Using Case-Based Reasoning in Traffic Pattern Recognition for Best Resource Management in 3G Networks

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ABSTRACT

With the underlying W-CDMA technique in 3G networks, resource management is a very significant issue as it can directly influence the system capacity and also lead to system QoS. However, the resource can be dynamically managed in order to maintain the QoS according to the SLA. In this paper, CBR is used as part of an intelligent-based agent management system. It uses information from previously managed situations to maintain the QoS in order to meet the SLA. The results illustrate the performance of an agent in traffic pattern recognition in order to identify the specific type of problem and finally propose the right solution.

Categories and Subject Descriptors

C.2.3 **[Computer-Communication Networks]:** Network Operations - *network management, network monitoring*.
I.6.6 **[Simulation and Modeling]:** Simulation Output Analysis.

General terms

Algorithms, Management, Performance

Keywords

3G Resource Management; Service Level Agreement; Intelligent agent and Case-based reasoning

1. INTRODUCTION

The third generation (3G) cellular system has been developed to satisfy increasing customer demands for higher bit-rate access in order to provide wireless Internet access anytime and anywhere. In addition, 3G networks will integrate different type of services like voice, data, and video.

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With W-CDMA, all users share the same spectrum and use codes to identify themselves. Hence the whole bandwidth can be reused in every cell. The system is considered a soft capacity system as all users simultaneously transmit so increasing the interference seen by others. The system capacity is, therefore, limited by the total interference that occurs from other users (in the case of the network being uplink-capacity limited) or other base stations (in the case of the network being downlink-capacity limited) and the background noise. The benefit of this technique is therefore providing the flexible, higher bandwidth services, and maintaining the best system capacity. On the other hand, it leads to more complexity in resource management.

Previous work [1] introduced the use of intelligent agents in managing the resources to meet the service level agreement (SLA) when congestion occurs. It shows that by using intelligent agents together with the assignment and admission scheme, the system environment can be monitored and the policy that is suitable for that particular situation will be selected and applied to the system. Also the quality of service (QoS) for each particular class of customer can be monitored and controlled according to the SLA. In [2], Case-Based Reasoning (CBR) is introduced as a mean of giving the agent more "intelligence". The aim of using CBR is so that the problem can be automatically solved by referring to a similar traffic pattern that the system has seen before and kept in the case library. The end solution from the previous case can then be applied immediately to give a fast and efficient response. In this paper, a wider range of traffic situations will be illustrated, which will also show the benefit of using CBR in order to identify different traffic patterns and to propose the best solution. In addition, results show the outcome of system flexibility in giving different priority patterns to customers according to the system requirements.

The paper is organised as follows. The agent system and architecture for the multi-agent system are described in section 2. In section 3, the implementation of CBR in SLA-based control by the agent will be introduced. The assignment and admission scheme is presented in section 4 and section 5 covers the simulation model. Traffic pattern recognition and numerical results are illustrated and discussed in section 6. Lastly, the conclusions of the paper are in section 7.

2. AGENT SYSTEM AND ARCHITECTURE

Critical in a radio network is the allocation of bandwidth to radio cells in order to avoid local congestion or degradation of the QoS and it is generally the capacity of the wireless link to the user that limits the overall system capacity, rather than any back-haul part of the network.

In [3], an agent approach for a distributed resource management system is introduced. The main reason for using intelligent agents is to give greater autonomy to the base stations; this gives an increase in flexibility to deal with new situations in traffic load and to decrease the information load (the messaging resulting from taking, or determining control actions) on the network.

In the past, mobile network operators have generally restricted the customer to only one service provider. With the influence of the Internet, more widespread choice of service providers (SPs) will be available to 3G users. By using an agent, it would be possible to allow selection of SP by offering on price, QoS, or value added service.

In this work, each agent uses three layers taking action and decisions on different timescales: reactive, local planning and co-operative planning.

As an individual connection must have the decision made in real-time, the reactive layer is designed for a very fast response. More complex functions have been implemented at the planning layers. Generally the local planning layer is concerned with long-term actions within its own instance, whereas the co-operative layer is concerned with long-term actions between peer agents, or with other types of agent. The reactive layer is, therefore very simple, implementing policies being passed down by the higher layer. This is discussed in more detail later in the paper.

3. CBR IN SLA-BASED CONTROL

3.1 Case-based reasoning (CBR)

CBR is an Artificial intelligence (AI) approach that can allow the agent to learn from past successes. It is a method that finds the solution to the new problem by analysing previously solved problems, called cases, or adapting old solutions to meet new demands.

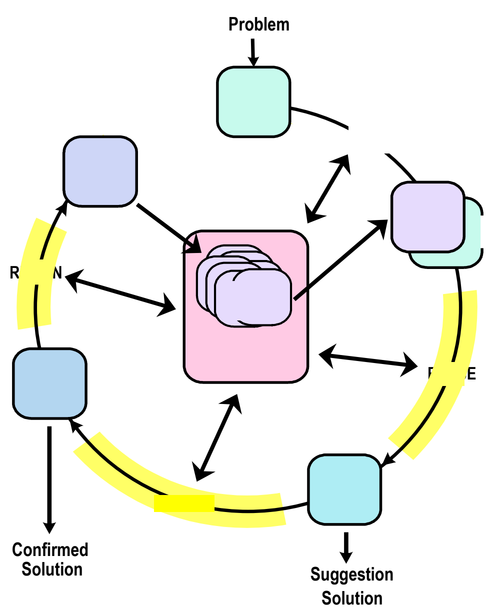

Figure 1 Case-based reasoning process model (Based on the CBR cycle in [4])

Figure 1 shows the process model of the case-based reasoning. The process of CBR starts when there is a new problem or new case happening. The first step is case retrieval, which uses the characterizing indexes of the event to find the best-match solved case(s) from the case library. The solution from the retrieved case(s) will be reused.

However, the solution might need to be modified to fit the new situation as the new situation will rarely match the old one exactly: this step is called "revising". Once the new solution is proposed, the next step is to test it with the real environment. The result is either success or failure. If the solution fails, a monitoring process will analyse the failure, repair the working solution, and test again. If the solution succeeds, this new solution will be indexed and retained in the case library to use for future problem solving.

The work shown in [5] gives an example of using CBR in network traffic control by using it to control traffic flow in the standard public switched telephone network of the Ile de France. In another work in [6], CBR is used to correct the error estimation of the required bandwidth computed by conventional connection admission control schemes.

In the work described in this paper, CBR is used to recognise traffic patterns as congestion occurs in a 3G network and to define the policies to respond to that congestion in the reactive layer of the resource agent. Congestion here means the situation where system could not maintain the QoS required by the SLA. (This is explained in more detail in section 5)

3.2 Resource agent

In this work the resource agent is the focus of attention as it is an important agent in managing the resource within the network. The architecture of the resource agent is illustrated in figure 2.

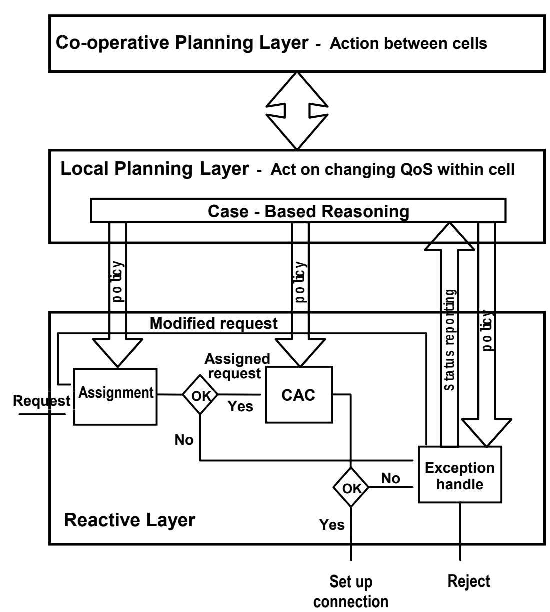

Figure 2 Resource agent internal architecture

The reactive layer is designed to be fast, performing the same function that would be in a conventional RNC (Radio Network Controller), assigning the connection a Node B, and performing

CAC (Connection Admission Control) but it does this according to policies assigned by the planning layer.

The connection request (containing information about the service provider, QoS, type of connection) is first considered for assignment to a Node B using an algorithm or set of rules passed down from the planning layer. As a result, the system performance can be monitored at all times. Any congestion occurring can be detected and reported to the planning layer which, will then find the best solution using the CBR approach in order to maintain the SLA.

4. ASSIGNMENT AND ADMISSION SCHEME

Assignment and admission control together determine which base station will have power control over a mobile, which means that base station must have available bandwidth to support the new call, and also must make sure that none of the existing connection will be dropped.

A great deal of work has been done in this area. In [7], a comparison is made between a transmitted power-based call admission control (TPCAC) that protects the ongoing calls and a received power-based call admission control (RPCAC) that blocks new calls when the total received power at a base station exceeds a threshold. The result shows that the RPCAC scheme is found to offer significant performance benefits. In [8], the number-based CAC and interference-based CAC are compared. SIR-based CAC (signal-to-interference based CAC) has been proposed in [9], the benefit being in improving the system performance at traffic hot-spots.

In this paper, a combination between the ideal scheme and SIR-based CAC has been chosen with uplink capacity limitation (which means the signal-to-interference of the received signal from mobile to base station is calculated) As for the ideal scheme, the system has to make sure none of the existing connections will be dropped when accepting a new connection request. Hence, two perfect power control loops are run to verify that the new request can really be accepted; otherwise it would be blocked or put into the buffer.

The admission process is as follow :

- With the new connection request, the new mobile's transmitted power is estimated in order to get the target SIR. (the open power control in section 5.4)
- If the estimated transmitted power is in the accepted range, it means the new mobile can make a connection. Otherwise, it will be blocked or held in the buffer.
- Set up the new connection and perform the first perfect power control loop. With this, the new transmitted power that is supposed to give each connection the target SIR can be determined.
- The second perfect power control loop is performed to achieve the actual SIR for each connection as a result of accepting a new connection request.
- If any existing connection would be dropped (by having SIR less than the threshold), the new connection is still rejected otherwise it is accepted and the connection can be made.

The rejected connection request will be put into a queue until the next calculation or new call arrival and it will be blocked at the expiry of a timer: setting the timer to zero means that a request is immediately accepted or rejected. Furthermore, the base station serving the mobile can be reassigned at anytime during the connection if the current base station cannot provide the required link quality.

5. SIMULATION MODEL

The simulation model has been implemented in MatLab. The system used for the results in this paper consists of 9 hexagonal cells (25 cells have been used for other work but the large model suffers from an excessively long run time) and each cell has its own base station with an omni-directional antenna placed at the centre of the cell. A number of mobiles have been generated randomly according to the input traffic. When considering different classes of user, it is quite common to use three classes: bronze, silver, and gold. In the results described here, 50% of the users are bronze, 30% are silver and 20% are gold. It is assumed that the gold customers will pay the highest service charge followed by silver and bronze customers, so that the gold customer is paying for the best service and more flexibility than the others.

5.1 Radio Propagation Model

In cellular systems, radio propagation is crucially influenced by the path loss according to the distance, log-normal shadowing, and multipath fading. The relationship between the transmitted power and received power can be expressed as [9].

$$P(r) = 10^{\xi/10} \cdot r^{-\alpha} \cdot P_0 \qquad (1)$$

where P(r) is the received power, P0 is transmitted power, r is the distance from the base station to mobile, ξ in decibels has a normal distribution with zero mean and standard deviation of σ (typical value of 8 dB), and α^2 represents the gain (typical values of α in a cellular environment are 2.7-4.0).

5.2 Traffic Model

The model consists of two traffic types, voice and video. The model has been simplified from the three type traffic model that also included data traffic, which was used in [2]. The reason in simplifying the traffic model is because modelling data traffic to the level of packet results in unrealistically long simulation times.

5.2.1 Voice traffic

Voice traffic is considered to be real-time traffic. The common model for a single voice source is illustrated by the ON-OFF process. It consists of two stages, active (ON) and silent (OFF) stage, with a transition rate μ from ON to OFF and λ from OFF to ON stage.

Figure 3 illustrates the ON-OFF model. The silent period is assumed to be the period that cannot be used to transmit data message or voice call.

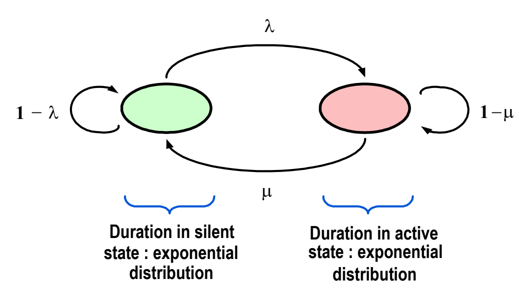

Figure 3 Traffic model for voice call (ON-OFF model)

To simplify the simulation, the approach of [9] is used with an activity factor of 0.45 is used. The transmission rate for voice traffic is assumed to be 8kbit/s and mean holding time is 180second.

5.2.2 Video traffic

Video traffic is also considered as real-time traffic. The common model for video source is illustrated by the discrete-state continuous time Markov process illustrated in figure 4.

The bit rate of video traffic is quantized into finite discrete level (0 A 2A… MA). Transitions between levels occur with exponential transition rates that may depend on the current level. [11]

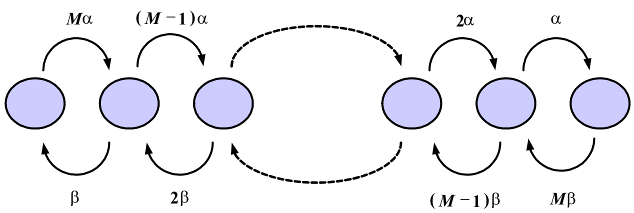

Figure 4 Video source model (Discrete-state continuous time Markov process)

The α and β are the state transitions and they are obtained by:-

$$\beta = \frac{3.9}{\left[1 + \frac{5.04458N}{M}\right]} \tag{2}$$

$$\alpha = 3.9 - \beta \tag{3}$$

where N is a Number of aggregated video sources (typical assumption 1) and M is a number of quantization levels (typical assumption 8).

Implementing this video traffic model in the simulation causes simulation times to be very long. Many authors therefore simplify this by using activity factor. [9][12] Here, an activity factor of 1 has been assumed for the real-time video source as use in [9]. The transmission rate for video traffic is assumed to be 64, 144, or 384kbit/s and mean holding time is 300 second.

5.3 Receiver Model

For the uplink capacity limited, the SIR of each transmission is calculated at the base station and it can be expressed as follows, (based on [13])

$$SIR = \left(\frac{W}{R}\right) \cdot \frac{\Pr}{I_{intra} + I_{inter} + N_{thermal}} \tag{4}$$

where, (W/R) is the processing gain, Pr is the received signal strength, I_{intra} is the sum of the received signal powers of other transmissions within the same cell, I_{inter} is the sum of the received signal powers from the other cells, and $N_{thermal}$ is the thermal noise power.

5.4 Power Control Model

Power control is the crucial part in the system since it is necessary to minimise the interference in the system by minimising the level of transmitted power to the optimum level, which means just enough to maintain the link quality. Power control in UMTS consists of three main functions: (i) open-loop power control, (ii) inner-loop power control, and (iii) outer-loop power control [14]. As the simulation focuses on the uplink-limited capacity, power control for the uplink is applied. In this work, the first two types are applied in the simulation since they have the major effect on the simulation result. Without outer-loop power control, the target SIR has to be fixed; here, it is assumed to be 6 dB and the threshold is 4 dB. [10] The power control step is assumed to be 1 dB at each power control cycle. [15][16]

5.4.1 Open-Loop Power Control

Open-loop power control is applied when new connection requests arrive in the system as initial step of the admission process (section 4). The total interference at the base station is calculated as it is the parameter that User Equipment (UE) needs to use in the estimation of its initial transmit power. According to the parameter and the target SIR, UE estimates the transmit power and uses it as an initial transmit power.

5.4.2 Inner-Loop Power Control

This is done periodically to allow the transmitted power of each connection to be kept as low as possible, yet maintain the target SIR. Firstly, the base station calculates the received SIR from the UE. If the SIR is less than the target SIR, the TPC (Transmit Power Control) command "up" is sent to the UE which increases the transmitted power by one step. If the SIR is more than the target SIR+1, the TPC command "down" is sent to the UE which decreases the transmitted power by one step. Otherwise, the UE maintains the same transmitted power. After the power control cycle has been performed, the new SIR for each mobile can be calculated. Any mobile that has an SIR less than the threshold will not be dropped immediately; instead the system will try to reallocate that mobile to another base station nearby that still has available bandwidth and can provide the link quality. If it is possible, the mobile will be handed over to the next base station, otherwise the mobile will be dropped. The transmitted power has a maximum of 21dBm; if the calculated transmit power is more than the maximum power, the maximum transmitted power will be applied.

In this simulation, the inner-loop power control is performed every 10ms. Experiments have been done by varying the power control time step and the results show that the blocking rate becomes erratic as the timing gets too high. From the experiment, the time step of 10ms has been chosen as it is the highest value that gives consistent results. From the simulation point of view, it is preferable to use the highest time as this reduces the length of the simulation.

The power control is essentially that used in 3G without including outer-loop power control.

5.5 Verification and Validation

One of the most important aspects in developing the simulation model is its credibility; therefore the validation and verification of any simulation model are essential. The simulation model was validated by comparing the result with the relevant result from [8]: this is discussed in [1].

5.6 CBR Model

According to [17], there are several proposed schemes of organizational structure and retrieval algorithms for CBR. In this work, the hierarchical memory with parallel search is used as it provides an efficient retrieval that is less time consuming, as the matching and retrieving happen in one step, which also give less complexity.

The monitoring process of the system performed every 10 seconds. This means the monitoring parameters will be collected for 10 seconds and sent to the local planning layer of an agent where the CBR model is located as shown in figure 1. The parameters will then be compared with the SLA requirements and any deviation from the SLA can be reported. The CBR model will then be used to find the best solution for the situation. Base on the process model in figure 1, a solution will be proposed, or where the best matched case cannot be found or the evaluating process fails, a calculation might be used instead in order to find the solution according to certain rules.

As the parallel search has been chosen for the CBR model, the whole library will be searched for each characterizing index in one step. If the new case is to be retained in the library, the library indexes have to be re-sorted according to the priority of the characterizing index of the new case.

5.7 Monitoring and case matching process

As explained above, the monitoring process is done every 10 seconds. The call blocking, call dropping and the accumulative value of blocking rate are calculated and by comparing them with the SLA requirements, the error can be detected. If the error being reported is significant, the CBR model will be called.

There are seven characterising indexes used to describe the case at the moment. Currently, they are obtained by matching the actual monitoring factors into a suitable range where the value belongs. Therefore, the characterising indexes will be in form of small integer numbers. The seven monitoring factors are as follows-:

- Total throughput for the whole system
- Offered traffic for the whole system
- Offered traffic for silver customer for the whole system
- Offered traffic for gold customer for the whole system
- Cell identity where offered traffic exceeds limit
- Accumulative blocking rate for silver class
- Accumulative blocking rate for gold class

In case that there is not an exact match, there needs be a way to identify whether the closest match is acceptable for the situation. However, in the current model, only the best match will be chosen. In future work, the acceptable level for each case will be determined by the distance to the seven-dimensional coordinates defining the individual point of the case. If it is within the tolerable range, the case will be used.

6. TRAFFIC PATTERN RECOGNITION AND NUMERICAL RESULTS

The previous work [1] was done to support the basic idea that the reactive layer of the agent system can be controlled by the planning layer in order to ensure system compliance with the SLA. Here, the SLA assumptions made for the maximum acceptable level of call blocking rate.

- Maximum acceptable call blocking rate for gold : 0.03
- Maximum acceptable call blocking rate for silver : 0.05

The gold customer pays the highest rate for the least elasticity of service level. These rates can either be instantaneous values or measured over a period of time; naturally the numerical limits would be different.

In [1], the random overload situation has been tested with the traffic load being increased after the system reached stability. The call dropping rate is acceptable before high traffic load was applied, but after changing the load, the call dropping rate increases, then slowly declines to about the same level as before, because of the implementation of ideal assignment and admission control. On the other hand, the call blocking rate increases as a greater number of mobiles attempt to get into the system and the system tries not to drop any existing connection, so more will be blocked. The call buffering time for all classes of customer and all types of service has been set to zero to give immediate accept or reject decisions.

Figure 5 shows the comparison between the result from the conventional system that does not chance the policy with the dashed lines and the result of policy chance as the solid lines. Without the SLA based control, the call blocking rate for all customer classes raises as the traffic load increases.

For the SLA based control, the implementation here uses a buffer mechanism so the a call request that cannot be served immediately is held for a short time in case resources become available. The buffering time is configurable. From solid lines at the point when the level of call blocking rate for gold customer reaches the maximum level, policy 2 is applied which allocates a short buffering time to call requests from gold and silver customers, with that for bronze customers still being set to zero. The result shows that the call blocking rate of gold and silver customers stabilises, but does not go below the limit set for gold. After waiting for a short period (here 2 minutes) to ensure the trend is stable, a further change in policy is applied; this gives longer buffering time for gold customers and slightly longer buffering time for silver customers, so increasing still further the probability of gold and silver customers (especially gold) being accepted at the expense of bronze.

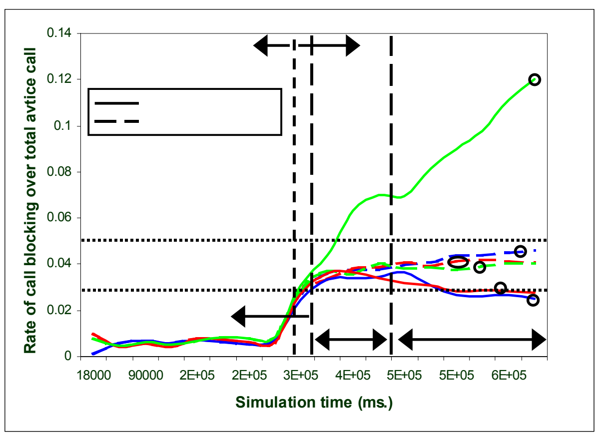

Figure 5 Comparison between the result from the conventional system and SLA based control system

A simple case library has been generated partly from this previous work and the knowledge from the work under current study. By using the simulation model mentioned before, a few traffic patterns can be implemented to test the system performance.

The two main environments being tested here are the random overload situation and the hot spot situation. As the system detects the congestion, the CBR model is called to analyse the situation and the simulation results will be divided in two sections.

6.1 Random overload case

For this case, the simulation repeated the previous work explained before by adding the CBR model and also use the simulation model illustrated in section 5. (In previous work [1] the less detailed simulation model has been used.)

Figure 6 shows the simulation results of the call blocking across the simulation time as the traffic load increases in a conventional system that does not change policy. The call buffering time for all classes of customers and all types of services has been set to zero to give immediate accept or reject decisions.

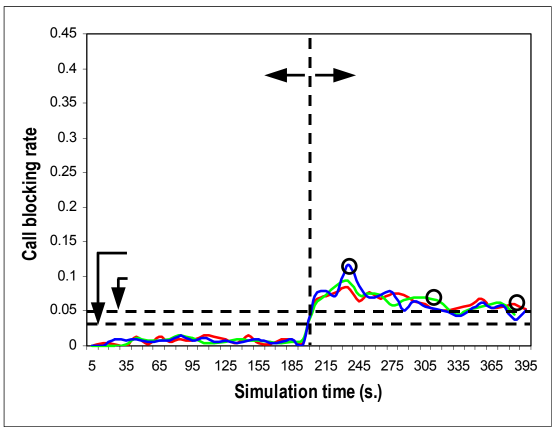

Figure 6 The simulation result from conventional system for the random overload situation

Figure 7, 8 and 9 show the effect of using the CBR approach to identify the current traffic pattern and manage the reactive layer policies accordingly.

It might be thought that these results are simply the normal result of applying priorities, but the technique is more powerful. In many SLAs, it is not short-term violations that are important: an SLA might specify for instance that the blocking rate must not exceed a certain value during a day or a month.

The new policy has been applied to the reactive layer as soon as the system recognises congestion, in this example using the accumulative error rate over a period of 10s.

The implementation here again uses a buffer mechanism to give short buffering time to call request that cannot be served immediately, especially for the higher priority customer. The buffering time is configurable. It can be seen from the result that CBR keeps the call blocking rate for gold and/or silver customers within the SLA bounds, according to the congestion pattern.

In figure 7, the traffic reaches overload when the accumulative call blocking rate for gold exceeds the limit, at that point silver is still in an acceptable range. In this case the chosen policy gives the highest buffering time to gold and lower value for silver with that for bronze still at zero.

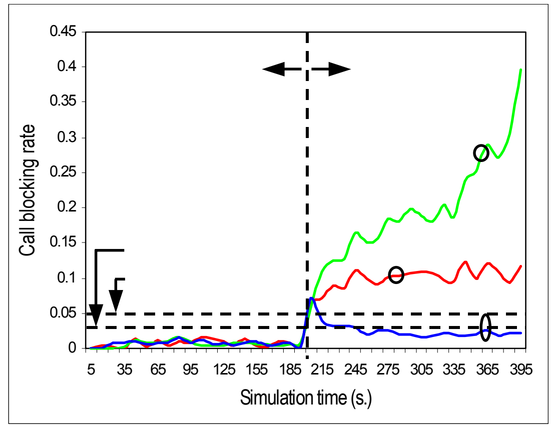

Figure 7 Simulation results showing the effect of SLA-based control by CBR approach for the first random overload case

It can be seen that the system detects the overload situation at the point where the traffic load increases and generates the appropriate policy. As the new policy gives priority to gold, the call blocking for gold customer is maintained within an acceptable range at the expense of both silver and bronze.

Figure 8 shows the result from the second case, where the traffic is overloaded with the accumulative call blocking rate for gold and silver exceeding the maximum value. In this case, both silver and gold QoS need to be handled. By giving highest buffering time to silver and slightly lower for gold, the blocking for both can be kept within the range. As the buffer in this implementation uses the priority arrangement, gold customers are always in the top of the queue, so, in order to also give priority to silver customers, their buffering time has to be higher.

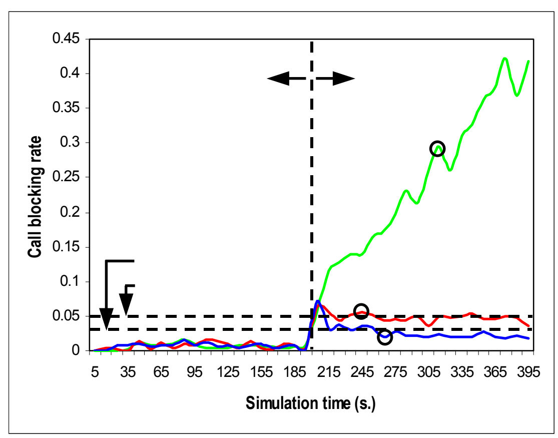

Figure 8 Simulation results showing the effect of SLA-based control by CBR approach for the second random overload case

In Figure 9 the situation is that the long-term value for gold customers has been met, but that for silver is at the limit. When congestion occurs then, silver customers have to be given priority in order that their long-term blocking is not exceeded, but gold customers can be allowed to have worse service since there is still "slack" in their SLA.

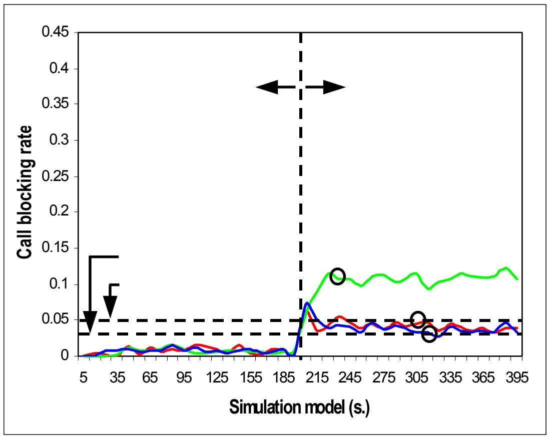

Figure 9 Simulation results showing the effect of SLA-based control by CBR approach for the last random overload case

The SLA monitoring here is looking at the long-term blocking, has detected that silver needs priority and has applied that priority.

These results show the flexibility of the control system which assigns different policies to different scenarios and also shows that the highest priority can also be a sacrifice in order to maintain the customer who normally has the overall long-term values.

In fact any SLA that can be evaluated numerically can be used as the basis for controlling the policy: the system is that flexible.

6.2 Hot spot case

With hot spots, the monitoring process is able to identify the congestion from the individual blocking and dropping parameters of each cell. CBR model will then match the pattern with the cases in the library. The proposed mechanism here can be seen in figure 10.

The bronze and silver users near the boundary will be transferred to the neighbouring cells that have normal traffic: effectively then by controlling the cell size in a more comprehensive manner than simple cell breathing from power control. By doing this, some of the capacity will be released for the hot spot cell in order to maintain the users nearer to the centre and high priority users.

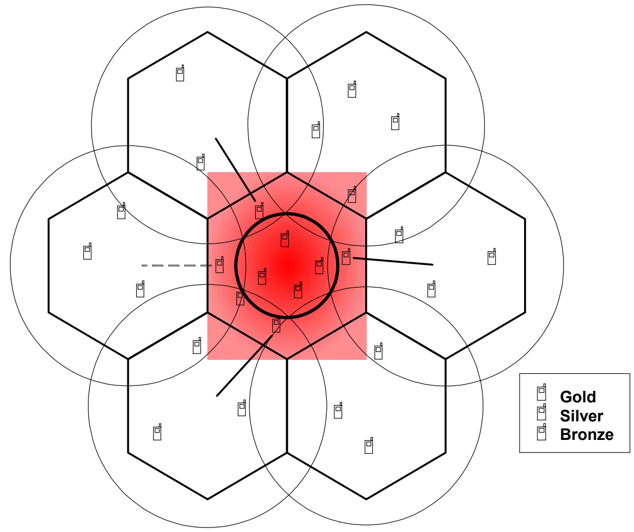

Figure 10 Hot spot situation and the proposed solution

In the initial work for this hot spot case, the transferring process or handover will be done every 10s, which is the frequency of the monitoring process. An example of results from the initial work in this case are shown in figure 11 and 12.

In figure 11, after the traffic load has increased in the hot spot cell, the call blocking rate for the hot spot call rise up while the other cells still have low blocking rate as the traffic was controlled within normal level.

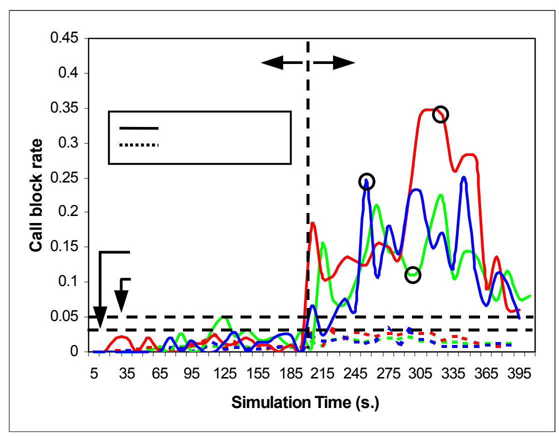

Figure 11 Result from the conventional system for the hot spot situation

Figure 12 shows the result of using the CBR model which instructs the system to perform the handover for bronze and silver users near boundary to the neighbouring cells every 10s. The blocking rate for the hot spot cell still increases after the traffic load has increased but by comparing with the result in figure 11, the call blocking rate is lower. Further work is being done on evaluating more complex scenarios.

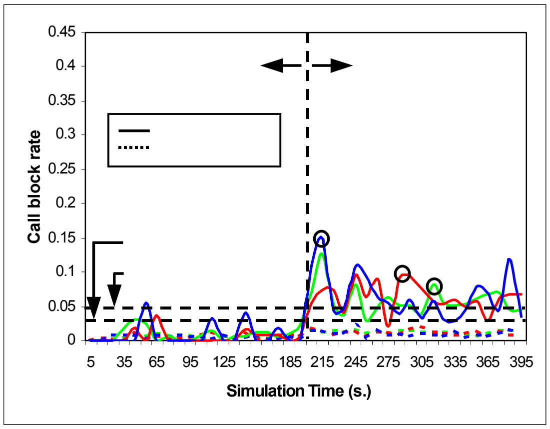

Figure 12 Result from SLA based control system with CBR model for the hot spot situation

7. CONCLUSIONS

This paper has introduced the concept of combining CBR with an intelligent agent layered architecture to manage SLAs in W-CDMA networks. The simulation results show that the CBR system has been able to detect congestion occurring and then apply the appropriate policy to manage the behaviour of the CAC to block those customers who, at that time, are perceived as less important to the operator.

The scenarios illustrated are fairly simple but further work is evaluating the approach over a much more complex range of situations.

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