Chapter 5

Simulation and Analysis
Chapter Overview

The proposed MAS is simulated for the domain of call admission control and evaluated according to the evaluation model presented in chapter 4. The simulated results are presented in the following order:

- **Simulating Multi Agent Call Admission Control (MA-CAC):** The first part of the simulation presents the simulation results of Multi Agent Call Admission Control (MA-CAC) strategies for single and multi class (non-priority and priority) traffic models. The four MA-CAC strategies namely: Static cutoff priority (S-CAC), Dynamic cutoff priority (D-CAC), Integral Mobility based channel reservation (IMBCR-CAC) and Fractional Mobility based channel reservation (FMBCR-CAC) schemes are simulated for single class traffic. And Static cutoff priority (S-CAC), Dynamic cutoff priority (D-CAC) are simulated for multi class traffic in Priority (P) as well as in Non-Priority (NP) mode of traffic model using multi agent environment i.e. using JADE. These MA-CAC strategies are presented for Centralised (C) as well as Distributed (D) Service Architecture.

- **Simulating Multi Agent based Service Architectures:** In the second set of simulations MA-CAC strategies for Centralised (C) and Distributed (D) Service Architectures (having different degree of distribution of agents) are simulated for measuring the performance of the system for measuring reactive and responsive estimates, effectiveness of the architecture towards handling high traffic (sustainability) and resource utilization, communication overhead, scalability etc.

- **Simulating Multi Agent Dynamic Channel Borrowing (MA-DCB):** Problem of congestion is mitigated with help of MAS of socially intelligent agent interacting with each other for Multi Agent based Dynamic Channel Borrowing. The third set of simulation results of this chapter present performance of system for call level parameters and effectiveness of using SIA based channel borrowing schemes. The SI agents demonstrate different traits of their attitude towards cluster of agents (society), from being selfish to partially society biased to partially self biased and having balanced attitudes being simulated as SIA-Non DCB, Partially Society...
Biased SIA-DCB, Partially Self Biased SIA-DCB and Balanced SIA-DCB respectively.

One of the most important aspects in developing the simulation model is establishing its credibility. Therefore, validation and verification of the simulation model are essential steps.

- **Verification** determines whether the simulation model performs as intended. Thus, verification checks the translation of the conceptual simulation model into a correctly working program.
- The **validation** process determines whether the conceptual simulation model is an accurate representation of the system under study.

The chapter begins with explaining the simulation model and then presenting the simulated results along with their analysis. Also these results are validated against their analytical model and verified with their Non-Agent (NA) based simulation in MATLAB.

### 5.1 The System Model

Manhattan model of a city consisting of square blocks with streets in between is used with 25 base stations for micro cell system. Each Radio Network Controller (RNC) caters to 25 square shape cells. All 25 cells are divided in 9 cell cluster the cell arrangement is as shown below.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
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<tbody>
<tr>
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<td>11</td>
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<td>22</td>
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<td>25</td>
</tr>
</tbody>
</table>

Figure 5.1 (a) Cellular Model for S-CAC

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
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<th>5</th>
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<td>6</td>
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<td>20</td>
</tr>
<tr>
<td>21</td>
<td>22</td>
<td>23</td>
<td>24</td>
<td>25</td>
</tr>
</tbody>
</table>

Figure 5.1 b) 25-Cells in Cluster of 9
The cell radius is of 1km. It is assumed that the cells are wrapped around to eliminate the edge effect. That is, if a user goes out of cell 25 from bottom, he enters into cell 5 and from right he enters 21 as presented in figure 5.1. Channel allocation uses FCA strategy with 30 carriers for each cell for CAC.

Assume the base station of each cell is at the center of the square; the receive-threshold is set to 1.414 Km in order to cover all cell area. The handoff threshold can be set at any distance between cell-center to receive-threshold. The area between handoff threshold and receive-threshold is called handoff-area (the shaded area in Figure 5.2). The user mobility pattern is described as follows. When a new call request is accepted for a cell, the call originating location of the mobile user is a uniform random variable of that particular cell, the motion of the mobile is restricted along the streets, and can move to left, right as well as top, bottom streets. The moving speed is uniformly distributed between 30km/h, 90km/h. User's location and Received Signal Strength (RSS) has been monitored at every second. The simulation is carried out for 5000 seconds for each call arrival rate value.

![Handoff Threshold and Receive Threshold](image)

**Figure 5.2: Handoff Threshold and Receive Threshold**

**Radio Propagation Model:** Propagation model is used to determine the number of cell sites required to provide the coverage requirement for the network. It is influenced by the path loss depending on the distance, shadowing and multipath fading. The relationship between the transmitter power and received power can be expressed as

\[ P(r) = 10^{\frac{\ell}{10}} r^{-\alpha} P_0 \]

Where \( P(r) \) is the received power  
\( P_0 \) is transmitted power
r is the distance from the reference node to the mobile node

$\xi$ In decibel has a normal distribution with zero mean and standard deviation of $\sigma$ typical value is 8dB)

$\alpha$ Represents the path loss slope (2.7 to 4.0)

Based upon the hypothesis discussed, simulation parameters are derived.

### Table 5.1: Simulation Parameters

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Parameter</th>
<th>Typical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cells per cluster</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>Cell radius</td>
<td>1km.</td>
</tr>
<tr>
<td>3</td>
<td>Carriers for control signals</td>
<td>1 per cell</td>
</tr>
<tr>
<td>4</td>
<td>Carriers for voice/data communication</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>Time slots per carriers</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>Simulation time for every call arrival rate</td>
<td>5000 simulation seconds</td>
</tr>
<tr>
<td>7</td>
<td>Velocity of User for S-CAC and D-CAC</td>
<td>30km/h, 90km/h (Uniform</td>
</tr>
<tr>
<td></td>
<td>(For MBCR specified later)</td>
<td>distribution)</td>
</tr>
<tr>
<td>8</td>
<td>Direction (Uniform distribution)</td>
<td>Top, right, bottom, left</td>
</tr>
<tr>
<td>9</td>
<td>Average Call Duration (voice)</td>
<td>120 Seconds</td>
</tr>
<tr>
<td>10</td>
<td>Average Call Duration (data)</td>
<td>300 Seconds</td>
</tr>
</tbody>
</table>

The main features implemented are listed below.

- Call setup/completion is modeled explicitly.
- Handoffs are performed automatically based on RSS value or parameterized handoff threshold.
- Emulation of forced call termination on insufficient signal strength is implemented.
- All mobile station has arbitrary trajectories.
- The simulation includes a poison distribution for call generation.
The simulation model of the system is a combination between discrete and continuous systems as some state variables change continuously with respect to time and some change at discrete points in time: for example, the cut off threshold calculation requires all the cells to periodically send the on going number of calls information at regular intervals. Although some states have a variable time advance, the use of a time step with a suitable value will ensure that all the continuously variable states are reasonably well covered. Hence, the fixed-increment time advance is the more suitable mechanism. The simulation time is increased by 1ms after each loop and the simulation process continues by repeating the next loop until a predetermined time. MA-CAC module of section 3.5 is revisited here and the flowchart is depicted in figure 5.3.

Completed duration of each call is monitored. If it equals the call depart time, that particular call will be terminated and resources occupied by this call will be made free, otherwise the users parameters are updated. User’s distance from the base station is updated based on current location, velocity and direction. Similarly, received signal strength is updated based on the new location (i.e. user’s distance from base station).

Call handoff decision is taken based on the updated received signal strength (RSS) value of the particular call. Handed off call will be accepted in the target cell depending on the availability of carrier-slots in the target cell, otherwise this call will be dropped/blocked and dropping probability values will be updated.

For multi class traffic for voice handoff calls, in case the cut off threshold (static/dynamic) is reached then the call is buffered for the duration according to the priority defined, if the call reaches its maximum buffering time/capacity only then the call is blocked and records leading to calculation of blocking probability are updated.

If the call is being blocked or dropped, if local flow control strategy needs to be applied or not is checked else if congestion needs to be handled, then the Congestion Resolver module through dynamic channel borrowing schemes is activated.
The Studies of Multi-Agent System in Mobile Computing for Mobile Application

Initialize Parameters

Call Request (New/modified)

From CutOff Threshold Calculator (Local Planning layer)

Is Threshold Reached?

New call Accept

Monitor Duration

Has finished?

Update Call Parameters

Is RSS< HO threshold?

HO request to target cell

Is Carrier-slot available in HO cell?

Modified Call

To Congestion Resolver (Local Planning layer)

Call Rccmcst (New/modified)

Call finished

Y

A

Simulation + 1

A

N

B

Call dropped

Figure 5.3: Flow Chart of Multi Agent – Call Admission Control (MA-CAC)
5.2 JADE Model

As explained in earlier section JADE 3.1 is an open source framework from TILab is complaint. The distributed nature, simplicity, JAVA language proficiency as well JADE forum support were the key issues while selecting JADE as agent based simulation platform. Efficiency in handling large number agents and full fledged FIPA compliance support for message exchange were few more reasons for choosing it for the proposed MAS model.

The agents implement the “Cyclic Behavior” of JADE to simulate the discrete event generation. The controller agent is used to maintain synchronization amongst NPRA and NPCAs. NPRA agent is simulated in the main container. NPCA agents can be invoked in different containers. JADE offers 12 message performatives out of which five have been implemented as shown in Table 5.2.

<table>
<thead>
<tr>
<th>Performatives</th>
<th>Meanings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propose</td>
<td>Issued by the NPCA to propose performing call admission control</td>
</tr>
<tr>
<td></td>
<td>or for channel borrowing to sent their weight as calculated by eq. 4.35</td>
</tr>
<tr>
<td>Inform</td>
<td>Issued as response to ‘Propose’. The message carries ‘ongoing calls’,</td>
</tr>
<tr>
<td></td>
<td>‘percentile of high/low velocity traffic’ and also the ‘class of traffic’</td>
</tr>
<tr>
<td></td>
<td>information/ Response of Query Ref.</td>
</tr>
<tr>
<td>Request</td>
<td>Requests NPRA to perform Congestion Control.</td>
</tr>
<tr>
<td>Accep, Reject Proposal</td>
<td>Rejects the call (for Centralised Service Architecture ) cell rejects</td>
</tr>
<tr>
<td></td>
<td>the proposal</td>
</tr>
<tr>
<td>Proposal, Accept Proposal</td>
<td>Channel is donated</td>
</tr>
<tr>
<td></td>
<td>Cell confirms the proposal and channel is donated</td>
</tr>
<tr>
<td>Query Ref.</td>
<td>Issued by borrowing cell to neighboring cells querying about the number</td>
</tr>
<tr>
<td></td>
<td>of available channels</td>
</tr>
</tbody>
</table>
The Studies of Multi-Agent System in Mobile Computing for Mobile Application

Here, coordinating cooperative interaction model ensures that the agents synchronize with each other and communicate the number of ongoing calls and mobility information. The JADE performative based interaction model for Centralised Service Architecture (eg. cluster of cell NPCA ‘0’ and its neighbouring NPCA cells 1-right, 4-left, 20-top and 5-bottom) is depicted in figure 5.4 for illustration purpose. The agents
communicate. The JADE agents can be sniffed by the ‘Sniffer’ and the interactions can be captured in JADE-GUI.

Figure 5.5: JADE Sniffer: NPCA-NPCA Interaction

Figure 5.5 illustrates the interaction model of Distributed Service Architecture for NPCA cell 7 and its neighboring NPCA cells forming a cluster (6-left, 2-top, 8-right and 12-bottom). The interaction uses the performative defined in table 5.2.
5.3 Simulating Multi Agent Call Admission Control (MA-CAC)

The simulation results evaluate performance of Multi Agent Call Admission Control (MA-CAC) strategies for single and multi class (non-priority and priority) traffic models. The call level parameters such as new call blocking probability, handoff call blocking probability for voice as well as data calls are presented. Also the effect of queue on these parameters for multi class is evaluated in this section.

5.3.1 Single Class Traffic

Four MA-CAC strategies namely: Static cutoff priority (S-CAC), Dynamic cutoff priority (D-CAC), Integral Mobility based channel reservation (IMBCR-CAC) and Fractional Mobility based channel reservation (FMBCR-CAC) schemes are simulated for single class traffic using multi agent environment i.e. using JADE. These CAC schemes are categorized as shown in figure 5.4 as 10 schemes for single traffic class. The nomenclature presented here will be used while presenting the simulated results. MA and NA stand for multi agent based and non agent based environment and D and C for simulation using Distributed Service Architecture or Centralised Service Architecture. For e.g. D_MA-D-CAC means Distributed Service Architecture, Multi-Agent, Dynamic Cutoff Priority CAC scheme.

The simulation model and assumptions in section 5.1 are used to analyze these schemes. Also traffic models presented in 4.1.1 and figure 4.1 are considered.

1. Cutoff threshold $m = 21, 25$ and $27$ (static)

2. $\mu_h = 1/400$, and $\mu$ varies from $1/600$ to $1/200$.

3. Traffic intensity is varied from 10 to 100 (Erlang)

where $\lambda$ is the arrival rate of new voice calls, $\lambda_h$ be the arrival rate of handoff voice calls, $1/\mu$ is average channel holding time for new voice calls, $1/\mu_h$ the average channel holding time for handoff voice calls and ‘$m$’ is the static cutoff threshold.
5.3.1.1 Static and Dynamic Cutoff Priority: MA-S-CAC and MA-D-CAC

The simulation results of figure 5.7 and 5.8 present the simulation of call blocking probabilities for Multi Agent based Static Cutoff Priority (MA-S-CAC) and Multi Agent based Dynamic Cutoff Priority (MA-D-CAC) schemes. The S-CAC scheme is available only in centralised mode of interaction of multi agents.

The call requests are generated according to the simulation model presented in section 5.1. The static threshold ‘m’ is chosen either as 21, 25 or 27 for C=30. The dynamic threshold is calculated at run time depending on the ongoing calls in the neighbouring cell agents according to the analytical model of section 4.1.2.3.

Analysis: Static and Dynamic Cutoff Priority

The figure 5.7 shows new call blocking probability for all three static thresholds for MA_S-CAC and also presents the results of new call blocking probability of MA_D-CAC in comparison. The traffic is increased from 10 to 100 Erlang.
By comparing the results it was noted that the new call block probability moved from 0.4 to 0.93 for \( m = 21 \), 0.3 to 0.9 for \( m = 25 \) where as it moved from 0.2 to 0.85 for \( m = 27 \).

It was observed that for low load (less than 40 Erlang) the new call blocking probability was less as compared to the S-CACs with cutoff thresholds (\( m = 21 \), \( m = 25 \) as well as \( m = 27 \)).
Figure 5.8 demonstrates the nature of curve of handoff call blocking probability which was simulated for $m=21, 25$ and $27$ and found to be $0.03$ to $0.13$, $0.13$ to $0.16$ and $0.16$ to $0.24$ respectively for each of the static threshold. The handoff call blocking probability was very less as compared to that of S-CACs.

This was because at low loads, even neighboring ongoing calls were less in number, thus less channels were required for handoff calls in the current cells. This resulted in higher dynamic cutoff threshold which in effect meant more number of channels being available for new calls, which resulted in reduced new call blocking probability. Whereas, as the traffic load increased, more calls were ongoing in the neighboring cells, thus the probability of more calls being handed off to the current cell from the neighboring cells also increased. This resulted in a lower value of dynamic
cutoff threshold, and higher number of channel reservation for handoff calls as compared to for the new calls. This increased the new call blocking probability for higher loads.

Figure 5.9: Verification and Validation S-CAC m=21

The call level parameters are compared with the analytical simulation to validate and verified with non agent based simulations carried to verify the schemes in figure 5.9 and 5.10, for m=21 and m=25.

The extent of the influence exerted by the neighbouring ongoing calls (in terms of no. of channels required), can be estimated in the current cell, and the new calls are only accepted keeping this influence in consideration.
Thus the handoff calls always get priority over the new calls and thus the handoff call blocking probability is considerably lower in D-CAC as compared to its S-CAC counter part. The D-CAC guarantees better QoS and thus handles real time SLA in better way.

( The analytical simulation results of Dynamic Cutoff Threshold for \( C=20 \) and \( C=50 \) for 1-D as well 2-D Manhattan city models are illustrated in section A.1 of appendix A. The results present the value of dynamic cutoff threshold with the increase in number of ongoing calls in the neighbouring cells. And for more validation and verification results refer Annexure B)
5.3.1.2 Mobility Based channel Reservation (MBCR)

The mobility based schemes reserve channels for handoff calls, implicitly defining dynamic threshold for new calls. For Dynamic Cutoff Priority MA-CAC the user velocity and the dwell time of a call remain constant.

Mobility Model

The cell-dwell-time probability density function $f_h(t)$ and $f_i(t)$ are exponential distributions with mean value 120 s and 600 s, respectively. The new call requests are generated by either high-speed mobiles or by low-speed mobiles with probability $P_{\text{high}}$ or $1 - P_{\text{high}}$ respectively. In the fixed reservation scheme for comparative purpose, the number of the reserved channel initial value is 1.

For various mobility patterns the dwell time is changed according to table 5.3. $T_{c_{\text{new}}}$ and $T_{c_{\text{handoff}}}$ are the average channel holding times of new calls and handoff calls, respectively, $P_{hf}$ high is the percentage of high-speed calls in the handoff traffic. The table shows that with the decrease of percentage of high-speed users, the average channel holding time of new calls becomes longer.

<table>
<thead>
<tr>
<th>$P_{\text{high}}$</th>
<th>$T_{c_{\text{new}}}$</th>
<th>$T_{c_{\text{handoff}}}$</th>
<th>$P_{hf}$ high</th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td>152.9s</td>
<td>120.5s</td>
<td>55%</td>
</tr>
<tr>
<td>30%</td>
<td>144.1s</td>
<td>109.2s</td>
<td>70%</td>
</tr>
<tr>
<td>40%</td>
<td>135.1s</td>
<td>101.2s</td>
<td>79%</td>
</tr>
</tbody>
</table>

The basic simulation model remains same as the one mentioned in section 5.3. When a new call or a handoff call enters a cell, the cell dwell time is also chosen according to its speed class to predict the rate of handoff. For a new call, if the cell dwell time is greater than its lifetime, this call will complete in the current cell; otherwise, this call must handoff to another cell. The handoff flowchart for MBCR is presented in figure 5.11.
The Studies of Multi-Agent System in Mobile Computing for Mobile Application

Find
\[ L_I(t, T) = 1 - e^{-RT} \]

\[ I_L = \alpha L_d \]
\[ R = B, I_L \]

Send HO request to target cell

Is channel Available?

Accept Handoff calls

Block H.O. Call

Find total number of Handoff call, blocked handoff calls

Calculate BP of new calls HBP and reserved channels

Plot result

STOP

Figure 5.11: Simulation Flow-Chart: MBCR
Before the handoff request is sent, a target cell is selected according to the directional factor; the residual life time is calculated by subtracting the cell dwell time in the current cell from the lifetime. For a successful handoff call, the residual lifetime and the cell dwell time in the new cell is compared and the above procedure is repeated.

Simulation and Analysis of D_MA-IMBCR, D_MA-FMBCR and D_MA-D-CAC

Figures 5.12 and figure 5.13 illustrate blocking probabilities for MA based Integral-MBCR and Fractional-MBCR with D-CAC along with their comparison. The new call blocking probability is very high in D-CAC as compared to that of MBCR.

Figure 5.12 : MA-MBCR verses MA-D-CAC : \( P_{nb} \)
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The handoff blocking probability of Fractional MBCR scheme is less (0.005-0.022) compared to even I-MBCR (0.01-0.055) for traffic load ranging from 10 to 100 Erlang in step of 10.

This is because of the optimum number of channel reservation in F-MBCR as compared to pessimistic attitude adapted by I-MBCR.
Mobility based schemes fair well as compared to dynamic cut off schemes (D-CAC) in terms of call level parameters.

Figure 5.14: Verification of MA D- CAC schemes with NA D-CAC

Figure 5.14 compares and verifies the non agent and multi agent Based D-CAC and MBCR schemes. This result shows that non agent MBCR as well as agent based MBCR provide same call level parameters. These results are used to verify the multi agent based simulated results.
Figure 5.15 shows Integral MBCR simulated for 20%, 30% and 40% (by changing the dwell time) of new calls being high speed ones to evaluated the nature of call level parameters. If the compositions of new call traffic of two speed classes are changed, it is found that with the decrease of percentage of high-speed users, the new call blocking probability is increased. This is because a high-speed user spends shorter time in a cell than a low-speed user does, therefore a cell that has more active high-speed users will exert more influence on its neighbors, and more reservation is required. And the handoff call blocking probability is decreased or maintained constant. This, again, justifies our statement that the MBCR scheme can adapt to the change of cell traffic condition typically mobility pattern of the user.
5.3.2 Multi Class Traffic

The simulation results of multi class traffic presented in section assume traffic combination of voice and data according traffic distribution given in table 5.4.

Table 5.4: Traffic Classes. (Voice, Data: - E-mail, Fax & Video conferencing)

<table>
<thead>
<tr>
<th>Traffic</th>
<th>Class</th>
<th>Traffic Distribution</th>
<th>Call Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voice Service</td>
<td>Class 1</td>
<td>0.6</td>
<td>60 seconds</td>
</tr>
<tr>
<td>E-mail, Fax</td>
<td>Class 2</td>
<td>0.30</td>
<td>180 seconds</td>
</tr>
<tr>
<td>Video conferencing</td>
<td>Class 3</td>
<td>0.10</td>
<td>600 seconds</td>
</tr>
</tbody>
</table>

Static cutoff priority (S-CAC), Dynamic cutoff priority (D-CAC) are simulated for Priority (P) as well as in Non-Priority (NP) traffic models (section 4.1.1) using multi agent environment i.e. using JADE.

The above mentioned multi class MA-CAC schemes are categorized into 8 schemes as shown in figure 5.16. The simulation parameters for call level parameters of these MA-CACs are also tabulated in table 5.5. The nomenclature presented here will be used while presenting the simulated results.

```
Call Admission control (Multi Class Traffic (M))

Non Priority (NP)                          Priority (P)
                                       S-CAC     D-CAC          S-CAC     D-CAC
                                      NP-NA-S-CAC NP_MA-S-CAC   P-NA-S-CAC P-MA-S-CAC
                                      NP-MA-S-CAC NP_MA-D-CAC   P-NA-D-CAC P-MA-D-CAC
```

Figure 5.16: Multi Class Traffic: CAC Schemes Classification
Table 5.5: Simulation Parameters (Multi Class Traffic)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic</td>
<td>10 - 100</td>
<td>Traffic Erlang</td>
</tr>
<tr>
<td>$\lambda_T$</td>
<td>Traffic / $\mu$</td>
<td>Total rate of arrival $\lambda_{nv} + \lambda_{nd} + \lambda_{hv} + \lambda_{hd}$</td>
</tr>
<tr>
<td>$\lambda_{nv}$</td>
<td>0.75* $\lambda_T$</td>
<td>Rate of new voice call arrival</td>
</tr>
<tr>
<td>$\lambda_{nd}$</td>
<td>0.35* $\lambda_T$</td>
<td>Rate of new data call arrival</td>
</tr>
<tr>
<td>$\lambda_{hv}$</td>
<td>0.25* $\lambda_{nv}$</td>
<td>Hand off voice call arrival rate</td>
</tr>
<tr>
<td>$\lambda_{hd}$</td>
<td>0.10* $\lambda_{nd}$</td>
<td>Hand off data call arrival rate</td>
</tr>
<tr>
<td>C</td>
<td>30</td>
<td>Total number of channels</td>
</tr>
<tr>
<td>$M=m_{c}^{tot}$</td>
<td>21/25/27/dynamic</td>
<td>New call blocking Threshold</td>
</tr>
<tr>
<td>$K$</td>
<td>0,1-3</td>
<td>Queue length of handoff call</td>
</tr>
</tbody>
</table>

5.3.2.1 Non Priority: NP_NA-S-CAC & NP_MA-S-CAC

The traffic intensity was increased from 10 to 100 Erlang. 1,25000 calls were simulated with mix of traffic classes in accordance to parameters given in table 5.5. The basic simulation model and traffic model described in section 5.1 and section 4.1.1 were followed.

The Figures 5.17 and 5.18 illustrate the new call blocking and handoff call blocking probabilities for non-priority based S-CAC strategy for static cutoff thresholds for (m=21,25,27);

The graphs compares new call blocking probabilities for data and voice calls for various thresholds and verify the Multi Agent (MA) results with Non Agent (NA) based simulations. Also results are validated against their analytical model of section 4.3.1.
It was seen that as the threshold increased from $m = 21$ to $27$, (reservation of channels for handoff call decreased), the new call blocking probability decreased for both voice as well as data calls.

This could be analyzed as; if more number of channels are available for new calls, the new call blocking probability decreases where as handoff call blocking for voice as well as data call would increase because the number of reserved channel for handoff calls has decreased, i.e. the new call blocking for $m=21$ static threshold is higher than that for $27$, where handoff blocking more.
From figure 5.18 it can be seen that the handoff call blocking probability for voice as well as data calls is very less for $m=21$ as compared to that for higher thresholds.

The difference between the handoff call blocking probabilities for voice and data can be estimated due to the less call dwell time of voice than of data calls, as more voice calls are terminating within the cells and more data calls are being handed over to the other cells, less voice hand off calls are blocked as compared to data handoff calls, for the same static threshold.

(Results of verification of Non-Priority, MA-S-CAC with Non Agent based simulations for multi class traffic, are presented in Appendix B)
5.3.2.2 Priority: $P_{NA-S-CAC}$ & $P_{MA-S-CAC}$

To maintain the SLA-QoS of voice handoff calls at a certain level, one can make use of queue based priority traffic model, which only buffers voice handoff calls. The size of the queue is assumed to be finite and also the limit to the size of the queue is chosen such that many calls do not terminate inside the buffer waiting to be assigned.

![Figure 5.19: Priority: NA-S-CAC & MA-S-CAC (K=1): ($P_{nb}$)](image-url)
The priority based traffic model (of section 4.1.1) buffers/queues only voice handoff call, thus giving priority to it. The graphs of figures 5.19-5.22 present the new call blocking the handoff call blocking probability for the same for different sizes of the queue and also verify the results with non agent based simulation results.

It was observed that new call blocking probability is more or less same for voice as well as data calls but handoff call blocking probability of voice reduces substantially for reduced cutoff priority thresholds.
The Studies of Multi-Agent System in Mobile Computing for Mobile Application

For $K=1$ and $K=2$ (figure 5.19 and figure 5.21), the new call probability almost remains same, but from figure 5.20 and 5.22 it can be seen that the data handoff call blocking has increased substantially at the cost of low voice handoff calls for the same cutoff threshold with increase in queue size.
The Studies of Multi-Agent System in Mobile Computing for Mobile Application

Figure 5.22: Priority: NA-S-CAC & MA-S-CAC (K=2): ($P_{hb}$)
Effect of Queue on Static Cutoff Priority: P_MA-S-CAC and NP_MA-S-CAC

The value of the multi class static cutoff threshold (M) is kept constant and the size of the voice handoff queue is varied from 0 onwards to study the effect of queue size on call level parameters. These results are presented in figure 5.23 and 5.24 for M=25 (For effect of queue on M=21 and M=27 refer to Annexure B).

![New Call Blocking Probability(Pbn) for voice and data for M= 25 and K=0,1,2](image)

Figure 5.23: Effect of Queue: Non-Priority, Priority S-CAC (M=25): (P_{bn})

It was observed that handoff call blocking probability of voice reduces substantially for thresholds queued voice handoff calls as compared to that of non queued ones as the less number of voices handoff calls are now blocked but the handoff blocking probability of data handoff calls increases. The new call blocking probability remains the same. Also for M = 25 handoff call blocking probability is better as compared to for M= 27.
The Studies of Multi-Agent System in Mobile Computing for Mobile Application

Effect of Queue on Dynamic Cutoff Priority : $P_{MA-D-CAC}$ and $NP_{MA-D-CAC}$

Figure 5.25 and 5.26 illustrate the natures of call parameters for dynamic cutoff threshold based CAC scheme (D-CAC)
It was observed that handoff call blocking probability of voice reduces substantially for thresholds queued voice handoff calls as compared to that of non queued ones as the less number of voices handoff calls are now blocked but the handoff blocking probability of data handoff calls increases. The new call blocking probability remains the same. If the QoS-SLA parameter passed by SP is the handoff call blocking probability and if it is expected to be significantly low, the results presented here demonstrate that the Non Priority based multi class CAC reduces the handoff call blocking probability effectively. And if voice handoff calls is the desired QoS parameter in the SLA, then by selecting certain queue size of Priority Multi class CAC, voice handoff call blocking can be further reduced, but at the cost of increasing the handoff call blocking probability of handoff data calls. Using D-CAC, along with Priority (P) scheme, further reduces voice handoff call blocking probability and thus effectively handles QoS-SLA.
5.4 Simulating Multi Agent based Service Architectures

This section presents the simulation results for measuring the effect of degree of distribution on the performance of the system for measuring reactive and responsive estimates, effectiveness of the architecture towards handling high traffic (sustainability) and resource utilization, communication overhead, scalability etc.

Figure 5.6 presents the classification of MA-CAC strategies, categorizing them under Centralised (C) and Distributed (D). These are the two service architectures (having different degree of distribution of agents) of interaction. The results presented in this section evaluate the system performance (other than call level parameters) by using MA-CACs in different service architectures. The simulation model, traffic model and
The Studies of Multi-Agent System in Mobile Computing for Mobile Application

agent model used as described in the previous sections. The simulations follow the qualitative analysis offered in section 4.2

5.4.1 Reactivity

\( T_{\text{RVTY}} \) measures the time the multi agent architecture takes from the event of call arrival at a particular NPCA cell, till the assignment of the call. For testing the reactivity of MAS service architectures, the traffic from 10 to 100 Erlang was increased in steps of 10, and noted the corresponding \( T_{\text{RVTY}} \).

Figure 5.27 shows that Distributed Service Architecture is more reactive, as reactivity time \( T_{\text{RVTY}} \), is less as compared to that of Centralized Service Architecture. Even when the load is increased the percentage difference of the reactivity between the two architectures remains between (13 %-15 %).

![Reactivity of Multi Agent Service Architectures](image-url)

Figure 5.27: Reactivity of Multi Agent Service Architectures
5.4.2 Utilization of Resources

To see the effect of change in traffic on the utilization of resources, average offered load to each cell was measured against the carried load. Figure 5.28 shows how the utilization of resources declines with the increase in offered traffic. The results were same as the call acceptance probability for each cell. It was seen that utilization of resources in Distributed Service Architecture is better for higher loads but remains same as that of Centralized Service Architecture for low loads.

![Figure 5.28: Utilization of Resource: Carried Load verses Offered Load](image-url)
5.4.3 Scalability

To test the scalability of the architectures, the numbers of cells, in clusters of 5, were increased from 25 to 135. The results were measured for the reactivity of both the architectures. As seen in Figure 5.29, the reactive time $T_{RVTY}$ for both the architectures increased almost linearly with increase in the number of cells. The Centralized Service Architecture could not scale in terms of reactivity as time taken by it to react with increase in no. of cell agent beyond 115 was very high. This was due to the bottleneck at NPRA whereas Distributed Service Architecture performed relatively well.

![Figure 5.29: Scalability: Reactivity verses No of Cells](image-url)
5.4.4 Communication Overhead

The message passing between the agents increases the overhead in both the architectures; this was measured by counting the no. of message exchanged per cluster for call admission according the interaction model. The messages are passed for Request, Propose, Inform, congestion resolving etc. Communication overhead in terms of number of messages per call remains approximately 9 (17 in case of channel borrowing required) messages for Distributed Service Architecture as compared to approximately 12 (22 in case of channel borrowing required) messages for Centralised Service Architecture. The other factors which increase the message overhead are the periodicity of exchange and total round trip time of the communication which depends on the distance between the agents. As NPCA cluster is cluster of peer agents, they are present in the same agent container. So the localized nature of the agents results in better reactivity for Distributed Service Architecture.

5.4.5 Sustainability

The sustainability of the two architectures under high traffic intensity was tested. The handoff call blocking probability was chosen as 0.055 toward QoS. It was observed that the Distributed Service Architecture could sustain more traffic load (app. 73 Erlang) as compared to Centralised Service Architecture (app. 69 Erlang) for the same handoff call blocking probability.

This evaluation helps in building knowledge for choosing the correct Multi Agent based CAC along with the most suitable Service Architecture for required QoS and traffic conditions of the SLA.
Figure 5.30: Sustainability: Handoff Blocking Probability verses Traffic
5.5 Simulating Multi Agent Dynamic Channel Borrowing (MA-DCB)

Figure 5.31: SIA-CB and SIA-Non CB Schemes: \( P_{hb} \)

Figure 5.31 shows the handoff call blocking probability of varied attitudes of SIA. The self-biased attitude of the SIA makes the agent unable to borrow channel, as there is no agent to accept the request because of its selfish nature. This leads to SIA based Non-Dynamic Channel Borrowing (DCB) scheme. It is seen that \( P_{hb} \) is reduces greatly for SIA-DCB as compared to SIA-Non DCB.

This is because SIA based DCB exchanges channels amongst cells such that the \( P_{hb} \) is kept as minimum as possible. Cells are intelligent to take a decision to ask that neighboring cell which has the highest probability of donating the channel when congestion occurs.
Figure 5.32 and 5.33 depict the effect of varied attitudes of channel borrowing on $P_{hb}$ and $P_{nb}$ of the system. The ‘Balanced’ attitude channel-borrowing scheme gives lower $P_{hb}$ compared to ‘Partially Society Biased’ or ‘Partially Self Biased’ SIA-DCB schemes. Whereas $P_{nb}$ increases as $P_{hb}$ is reduced.

This is because ‘Partially Society Biased’ SIAs try to gain extra channels whenever there is slight increase in its utility. However, since other agents are also ‘Partially Self Biased’ in the environment, they are reluctant to donate their extra channels and reserve them for future unexpected crisis. ‘Partially Society Biased’ agents are ready to donate their channel at all times. Every agent waits for a request from other
agents for their channel. When congestion takes place, the agent calculates social welfare functions. If there is a significant increase in its own utility, it asks a channel using ‘Query Ref.’ to its neighbour.

Figure 5.33: SIA-DCB Schemes: (P_{nb})
Measuring the effect of attitudes on the utility of the system verses the utility of agent demonstrates fairness of resources distribution. Figure 5.34 depicts the standard deviation from the mean of utility, which shows that the standard deviation for ‘Balanced’ attitude based DCB scheme reduced by nearly 90% as compared to the ‘Self-Biased’ attitude channel-borrowing scheme. Whereas reduction in standard deviation is, 61% for ‘Partially Society Biased’ and 56% for ‘Partially Self Biased’ attitudes based DCB schemes. This shows that ‘Balanced’ attitude SIA based MAS not only increase the utility of the system but also are fair in resource distribution to each cell.
5.6 Chapter Summary

The Dynamic Mobility based channel reservation schemes are more suitable for real time traffic but at the cost of more communication overhead as compared to Static Cutoff Priority CAC scheme. The Multi class schemes handle the voice and data traffic effectively. The priority based multi class CAC handles voice handoff calls effectively but at the cost of increasing call blocking probability of data handoff calls and new calls.

Distributed Service Architecture based MAS, though has better reactivity, scalability and sustainability and has less communication overhead but is complex to design and lacks global viewpoint. The congestion control through different attitudes of Socially Intelligent Agents, give rise to different dynamic channel borrowing schemes and different performance characteristics of the system.

The results presented in this chapter, provide call level and system level performance for the MAS, for MA-CAC strategies, service architectures and dynamic channel borrowing (MA-DCB) strategies using SIA. The results demonstrate that these three subsystems, individually and collectively, can help in meeting different QoS requirements, specified in the SLA.

The multi agent system is easily integrated with the Shuffle model thus making the system extendable and extensible by easily changing/varying the capabilities of the agents according to the type of traffic.