Coverage-based Common Radio Resource Management in heterogeneous CDMA/TDMA Cellular Systems

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Abstract. In this paper, we proposed a coverage-based common radio resource management (CRRM) strategy to improve the system performance for a heterogeneous CDMA/TDMA cellular system. In this strategy, with full coverage guaranteed by FDMA/TDMA systems, our theoretical numerical results show that the proposed coverage-based CRRM has the potential to improve the overall blocking rate by controlling the effective coverage of the co-sited CDMA system. Then, a simulation study is performed to implement this strategy by using the pathloss information. Our simulation results show clear advantages of the new proposed scheme against conventional load-balancing strategy for voice traffic.

I. INTRODUCTION

With the rapid development of wireless communication, various radio access technologies (RATs) such as cellular network, WLAN, and WiMAX have been developed independently to meet the diverse need of mobile users. These co-existing RATs differ from each other by air interface technology, cell-size, services, price, access, coverage and ownership. This integration of these RATs based on common all-IP packet core has become one of the most common visions for future mobile networks (e.g., 4G or beyond 3G) in mobile research community. The complementary characteristics offered by the different RATs make the integration possible to exploit the trunking gain leading to a higher overall performance than the aggregated performances of the stand-alone networks. Clearly, this potential gain of the future heterogeneous network can only turn into reality by means of a proper management of the available radio resources. Common Radio Resource Management (CRRM) refers to the set of functions that are devoted to ensure an efficient and coordinated use of the available radio resources in heterogeneous networks scenarios [1][2].

CRRM strategies should ensure that the operator’s goals in coverage and QoS are met while providing as high as possible overall capacity (i.e. higher than the sum of the capacities achieved in every single RAT). Within CRRM, the initial RAT selection, i.e. the allocation of connections to specific RANs at session initiation, and the vertical handover (VHO), i.e. the capability to switch on-going connections from one RAN to another, are the key enablers to properly manage the heterogeneous radio access network scenario and become then key CRRM functions [1][2][3][4]. The research in this field starts initially focusing on hierarchical heterogeneous network such as UMTS/WLAN [5]. In such as system, CRRM is to improve the system capacity by co-ordinate the resource in the hot-spot area where non-real-time traffic is handed over to WLAN to reduce the congestion in UMTS network. In [6][7], load balancing CRRM strategy has studied to improve the system performance in a hierarchical cellular system where multiple RATs co-exist in different layers. In [4], a policy-based RAT selection has been implemented in CRRM context to improve the resource utility in a multi-service cellular environment.

In this paper, we developed a coverage-based CRRM strategy to improve the system performance in terms of blocking rate for a heterogeneous CDMA/TDMA radio network. This strategy is designed to exploit the difference of the sensitivity of the two systems to multi-user interference (MUI). In FDMA/TDMA-based access systems (e.g. GSM/GPRS) there is no intra-cell MUI while inter-cell MUI is caused by the distant users in every co-channel cell. In contrast, in CDMA-based systems (e.g. UMTS) the intra-cell MUI is caused by every single user transmitting in the cell. Furthermore, inter-cell MUI is also originated by all simultaneous users in all neighbouring cells, because of the universal frequency reuse. Consequently, CDMA system capacity is more sensitive to MUI. The CRRM approach developed in this paper is to take advantage of the coverage overlapped by these two access technologies. With full area covered by FDMA/TDMA-based RAT, the proposed the coverage-based CRRM is designed to control the effective cell radius of the CDMA-based systems through initial cell selection and vertical handover. With this scheme, users with larger pathloss profile have more chance to be admitted into the FDMA/TDMA-based system, while users with smaller pathloss will have higher probability to be admitted into CDMA-based system. Thus, the interference level in CDMA-based RATs is reduced while at the same time the target coverage area is assured by the cooperation of the FDMA/TDMA-based RATs and an overall performance improvement is expected.

In this paper, a simple theoretical model is developed to assess improvement brought by the proposed CRRM. The model provides some insight views on the design of coverage-based CRRM. However, in reality, the coverage of a cell is difficult to predict in a wireless environment. Following the theoretical study, a more realistic approach is proposed to implement the
coverage-based CRRM concept. In the implementation, the pathloss information of each mobile derived through measurement and measurement reporting scheme in UMTS/GSM is deployed to control the effective coverage of UMTS system. A simulation study is performed to compare this implementation with load balancing CRRM strategy in a more realistic environment.

This paper is organised as follows. In section II we present the concept of the coverage-based CRRM and a simple analytical model is applied to show the potential of coverage-based on improving the system capacity. In section III, an implementation of this concept in a more realistic environment is developed, and finally conclusions and future work are presented in Section IV.

II. COVERAGE-CRRM

A. HETEROGENEOUS SCENARIO

The scenario we studied is illustrated in Figure 1 for a situation where CDMA and FDMA/TDMA Base Stations (BS) are co-sited. $RT$ denotes the planned cell radius in FDMA/TDMA and $RC$ denotes the effective cell radius in CDMA. With CRRM functionalities placed in this heterogeneous network, the traffic can be freely located between the two systems through the vertical handover (VHO) and initial RAT selection procedures. Thus the resource pool co-ordinated by CRRM in one cell is given as

$$CT = C_{CDMA} + C_{F/T}$$

where $C_T$ is the total number of channels offered by the two systems, $C_{CDMA}$ is the number of channel that can be offered by the CDMA system and $C_{F/T}$ is the number of channels offered by the FDMA/TDMA system.

If both CDMA and FDMA/TDMA systems offer the same coverage (i.e. $RT=RC$), the total the number of channel is $CT$ for all the users in the cell coverage and then the blocking rate of the cell is given as

$$P_b = A^{C_T} / C_T! \cdot \sum_{i=1}^{C_T} A^i / i!$$

where $A=\lambda/\mu$ is the traffic load, $\lambda$ is the arrival rate and $\mu$ is the depart rate.

B. COVERAGE-BASED CRRM

Based on (2), the blocking rate increases as traffic load $A$ increases and, a bigger value of $C_T$ leads to a better blocking rate performance. In the FDMA/TDMA system, $C_{F/T}$ is given as the number of time slots for the traffic, which is fixed according to the number of frequency channels allocated in this cell. However $C_{CDMA}$ which is defined as the number of simultaneous links that can be supported in the cell for a given service with a certain quality requirements, is actually a coverage dependent value. In particular, Table 1 shows the downlink value of $C_{CDMA}$ against the CDMA cell radius $RC$ in a scenario for a voice service with Eb/No requirement of 5 dB through our simulation results (Table 2 gives the system parameters).

![Figure 1 Co-sited CDMA and FDMA/TDMA](image)

**TABLE 1. CDMA CAPACITY AS A FUNCTION OF THE COVERAGE RADIUS**

<table>
<thead>
<tr>
<th>Radius in m</th>
<th>1000</th>
<th>900</th>
<th>800</th>
<th>700</th>
<th>600</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{CDMA}$</td>
<td>30</td>
<td>38</td>
<td>45</td>
<td>55</td>
<td>69</td>
<td>91</td>
</tr>
<tr>
<td>Gain (%)</td>
<td>0</td>
<td>27</td>
<td>18</td>
<td>22</td>
<td>25</td>
<td>31</td>
</tr>
</tbody>
</table>

And the pathloss model is given as

$$Lp(dB) = 144 + 38.4 \log (d(km)) + S(dB)$$

where $S(dB)$ corresponds to the log-normal shadowing with $s=10$ dB standard deviation.

In table 3, with a smaller coverage, a larger $C_{CDMA}$ is expected. Roughly 20-30% capacity gain can be obtained for CDMA systems by reducing 100 meters in the $RC$. Thus, a coverage-based CRRM is proposed here to increase the $C_T$ by controlling $RC$.

In this strategy, for a given service such as voice, the FDMA/TDMA cells ensure coverage in the whole area. For the CDMA system, we can increase $C_{CDMA}$ value by controlling $RC$, e.g. when we reduce the $RC$ from 1 km to 0.9km, we have an increase of 8 in $C_{CDMA}$ (see Table 1). However since if we reduce the CDMA BS coverage, a certain amount of traffic has to be handed over from CDMA to FDMA/TDMA system, this would affect the blocking probability of the FDMA/TDMA system. This might not lead to any improvement even degradation on the performance outside of the CDMA effective coverage. In order to assess the feasibility if coverage-based CRRM is able to improve the system performance, in the following we develop a simple model.

The total FDMA/TDMA cell is divided into two areas: IN area ($RC$) and OUT area ($RT$) as shown in Figure 1. The IN area is covered by both FDMA/TDMA and CDMA BSs, and the OUT area is only covered by the FDMA/TDMA BS. To guarantee the continuous coverage for the whole area, $RT$ in this case is kept at constant by FDMA/TDMA system. And the IN area radius ($RC$) is controlled by the CRRM. With this division, a
number of FDMA/TDMA channels, denoted as $N_2$, are allocated for the OUT area calls. Then the number of channels for IN area is given as

$$N_1 = C_T - N_2$$

To clearly show how the coverage based CRRM works, we introduce another two performance measures, IN area blocking rate $P_1$ and OUT area blocking rate $P_2$, which are given as

$$P_1 = \frac{A_1^{N_1}}{N_1!} \sum_{i=0}^{N_1} \frac{A_1^i}{i!} \quad \text{and} \quad P_2 = \frac{A_2^{N_2}}{N_2!} \sum_{i=1}^{N_2} \frac{A_2^i}{i!}$$

where $A_1$ and $A_2$ are the traffic load in IN area and OUT area respectively. If the CDMA radius is given as $R_C$, then we define the coverage probability of $p_1$ as the ratios of the IN area over the whole cell as the following,

$$p_1 = A_1 / (A_1 + A_2)$$

Then, the blocking rate for a the whole cell is given as

$$P = p_1 \frac{A_1^{N_1}}{N_1!} \sum_{i=0}^{N_1} \frac{A_1^i}{i!} + (1 - p_1) \frac{A_2^{N_2}}{N_2!} \sum_{i=1}^{N_2} \frac{A_2^i}{i!}$$

Figure 2 gives the blocking probability as the function of traffic load. In this evaluation, the number of channels allocated to the OUT area is fixed at 15. With reducing CDMA coverage to 0.9 $R_T$, the blocking rate performance is improved. If we consider 0.05 as acceptable blocking rate for users, the capacity is almost improved by 12% (when both systems offer the same coverage, the traffic that can be supported is 45 erlangs, and with $R_C/R_T=0.9$, it is 50.4 erlangs). This means it is feasible to improve the system performance by controlling the coverage. However, if the radius is reduced to 0.8 $R_T$, the performance is even worse than that with $R_C/R_T=1$. In fact, as the radius of CDMA system decreasing, the performance in the IN area enjoys an improvement favored by reduced traffic load and increased capacity. However, with a fixed value of $N_2$, users in the OUT area face a different situation. As more traffic load move from IN to OUT area, a higher blocking rate is expected in the OUT area. If the blocking rate improvement in the IN area is not big enough to compensate the degradation in the OUT area, the whole performance will be brought down. In this situation, we need to bring more FDMA/TDMA channels to the OUT area or increases the CDMA coverage.

An interesting challenge here is possible to improve the both area performance by the coverage control strategy. Figure 3 shows both IN and OUT area the blocking rate with the $R_C/R_T$ ratio value of 0.9 and 0.8 as a function of $N_2$. Clearly as $N_2$ increases, the OUT area blocking rate decreases and the IN area blocking rate increases in both cases. It is easy to find that after $N_2=14$, $R_C=0.9 R_T$ can produce a better blocking rate in both areas than that with $R_C=R_T$. And further for $R_C=0.8 R_T$, after $N_2=23$, this also happens. This indicate that, if there are sufficient channel available for OUT area, it is possible to achieve a true improvement i.e. improvement in both IN and OUT area, through coverage-based CRRM.

III. IMPLEMENTED IN UMTS/GSM WITH PATHLOSS INFORMATION

In the previous section, we have shown the potential to increase the heterogeneous network capacity by controlling the radius. However, in realistic environment, it is difficult to predicate CDMA coverage because of the randomness of the propagation and also the breathing effects of CDMA network. Nevertheless, in both GSM and UMTS systems, uplink and downlink has formed a close-loop measurement and measurement-reporting scheme, which is used for power control and handover purpose. With this scheme, the pathloss of a mobile usually can be derived [3].

Motivated by the coverage-based CRRM concept, a pathloss threshold ($Thr$) is set up in our implementation. This implementation will make the users with pathloss less than the threshold have more chance to be admitted in UMTS while the
users with pathloss greater than the threshold have more chance to be admitted into GSM. Thus, in average, less power is needed for UMTS users’ transmissions and consequently less MUI is generated. This will lead to a capacity gain. The CRRM call admission procedure is shown in Figure 4 for new calls and on-going connections (handover). In this implementation, we do not set specific number of GSM channels for the OUT area, thus the system performance is mainly subjective to \( \text{Thr} \) value. And a load balancing CRRM strategy [5][6][7] shown in Figure 5 is proposed here as a benchmark of the proposed implementation. In this figure \( L1 \) and \( L2 \) is the traffic load for TDMA and CDMA system respectively, and are given as

\[
L1 = \frac{C_{\text{busy}}}{C_{F/T}}
\]

where \( C_{\text{busy}} \) is the number of occupied channels and \( C_{F/T} \) is the total number of traffic channels.

And

\[
L2 = P_{\text{traffic}} \left( \frac{P_{\text{max}} - P_{\text{CCH}}}{} \right)
\]

\( P_{\text{traffic}} \) is the power for traffic, \( P_{\text{max}} \) is the total downlink transmission power, \( P_{\text{CCH}} \) is the power allocate for control channels.

![Figure 4 Coverage-based CRRM CAC](image)

TDMA and CDMA CAC algorithms are presented in Appendix 1. The results are shown the forward link capacity for voice communications and the main system parameters are listed in Table 2. In this simulation, seven cells are considered and wrapping around technique used to avoid corner effects. The simulator is developed under IST EVERST and IST AROMA project [8][9]. The handover conditions follow the conditions in [3] for both GSM/UMTS. A BS station will be added into the handover window if its signal strength plus the handover margin is greater home BS’s handover margin for the duration greater than the handover timer. And the user will send a handover request if the signal strength from any BS in its handover window minus the handover margin greater than its home BS’s.

With real-time traffic such as voice committing continuous communications in UMTS unlike the discontinuous transmission in TDMA and packet transmission for the non-real time traffic, compress mode is required to generate the necessary transmission gap in order to perform the measurement for inter-system handovers. The compress mode is operated in a way that, the bit rate of traffic is temporally increased by reducing the spreading factor, thus a time gap is generated by this higher bit rate for this continuous transmission, and the gap is used for transceiver to do the intersystem measurements and reporting. A typical UMTS compress mode operation is like, transmission every other frame by double normal transmission rate or every two frames (a frame’s duration is 10ms) [3]. Also since the transmission gap is generated to do the measurement for other system, fast close loop power can be performed. So if the mobile in the compress mode, a higher target Eb/No is needed to guarantee the transmission quality. Thus, a mobile in the compress mode, will consume more radio resource than that in normal mode. And consequently, it will generate more interference to other mobiles. In our simulation the compress mode operation is also included in order to asses the impacts of this operation on these two algorithms. Outage is the main performance measure which is defined as the sum of call drop due to insufficient power or call blocking as the results of call admission procedures shown in Figure 4 and Figure 5.

![Figure 5 Load balancing CRRM CAC](image)

Table 3 shows the system capacity which is defined as the traffic load with 5% outage probability. Comparing with LB-based CRRM, the coverage-based CRRM can achieve the capacity of 31% without considering compress mode and still achieve a capacity gain of 27% with compress mode. And the compress mode degrades the system 2.7% for LB and 6.7% for coverage-based CRRM. The reason why coverage-based CRRM has a better performance is shown in Figure 6. Figure 6 shows the average power allocated to a UMTS link. The coverage-CRRM consumes less power per link because higher path loss users have the more probability to be admitted into GSM rather UMTS. The lower power consumption leads to less inter-cell and intra-cell interference and then results in capacity gain. And further, a power-based CAC (Appendix 1) will take advantage of less power consumption per link to admit more users in the systems.
Coverage-based CRRM uses a predefined $\text{Thr}$ value to control the effective radius to improve the system performance. In this section, we discuss how this value is going to affect the system performance. For an illustration purpose, we introduce a concept called effective radius, which is given as

$$R_{\text{eff}} = \text{Pathloss}^{-1}(\text{Thr}) \tag{12}$$

where pathloss function is given in (3).

So, the effective radius actually gives a more straightforward view on the coverage than the pathloss threshold. Figure 7 gives the effects of the effective radius on the outage probability (the effective radius is normalized to 1.2km). First, with or without considering compress mode, the outage probability is quite sensitive to the effective radius, especially with considering the compress mode. Also there is an optimum value at which the outage probability is minimized. This is because that, if the effective radius is too small, eventually, more users will get high probability to be admitted into the GSM following the CRRM procedure shown in Figure 4 and Figure 5 and so GSM capacity is easy to be filled up. This will lead the outage probability in GSM growing faster than the outage probability reduction rate in UMTS, and thus degrade the overall performance. If the radius is too big, the pathloss profile of users in UMTS will be not much different from without coverage-based CRRM, the improvement for UMTS will be limited.

**TABLE 2** System Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Cells</td>
<td>1</td>
</tr>
<tr>
<td>Activity Factor</td>
<td>1</td>
</tr>
<tr>
<td>Max. BS TX Power</td>
<td>43dBm</td>
</tr>
<tr>
<td>Max. Power Per Link</td>
<td>33dBm</td>
</tr>
<tr>
<td>Initial CIR Power</td>
<td>3.5dBm</td>
</tr>
<tr>
<td>Downlink Noise Power</td>
<td>10.3dBm</td>
</tr>
<tr>
<td>Service Mix</td>
<td>100% VoIP</td>
</tr>
<tr>
<td>GSM Channel</td>
<td>8(Simulation)/2% (Theory)</td>
</tr>
<tr>
<td>GSM Max Power</td>
<td>43dBm</td>
</tr>
<tr>
<td>GSM Sensitivity</td>
<td>-106dBm</td>
</tr>
<tr>
<td>Mobile Speed</td>
<td>3-60km/h</td>
</tr>
<tr>
<td>Target Eb/No</td>
<td>5(Simulation)/7(compress)/65</td>
</tr>
<tr>
<td>Spreading Factor</td>
<td>64/Compress Mode/32X32</td>
</tr>
<tr>
<td>The distance between Two BS</td>
<td>2.1km</td>
</tr>
<tr>
<td>Handover Threshold</td>
<td>3.0dB</td>
</tr>
<tr>
<td>Margin</td>
<td>0</td>
</tr>
<tr>
<td>Handover Time</td>
<td>1</td>
</tr>
</tbody>
</table>

**TABLE 3** System Capacity (5% Outage)

<table>
<thead>
<tr>
<th></th>
<th>Compress</th>
<th>No Compress</th>
<th>Capacity Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>LB</td>
<td>34</td>
<td>55</td>
<td>37.4%</td>
</tr>
<tr>
<td>Coverage</td>
<td>46</td>
<td>46</td>
<td>0%</td>
</tr>
<tr>
<td>Capacity Change</td>
<td>39%</td>
<td>33%</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 6** Average power each UMTS Link

**Figure 7** Effects of the effective Radius

**Figure 8** gives the effects of mobility on the system performance. In this figure, the optimum $\text{Thr}$ is almost same for all three mobility speed. And the lower speed mobiles are more sensitive to the $\text{Thr}$ because low mobility users are easier to get “trapped” in particular situation. With coverage-based CRRM, if the $\text{Thr}$ is not an appropriate value, the low mobility users’ performance is even worse than that with the high mobility users e.g. with effective radius of 0.8, outage probability for users at speed of 3km/h is 13% while it is less than 10% for users at speed of 30km/h.

IV. **Conclusions and Future Work**

In this paper, we present the coverage-based CRRM concept for hybrid FD/TDMA and CDMA cellular systems, which intend to improve system efficiency by taking advantage of the complementary characteristics of FD/TDMA and CDMA systems, i.e. FD/TDMA is able to offer a rather static coverage and capacity while the coverage and capacity trade-off in CDMA is much more straightforward. A basic theoretical framework is presented to assess the feasibility of improving the systems capacity in terms of system blocking rate. Through this framework, we study the system performance with uniform traffic distribution. The results show that it is possible to achieve some capacity gain through appropriate controlling the CDMA coverage, providing that the FD/TDMA system is able to ensure the whole area coverage. And then, an implementation based on UMTS pathloss measurement scheme is developed for a heterogeneous UMTS/GSM environment. From our simulation results, the proposed scheme performs better than conventional load-balancing algorithm roughly with a capacity gain of 30%. In this implementation, the pathloss
threshold value for triggering inter-system handover is a critical design parameter and need to be careful dealt with.

Figure 8 Effects of speed on Effective Radius

ACKNOWLEDGEMENTS

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[2] 3GPP TR 25.891 v0.3.0 “Improvement of RRM across RNS and RNS/BSS (Post Rel-5)” (Release 6).

APPENDIX I. CALL ADMISSION CONTROL

A. CDMA CAC

In UMTS, the total output of BS power ($P_T$) is divided into control power for Common pilot channel (CPICH)/Synchronization Channels (SCH) and traffic power for traffic channels ($P_{traffic}$). The output power is limited by the maximum BS output power due to either safety reason or hardware implementation. The output power relationship for cell $i$ is given as follows

$$P_{T,i} = P_{CPICH,i} + P_{Traffic,i}$$

The UMTS call admission control used this study is a power based admission control algorithm. In this call admission scheme, if a new call and handover call arrive, the CAC will estimate the power that the call needs. The power estimation $j$ mobile located in cell $i$ is based on the following

$$\tilde{P}_j = \left( \sum_{b=1}^{N_b} P_{T,b} g_{b,j} + N_0 + \alpha P_{T,j} \right) / (G_j / \gamma_j + 1)$$

Where $N_b$ denotes the number of interfering base station, and $N_0$ is the background noise, $\alpha$ is the orthogonal factor that is a value between 0 and 1, $G_j$ is the spreading factor of the mobile $j$ and $\gamma_j$ is the target Eb/No for mobile $j$.

After this estimation, the CAC will check if there is sufficient power for this call as follows

$$P_{T,j} + \tilde{P}_j \leq P_{max} - \Delta$$

where $\Delta$ is the reserved power margin value.

If the above condition satisfied, it means there is sufficient power available for this call. It will be admitted into UMTS system. Otherwise, CAC will block this call if it is a new call, or reject the handover request for a handover call. And also in the process, handover calls has priority over new calls.

B. TDMA CAC

In GSM, the resource will be number of physical TDMA channels. In a GSM cellular system, each frame consists of 8 time slots is periodically transmitted over a frequency. Among of the 8 time slots, one slot is reserved for control purpose such as broadcasting and paging, so 7 other time slots are used for traffic. There is possibly more than one frequency in one cell (FD/TDMA) which depends on frequency reuse pattern. In that case, the total number of channel is the number of frequency multiplying the number of slot in each time frame. In our following study, if more than one frequency is allocated to the cell, there are at least two physical channels to reserve for control purpose. When a new call or handover call (handover call has priority over new call) arrives, if there no free traffic channel, the new call will be blocked and the handover call request will rejected ( it will be either hand back to its original cell for inter-cell handover, or hand back to its original system for inter-system handover). Otherwise, the call will be admitted into the GSM system.