. On the other hand UE 2 does not detect HNB WiFi and does not send “entering” CSG proximity indication to the SRNC. The SRNC does not configure UE 2 for measurement gaps to perform measurements. This increased precision helps reduce the number of configured measurements gaps for connected mode UEs thereby preventing loss of macro capacity.

The fingerprint and HNB information are stored in the UE in exactly the same way as described in Section II. Additionally the HNB WiFi information is also stored in the UE during 1st visit as discussed below.

a) Updating HNB information with WiFi information

After discovering a CSG or hybrid HNB for the first time and storing the fingerprint and HNB information, the UE tries to determine if the HNB is integrated with WiFi while still in the HNB coverage. The HNB does not indicate its WiFi capability over the Wireless Wide Area Network (WWAN) air interface. So the UE starts scanning the WiFi channels using either active or passive scanning [8] as shown in Fig. 3. In case of active scanning, the UE performs basic medium access procedure of Distributed Coordination Function (DCF) and transmits a broadcast probe request with broadcast destination and broadcast basic service set identification (BSSID). If no probe response is received within a specified time, the UE moves to scan the next channel. If response is received the UE processes that response and then scans the next channel till all channels are exhausted.

If doing passive scanning, the UE waits for several beacon intervals per channel to receive beacon frames before moving to the next channel. WiFi full scanning is a time-consuming process but is done only for the first time for a given HNB unless the SSID or channel of operation is changed later. If no probe response or beacon is received over all the WiFi channels, the UE determines that the HNB is not WiFi equipped. However if beacon or probe response is received, the UE still does not know if the HNB is integrated with WiFi as those could have come from WiFi Access Points (APs) proximate to the HNB.

There are a number of ways to map the HNB and WiFi identification. WiFi SSIDs have a maximum length of 32 characters and the SSID broadcast by the HNB WiFi can be configured to have the format 

<Operator_Frequency_RAT_CSG_Id>

to include HNB information like operator name, frequency, RAT, CSG ID etc. When UE detects the SSID, it gets the mapping information between the HNB and WiFi. This method is simple but it is not clear whether the operator or the end user will do the provisioning of the SSID.

If SSID provisioning is not done, the mapping between HNB and WiFi information may also be obtained using an application running on the UE and the HNB. The application maintains the HNB information and the HNB WiFi information. After discovering a member CSG/hybrid HNB for the first time, the UE would access the application either over the HNB WWAN or the HNB WiFi. If HNB WWAN is used, the UE might not need to scan for HNB WiFi initially.
Otherwise the UE would scan for the HNB WiFi as described above and then attempt to connect to the detected WiFi AP(s) to determine if it is the HNB WiFi AP and obtain the mapping information over the WiFi. Once the UE determines the mapping information between HNB and WiFi by any of the above methods, it stores the HNB’s WiFi information e.g. SSID, WiFi channel of operation, Medium Access Control (MAC) address of the HNB WiFi etc. This mapping information helps the UE to infer proximity to the HNB during subsequent visits to the HNB based on detection of the HNB WiFi.

b) WiFi scanning for HNB WiFi for proximity detection

During subsequent visits once the UE finds itself in the HNB fingerprint, the UE retrieves the WiFi channel of operation and HNB WiFi SSID from the stored information. There could be multiple proximate HNBs that the UE might have to scan and the scan list could be like as follows

\[<\text{channel 1: SSID1}>;<\text{channel 6: SSID2, SSID3}>\ldots.\]

If there is only one proximate HNB on any channel, the UE sends a directed or broadcast probe request on that channel with the MAC address of the HNB WiFi in the BSSID field. If there are multiple proximate HNBs on any channel, the UE sends a broadcast probe request with broadcast address as the destination and broadcast BSSID on that channel. The UE repeats the above procedure for each channel to be scanned.

If probe response is received the UE processes the probe response and sends the proximity indication on the WWAN for the corresponding HNB. When all channels have been scanned and probe response from at least one HNB has not been received, the UE attempts the next scan after a predetermined time interval for those HNBs whose fingerprint is satisfied. The time interval can be adjusted to trade off the HNB detection latency with the UE power consumption. If the number of scans for the HNB(s) has reached a limit and no response has been received, the UE performs a full WiFi scan. The maximum number of scans before full scan is performed depends on how big the HNB fingerprint area is compared to the HNB WiFi coverage [5] and can be refined over time based on the UE observations. If HNB is detected during full scan and the WiFi channel of operation or SSID has changed, the UE updates the stored HNB WiFi information. If HNB is not detected after full scan, the UE attempts the next scan as per the flowchart in Fig. 4 after a second interval is elapsed. The repeat scans for the HNB increases the reliability of the HNB WiFi detection when the UE is in HNB WiFi coverage.

c) Optimizing WiFi scanning for proximity detection

The WiFi scan for the HNB can delayed by a time offset from the time when the HNB fingerprint match occurs. This helps to save UE power consumption as the HNB fingerprint being based on macro cell is much larger than the HNB WiFi coverage. Let

\[T = \text{periodicity of WiFi scanning in the UE}\]
\[n = \text{number of probe requests till probe response is received}\]
\[T_{out} = \text{timeout for probe request}\]
\[T_{b} = \text{delta between probe request and probe response in the last i.e. successful attempt}\]
\[T_{off} = \text{delay in starting the HNB WiFi scan after fingerprint match occurs}\]

It is seen from Fig. 5 that the delay from the first probe request till probe response is received is given by the following.

\[T_{\text{probe delay}} = (n - 1) \times (T_{out} + T) + T_{b}\]
The overall delay from the time the HNB fingerprint match occurred till probe response is received is as follows.  
\[ T_{\text{overall}} = T_{\text{probedelay}} + T_{\text{off}} = (n-1) \times \left( T_{\text{wait}} + T \right) + T_{b} + T_{\text{off}} \]

\( T_{\text{overall}} \) also depends on how big the HNB fingerprint is compared to the HNB WiFi coverage and the UE mobility model while \( n \) depends on \( T_{\text{off}}, T, \) HNB fingerprint area and the UE mobility model. The default periodicity of scanning may be operating system dependent but can be changed. With everything else remaining same, with higher \( T_{\text{off}}, \) \( n \) would be lower and vice versa. Higher value of \( n \) would mean higher UE power consumption for WiFi scanning while higher \( T_{\text{off}} \) might result in a delay in starting scan for the HNB WiFi as UE might be already in HNB WiFi coverage. Higher \( T_{\text{off}} \) is desirable (\( n \) could be 1 in the extreme) compared to higher \( n \) as the latter does not offer any benefit except expedited macro offload in some cases. Each HNB can have different \( T_{\text{off}} \) and the value can be refined over time from the UE measurements of \( T_{\text{overall}}. \) As the orientation of UE’s approach towards HNB can be one of the many different possibilities, a conservative estimate of \( T_{\text{off}} \) is given by \( \max \{ \text{mean} \left( T_{\text{overall}} \right) - T, 0 \} \) \( \text{-------- (1)} \) while a slightly aggressive estimate of \( T_{\text{off}} \) is \( \text{mean} \left( T_{\text{overall}} \right) \) \( \text{-------- (2)} \)

Let us assume that the probability of HNB detection on first attempt within the HNB WiFi coverage is 100\% and the macro cell radius is \( R=0.5\text{Km} \) [5]. From Fig. 2 the best case distance from the point of HNB fingerprint match to edge of HNB WiFi coverage is \( \sim R \). Considering the UE speed to be 60kmph, time taken for the UE to move within the HNB WiFi coverage from the time of HNB fingerprint match is 30 sec. The worst case distance from the point of HNB fingerprint match to the edge of HNB WiFi coverage is \( \sim 2R \); however that might not correspond to the worst case time depending on the route taken by the UE and the UE speed. Let us assume that the average call duration inside the HNB fingerprint is 60 sec, within which the UE may move within the HNB WiFi coverage. Assuming the time taken for the UE to move within the HNB WiFi coverage from the time of HNB fingerprint match is uniformly distributed between 30 sec and 60 sec and ignoring \( T_{\text{wait}} \) and \( T_{b} \), the number of scans spaced \( T = 6 \text{ sec} \) apart is shown in Fig. 6.

It is seen from Fig. 6 that the number of scans for (2) is less than that for (1) and thus (2) is better from the point of UE power consumption. This is because \( T_{\text{off}} \) in (2) is the average of the overall latencies measured so far and the WiFi scan for the HNB is triggered after this time offset has elapsed. In some cases, this may result in additional delay for the HNB WiFi detection after the UE moves into HNB WiFi coverage compared to (1). One the other hand a reduced \( T_{\text{off}} \) in (1) results in a lower HNB detection latency but at the cost of more scans. An even more conservative estimate of \( T_{\text{off}} \) would result in more number of scans and reduced latency while an even more aggressive value of \( T_{\text{off}} \) would result in the opposite. The scanning interval \( T \) has similar impact as \( T_{\text{off}} \) and larger \( T \) results in lower \( n \) and vice versa. However this is not investigated further.

IV. COMPARISON OF BASELINE AND ENHANCED METHODS

The SRNC might have to configure the UE for measurement gaps even outside the HNB fingerprint if the CSG proximity detection feature is not supported for detecting proximity to the member HNB on a different frequency/RAT. These measurement gaps impacts macro cell’s capacity. The CSG proximity detection and subsequent proximity indication reporting was introduced in 3GPP Release 9 to limit the geographical area (e.g. the HNB fingerprint for baseline method) over which measurement gaps would be needed to scan for member HNB on different frequency/RAT. The enhanced method further limits the geographical region over which measurement gaps would be needed thereby improving the network performance. It is to be noted that the signaling overhead i.e. sending “entering” and “leaving” proximity indication to the SRNC is negligible compared to the benefits of less measurement gaps being configured. There is also no additional signaling in the enhanced method compared to the baseline method.

The performance of the enhanced method using the OOB link is compared against the baseline method as the specification leaves it to implementation. As noted earlier, the baseline method is similar to the baseline reference implementation being considered in 3GPP RAN Working Group # 4 for testing CSG proximity detection feature [9]. The performance comparison is done by evaluating the number of unnecessary proximity indications sent by a macro UE to the SRNC i.e. how often a macro UE thinks that it is in proximity of its member HNB using baseline fingerprint method when actually it is not.
It is assumed that the macro UE is in connected and that the HNB is on a different frequency than the macro. For the sake of simplicity of the analysis, it is also assumed that UE is member of only one HNB and that a UE does not enter its HNB coverage immediately after transitioning to connected mode. The latter assumption is because the benefit of the enhanced method over baseline method is mostly for a UE that spends considerable time outside the HNB coverage but within the HNB fingerprint in connected mode and sends proximity indications to the SRNC when it is still outside the HNB coverage.

The analysis also depends on the rate at which the user makes calls, duration of the calls, time spent inside the HNB fingerprint but outside the HNB coverage, frequency at which user moves in and out of the HNB fingerprint, etc. Since it is very difficult to capture all possible scenarios, in this paper the benefit of the enhanced method is illustrated using two possible scenarios:

**Scenario 1:** The HNB is located at a coffee shop near user’s office or residence. The user spends about 8 to 16 hours near the shop (i.e. inside the HNB’s fingerprint but outside the HNB coverage), by the virtue of spending that much time in office/residence. As a loyal customer to the coffee shop the user has subscription i.e. is a member of the coffee shop HNB.

**Scenario 2:** The HNB is located at either user’s office or residence and the user is subscribed to the HNB. Both office and residence are close to each other such that both locations are included in the HNB fingerprint. The user spends 8 to 16 hours inside the HNB fingerprint but outside the HNB coverage due to the presence in either office or residence.

Fig. 7 compares the number of proximity indications sent by a UE implementing the baseline method versus the enhanced method for the above two scenarios when the UE is present outside the HNB coverage but within the HNB fingerprint. The benefit of the enhanced method is compared against the baseline method for different call initiation rates (Ri) i.e. the average rate at which user initiates a call per hour when inside the HNB fingerprint but outside the HNB coverage. As the HNB WiFi coverage is assumed to closely match the HNB WWAN coverage, a UE implementing the enhanced method does not send any unnecessary proximity indication to the SRNC outside the HNB coverage. Fig. 7 shows that more benefit is obtained from the enhanced method for the users that make frequent voice or data calls and spend more time near but outside their HNB coverage.

V. CONCLUSION

In this paper a baseline CSG proximity detection method using macro cell based fingerprint has been proposed where the UE sends proximity indication to the SRNC when it is inside the HNB fingerprint. For HNBs integrated with OOB radio, an enhanced method is also proposed where the UE starts scanning for the HNB over the OOB link when it is inside the HNB fingerprint and sends the proximity indication to the SRNC when it detects the HNB over the OOB link. The baseline method offers reliable triggering of proximity indication while the enhanced method improves the precision of triggering proximity indication and improves network performance. Some optimizations were proposed for the OOB scanning for proximity detection to save the UE power consumption by avoiding unnecessary OOB scans. The enhanced method was also compared against the baseline method to illustrate its benefits.

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