Developing Cell Cluster based CAC for Cellular Networks

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Abstract

Cluster Connection Admission Control (Cluster CAC) schemes for wireless cellular networks are discussed. After reviewing the basic admission schemes for single-cluster network architecture, new more realistic multiple-cluster schemes are defined. Unlike single cluster schemes, such new multiple-cluster environment takes into account the hand-off events between different clusters. Two thresholds are defined in order to guarantee in the multiple-cluster network architecture the same performance level of single-cluster schemes. Computer simulation has been used to evaluate the main performance metrics assuming a Wireless ATM network environment.

1 INTRODUCTION

Next generation cellular networks have some certain new evolution trends [13]. They are shifting towards increasingly greater carrier frequencies (at SHF frequencies, 3-30 GHz), necessary to achieve new transmission capability on the radio channel. They are shifting towards network architecture with smaller cells (pico-cells with radii around $50\ m$), necessary to counter the high attenuation at SHF frequencies and to achieve high reuse factors of the limited radio spectrum. They are shifting towards packet switching technologies, which enable statistic multiplexing of different traffic types (voice, video, and data) for multimedia applications. Finally, they should shift toward a maximum technological compatibility with the network backbone to reduce processing at the wireless-wireline interfaces.

Connections Admission Control (CAC) assumes greater importance in this context. The shift at SHF frequencies causes a greater impact of multipath fading, which requires connection QoS efficient control, beginning in the admission phase and continuing in the execution phase. The shift towards pico-cell network architecture gives rise to greater hand-off rates, which require optimum management that has to be in strict relation with the admission procedure. The shift towards packet switched technologies requires an efficient control of the traffic conditions on the network from the admission phase to obtain high utilization coefficients of the limited radio resource.

This paper develops cellular networks CAC schemes based on cell cluster concept (Cluster CAC), proposed in [3, 4] and developed in successive works [4, 5, 6, 15, 10, 11]. All these works analyze such Cluster CAC schemes on a single-cluster network model. We will develop Cluster CAC analysis adopting a more realistic multiple-cluster network model. New secondary metrics will be defined to measure the hand-offs between cells belonging to different clusters. The analysis will be carried on using the cellular Wireless ATM (WATM) network simulator developed in [7].

The paper is organized as follow. Section 2 contains a general description of CAC schemes for wireless cellular networks. In section 3, Cluster based CAC schemes are analyzed on single-cluster and multiple-cluster model, while section 4 presents the simulation environment used and section 5 discusses the simulation results. Finally, section 6 contains our conclusions.

2 CAC FOR CELLULAR NETWORKS

The CAC function aims at optimizing the network resource utilization, allowing the largest number of connections into the network, to which it is possible to ensure their QoS requirements.

In cellular networks, the CAC procedure manages the admission of Mobile Terminal (MT) connections to individual cells, each one covered by its own Base Station (BS). The CAC schemes for wireless networks must differentiate new connections from hand-off connections to ensure a given level of priority to the already active hand-off connections. Furthermore, they must be simple, so as to be sufficiently fast in the management of the hand-off events (transparent to users) and capable of managing pico-cell network architecture.

Therefore, the CAC function controls the network QoS in terms of optimizing resources utilization; furthermore, it controls the connection QoS in terms of their blocking, dropping and forced termination probability. The ***main metrics*** that measure the performance of CAC schemes for cellular networks are defined as follows [8]: *new connection Blocking Probability* (P_{ncB}) is the probability that a newly arriving connection cannot access the network, defined by the ratio between the number of new connections blocked by the CAC function and the number of new connections requested to the network; *hand-off connection Dropping Probability* (P_{hcD}) is the probability that an hand-off attempt fails, defined as the ratio between the number of hand-offs dropped by the CAC function and the number of hand-offs attempted by active connections; *forced connection Termination Probability* (P_{fcT}) is the probability that an existing connection is dropped because of hand-off failure; it is a function of P_{hcD} and p_h (probability of executing an hand-off, i.e., a mobility parameter).

Several CAC schemes for wireless cellular networks have been proposed. The first solutions proposed the guard channel CAC schemes [16, 18] and developed them with several variations and optimizations (e.g., [17]). In general, these schemes reserve a part of the cell bandwidth exclusively for the hand-off connections, so that high connectivity is ensured. Cell cluster CAC schemes were later proposed [3, 10]. Both guard channel schemes and cell cluster schemes adopt a Fixed Channel Allocation (FCA) architecture, without any adaptive mechanism to control network traffic, without any predictive CAC algorithm, and without any terminal mobility estimate mechanism. We will maintain these assumptions because we are focusing on the difference between elementary single-cluster architecture and realistic multiple-cluster architecture. Anyway, sophisticated CAC schemes based on adaptive or mobility estimate mechanisms may be applied to cell-cluster schemes in a later development phase.

3 CELL CLUSTER CAC

Figure 1 illustrates a cluster CAC scheme based on Virtual Connection Tree (VCT) concept, which is a collection of BS (the Cluster of cells) and wired network switching nodes and links; the root is a fixed node linked to the ATM network backbone (assuming a Wireless ATM environment) and the leaves are the BSs.

When a mobile connection requires admission to the network, the Cluster CAC procedure is executed in two steps. In the first step, the cluster CAC controller makes the cluster admission decision, by taking into account the cluster bandwidth available and some connection requirements (bandwidth, hand-off rate, and call duration) so as to guarantee connection QoS metrics (***cluster admission*** phase). In the second step, the requiring connection has to gain access to its base station (***BS access*** phase); the BS access phase will be successful if and only if the BS has free bandwidth enough for the incoming connection.

Once an MT is admitted to a cell cluster, it can freely hand-off to all the other BSs in the same cluster (***cell hand-off***), without involving the cluster admission controller (it is executed just the *BS access* phase because, remaining in the same cell cluster, the *cluster admission* phase is not necessary). Whenever an MT seeks admission to a new cell cluster (***cluster hand-off***) because it is executing a hand-off between two adjacent cells belonging to different clusters, the admission controller must again become involved: both the *cluster admission* phase and the *BS access* phase must be executed. Since the cluster geographical coverage is larger than the radio cells size, the cluster hand-off rate is much smaller than the cell hand-off rate.

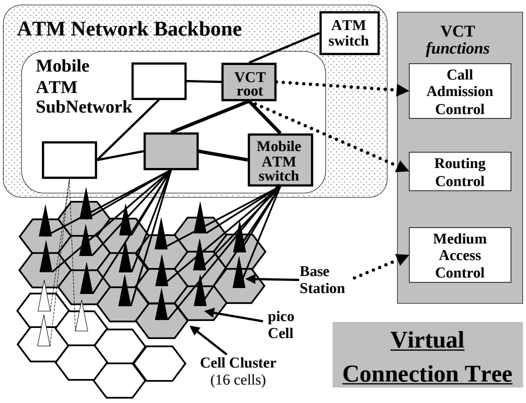

Figure 1: Cluster CAC scheme.

The following new ***auxiliary metrics*** are defined alongside the main metrics defined in Section 2 to measure the performance of Cluster CAC schemes: *new connection Admission Blocking Probability* (P_{ncAB}) is the probability that a newly arriving connection can not be admitted in the cluster (*cluster admission* phase failure of a new connection), defined by the ratio between the number of new connections blocked in the *cluster admission* phase by the CAC function and the number of new connections requested to the network; *connection Cell Dropping Probability* (P_{cCD}) is the probability that a generic connection (coming from a new request or from a cell hand-off or from a cluster hand-off) can not access the destination cell (*cell access* phase failure), defined by the ratio between the number of dropped access requests to the BS (due to bandwidth saturation) and the total number of access requests to the BS (equivalent to the failure probability of a cell hand-off); *hand-off connection Admission Dropping Probability* (P_{hcAD}) is the probability that a cluster hand-off arriving connection can not be admitted in the new cluster (*cluster admission* phase failure of a cluster hand-off connection), defined by the ratio between the number of cluster hand-off connections dropped in the *cluster admission* phase by the CAC function and the number of cluster hand-off connections requested to the network.

These secondary metrics are necessary since they define different connections blocking or dropping causes, by which it is possible to express the main metrics. New connection blocking probability is given by the following equation:

$$P_{ncB} = P_{ncAB} + P_{cCD} - P_{ncAB} P_{cCD} \qquad (1)$$

The equation expresses the operating mechanism of the Cluster CAC scheme towards new connections, which can be blocked either in the *cluster admission* phase by the admission controller when the cluster admission threshold is reached or in the *cell access* phase by the BS when cell bandwidth saturation occurs. The main probabilities P_{hcD} and P_{fcT} are functions of the auxiliary probabilities with expressions depending on the particular Cluster CAC policy adopted (Section 3.1.1, 3.2.1).

3.1 SINGLE-CLUSTER CAC MODEL

The single-cluster analysis proposed in [4] does not incorporate explicit cluster hand-offs. This approximation considers a homogeneous system, in which the aggregate hand-off traffic leaving a cluster is statistically equivalent to the aggregate hand-off traffic arriving at the cluster from all the other adjacent clusters. In this way, the model implicitly incorporates cluster hand-off traffic, assuming the cluster outgoing traffic exactly balanced by the cluster incoming traffic; there is no possibility of cluster hand-off drop due to *cluster admission* phase failure ($P_{hcAD} = 0$).

The main analysis points are here reported. New call arrivals are Poisson with rate λ_n, the call duration is exponentially distributed with a mean $1/\mu_d$ and the time before handing-off is exponentially distributed with a mean $1/\eta_h$: the probability of executing a hand-off is found to be $p_h = \eta_h/(\mu_d + \eta_h)$ [8]. Then the analysis develops a **mono-class traffic model on a single cluster** of D_{Cl} cells (Cluster Dimension), each cell being modeled as a Markovian system of $N = B_{BS}/b_{CBR}$ servers (where B_{BS} is the BS bandwidth and b_{CBR} is the connection bandwidth in the hypothesis of a Wireless ATM network loaded by a mono-class CBR real-time traffic). Finally, the overall model is described analytically by a multi-dimensional system, whose state is defined by the number of servers reserved by the active *CBR* connections in each cell of the single-cluster.

3.1.1 *Single-Cluster QoS metrics*

The expressions of the main metrics as a function of the auxiliary Cluster CAC metrics are simple under the $P_{hcAD} = 0$ hypothesis. P_{ncB} maintains the same expression of equation (1): $P_{ncB} = P_{ncAB} + P_{cCD} - P_{ncAB}P_{cCD}$, since new connections do not depend on hand-off hypothesis. The hand-off connection dropping probability P_{hcD} is simply $P_{hcD} = P_{cCD}$, since hand-offs can fail only due to saturation of the destination cell under the cluster hand-off balance assumption. Finally, the probability of forced connection termination P_{fcT} has the following expression

$$P_{fcT} = \frac{p_h P_{hcD}}{1 - [p_h(1 - P_{hcD})]} = \frac{P_{hcD}}{\mu_d/\eta_h + P_{hcD}} \quad (2)$$

analogous to the guard channel schemes expression [8], since the *cluster admission* phase is executed just for the admission of new connections under the cluster hand-off balance assumption.

3.2 MULTIPLE-CLUSTER CAC MODEL

The assumption adopted in the single-cluster model in a strict sense presupposes that all cluster hand-offs are instantaneously balanced by an equal number of equivalent cluster hand-offs in the opposite direction, so that an instantaneous, as well as a statistic, balance is achieved between the incoming and outgoing cluster hand-offs. It follows that: cluster hand-offs are completely disregarded; all hand-offs are just cell hand-off, never involving the *cluster admission* phase; the probability of cluster hand-off drop due to *cluster admission* phase failure is null ($P_{hcAD} = 0$).

This assumption would be justified in case the number of cluster active connections were high; in this case the instantaneous balance would tend towards the average statistic balance value, verified according to a general assumption of homogeneous system. In reality, this assumption does not appear to be particularly justified, since the number of active connections in a cluster consisting of pico-cells will not be high, due to the limited dimensions of the cells and the wide bandwidth reserved for new multi-media connections.

By removing the hypothesis $P_{hcAD} = 0$, we now analyze the Cluster CAC schemes implemented on a ***multiple-cluster architecture***.

3.2.1 *Multiple-Cluster QoS metrics*

In a Multiple-Clusters architecture the expressions of the main metrics as a function of the auxiliary Cluster CAC metrics are different when compared to the expressions that are used under the Single-Cluster hypothesis.

P_{ncB} always maintains the expression of equation (1) since it does not depend on hand-off events. To express the other two main QoS metrics (P_{hcD}, P_{fcT}) as a function of the auxiliary cluster specific metrics (P_{ncAB}, P_{cCD}, P_{hcAD}) new auxiliary metrics are necessary.

We define the new metric *Probability of executing a cluster hand-off* p_{cl-h} by making a distinction between cell hand-offs and cluster hand-offs. Then, we split the general probability of executing a hand-off, p_h, into the sum of the probability of executing a cell hand-off $(1 - p_{cl-h})p_h$ and the probability of executing a cluster hand-off $p_{cl-h}p_h$: $p_h = (1 - p_{cl-h})p_h + p_{cl-h}p_h$.

Now we define the *Probability of cell hand-off Dropping* $P_{cell-hD}$ (P for brevity), which is equal to the probability of cell saturation, since such hand-off can only fail due to saturation of the BS bandwidth ($P \equiv P_{cell-hD} \triangleq P_{cCD}$). Finally, we define the *Probability of cluster hand-off Dropping* (Q for brevity), as follows: $Q \equiv P_{cl-hD} \triangleq P_{hcAD} + (1 - P_{hcAD})P_{cCD}$. In fact, with an expression analogous to (1), the cluster hand-offs execute the complete CAC procedure and may fail in the *cluster admission* phase with a probability P_{hcAD} (as a result of the CAC procedure, due to cluster hand-off admission threshold limit) or in the *cell access* phase with a probability P_{cCD} (as a result of the BS, due to its bandwidth saturation).

We can now express P_{hcD} as weighted mean of the two hand-off failure probabilities:

$$P_{hcD} = (1 - p_{cl-h})P_{cell-hD} + p_{cl-h}P_{cl-hD} =$$

$$= P_{cCD} + p_{cl-h}(1 - P_{cCD})P_{hcAD} \triangleq P_{hcD}^{(cl)} \quad (3)$$

obtained by introducing the probabilities defined above. $P^{(cl)}_{hcD}$ is the hand-off failure probability specific for Multiple-Cluster CAC schemes: a hand-off may fail due to saturation of the destination cell or due to admission cluster threshold, in the case of cluster hand-off and not-saturated cell.

The *forced connection Termination Probability* P_{fcT} can be calculated by taking into account the fact that each hand-off event may be of the cluster type (with a probability of $(1-p_{cl-h})p_h$ and with a failure probability of $P \equiv P_{cell-hD}$) or of the cell type (with a probability of $p_{cl-h}p_h$ and with a failure probability of $Q \equiv P_{cl-hD}$); it is found that [2]:

$$P_{fcT} =$$

$$= \frac{p_h[(1-p_{cl-h})P + p_{cl-h}Q]}{1-p_h\{[(1-p_{cl-h})(1-P)]+[p_{cl-h}(1-Q)]\}} =$$

$$= \frac{P^{(cl)}_{hcD}}{\mu_d/\eta_h + P^{(cl)}_{hcD}} \qquad (4)$$

where the last expression (obtained by introducing $p_h = \eta_h/(\mu_d+\eta_h)$) is analogous to the expression (2) for guard channel CAC schemes, when considering the $P^{(cl)}_{hcD}$ defined in equation (3) as the hand-off failure probability specific for Multiple-Cluster CAC schemes.

3.2.2 *Single-Threshold Cluster CAC (Cl_1)*

In the single threshold option, the Cluster CAC function allows both new and hand-off connections (from adjacent clusters) up to saturation of the same cluster bandwidth percentage of the overall cluster bandwidth, i.e., a common threshold T_{Cl} for both types of connections. This scheme does not give priority to cluster hand-off connections with respect to new connections.

In this option the admission probabilities of new connections P_{ncAD} and of cluster hand-off connections P_{hcAD} have similar values, since they are managed by the CAC function based on the same threshold T_{Cl}:

$$P_{ncAD} \simeq P_{hcAD} \qquad (5)$$

behavior may be potentially dangerous with high input traffic conditions. In fact, under these conditions the busy cluster bandwidth will be next to the admission threshold: P_{ncAB} will have high average values and therefore also P_{hcAD} (having comparable values), this condition will generate high asymptotic values of P_{fcT} [2]:

$$P_{fcT} \xrightarrow{\lambda_n \to \lambda_n^{(\infty)}} \frac{p_{cl-h}}{\mu_d/\eta_h + p_{cl-h}} \qquad (6)$$

These P_{fcT} high values depend on terminal mobility (μ_d/η_h) and on clusters dimension, indirectly expressed by the cluster hand-off execution term p_{cl-h}. To improve P_{fcT} it is possible to adopt architecture with *greater cluster dimensions* D_{Cl} that decrease p_{cl-h} and, consequently, the probability of cluster hand-offs. A different approach to overcome this problem consists in foreseeing some form of *priority mechanism* for the cluster hand-off connections, which decreases P_{hcAD} and differentiates it from P_{ncAD} , as achieved in the double threshold Cluster CAC schemes.

3.2.3 *Double-Threshold Cluster CAC (Cl_2)*

The simplest solution to achieve a priority approach for the cluster hand-off connections consists in adopting two admission thresholds: one threshold T_1 for the new connections and a second threshold T_2 graduated to a greater degree for the hand-off connections ($T_1 < T_2$), in accordance with the analogous guard channels principle. This simple solution can differentiate the new connections admission blocking probability P_{ncAB} from the cluster hand-off connections admission dropping P_{hcAD}:

$$P_{hcAD} < P_{ncAB} \qquad (7)$$

Moreover, by suitably selecting the second threshold, it is possible to obtain very low values of P_{hcAD}, from which one obtains a behavior of the cluster hand-off approximately equal to that of the cell hand-offs ($P_{cl-hD} \simeq P_{cell-hD} = P_{cCD}$); thereby it is possible to obtain an expression of the forced termination probability P_{fcT} analogous to the expression (2) for the guard channel schemes and for cluster schemes under the cluster hand-off balance assumption [2]:

$$P_{fcT} \xrightarrow{P_{hcAD} \to 0^+} \frac{P_{cCD}}{\mu_d/\eta_h + P_{cCD}} \qquad (8)$$

4 SIMULATION ENVIRONMENT

The simulation model adopts a cellular **network architecture** of 49 regular hexagonal cells with a toroidal topology. The following arrangements have been taken into consideration as regards the topology of the cell clusters utilized to simulate the Cluster CAC schemes. **7-cells cluster** adapts perfectly to the 49-cell network, without rounding off; the probability of executing a cluster hand-off is found to be: $p_{cl-h} = 1/7 \cdot 0 + 6/7 \cdot 1/2 = 3/7 \simeq 0.42857$. **12-cells cluster** adapts to the 49-cell network with a remainder of 1; by disregarding the non-regular cluster, the probability of executing a cluster hand-off is found to be: $p_{cl-h} = 2/12 \cdot 0 + 6/12 \cdot 2/6 + 4/12 \cdot 4/6 = 7/18 \simeq 0.38889$. **16-cells cluster** adapts to the 49-cell network with a remainder of 1; by disregarding the non-regular cluster, the probability of executing a cluster hand-off is found to be: $p_{cl-h} = 4/16 \cdot 0 + 7/16 \cdot 3/6 + 4/16 \cdot 2/6 + 1/16 \cdot 1/6 = 5/16 \simeq 0.3125$.

The **simulation model** has been developed starting from the model implemented in [7], based on a cellular Wireless ATM network.

The **radio channel** has been realized with the Markovian two-state model (good state and bad state) proposed in [19]. The *bursty* type behavior of errors on the wireless transmission channel is summarized by the parameter abl (*average burst length*), average time of the channel in the bad state (block errors mode). All other **physical layer** transmission (such as modulation, coding, rates and power) and reception (such as recognition of the carrier signal, synchronization, optimum reception, demodulation) aspects are summarized using the simulator parameters ccr (*channel cell rate*), BS bandwidth capacity (a simulator time slot is equivalent to a WATM cell transmission time), and cer (*cell error rate*), transition probability from the good state to the bad state of the radio channel.

DQRUMA (proposed in [9]) has been chosen as the reference protocol to realize the **MAC layer**; only its main aspects are realized. In particular, the transmission of scheduling request messages from MTs has been realized via the *request packets (REQ)* on an ideal out-of-band channel and the transmission of scheduling permission messages from BSs has been realized via the *permission packets (PERM)*. The transmission of WATM cells has been realized in the *uplink* direction by a BS controlled dynamic TDMA-TDD. The scheduling algorithm for the *CBR* connections is of the GCRA type ([1]). Simulator **LLC layer** transmits ATM cells having a non-specified structure (the WATM header, the compressed ATM header and FEC fields are not implemented). The re-transmission SR-ARQ protocol has been implemented via the *reception acknowledge (ACK/NAK)* packet. The lost cell re-transmissions have been implemented with possible different return delays via the parameter fd (*feedback delay*) and possible different error rates of the ACK/NAK packets via the simulator parameter fer (*feedback error rate*).

Among the **network layer** procedures, the *localization management* function has not been realized, while the *admission management* and *handover management* functions have been implemented according to the different bandwidth reservation schemes presented. Signalling protocols to manage the admission and handoff events are reduced to their main form with communication assumptions on an ideal out-of-band channel.

The **simulation parameter** values adopted in the simulated WATM environment are based on the European Project Magic WAND [14, 12].

The parameters of the Markovian two-state channel model cer and abl are the same for all MTs active on the network. The value of the $cer = 10^{-2}$ is equivalent to BER less than 10^{-4} ([7] for more details). The average sojourn time value in a cell is $\bar{\tau_r} = 40$ s. Finally, the radio channel has a transmission capability of 50,000 slot/s per cell, where 1 slot is equivalent to the transmission time of 1 WATM cell (always at 53 bytes), and therefore has a transmission capability of approximately 20 Mbit/s, always analogous to the capability of the Magic WAND prototypes.

Simulations have been executed with a single class of active connections on the network, in order to understand the behavior of the different Cluster CAC schemes; in fact we are focusing on the difference between elementary single-cluster architecture and realistic multiple-clusters architecture and we are not focusing on the multimedia issues that impact on the CAC procedure. The simulated traffic is a real-time ATM Constant Bit Rate traffic (CBR_1) at 32 kbit/s, i.e., a generic low compression voice service.

The most suitable independent parameter to evaluate the performance of the CAC schemes is the new connection request rate, represented by the mean λ_n of single cell Poisson input process $Poi(\lambda_n)$. On a network level the aggregate new connections request rate is the mean $\Lambda_n = 49 \cdot \lambda_n$ sum of the 49 single cell processes (which is the independent parameter Input Rate [reqst/sec] in the graphs). Λ_n is varied in an interval including the significant value $\Lambda_n^{Max} = 49 \cdot \lambda_n^{Max}$ (**maximum nominal rate**), representing the maximum traffic nominally manageable by the network, according to the nominal duration of the connections $\bar{\tau_d} = 1/\mu_d = 40$ s. We can calculate the significant reference value $\Lambda_n^{Max}(CBR_1)$ by the expression: $\Lambda_n^{Max}(CBR_1) = 49 \cdot \frac{B_{BS}/b_{CBR_1}}{\bar{\tau}_{d,CBR_1}} = 685.4$ reqst/s.

5 SIMULATION RESULTS

5.1 MULTIPLE-CLUSTER CAC WITH SINGLE-THRESHOLD (Cl_1)

5.1.1 P_{ncB}, P_{cCD} *vs. Cluster admission Threshold* T_{Cl}

In the graph shown in Figure 2 it is possible to observe the increase in P_{cCD} for increasing T_{Cl} values (from $T_{Cl} = 0.9$ up to the limiting values $T_{Cl} = 1$). It is possible to observe a constant regular increase of the saturation level of P_{cCD} (the bold lines with black squares ■). At the same time a slight decrease of P_{ncB} can be observed in the upper section of the graph for increasing T_{Cl} values. Auxiliary metric $P_{ncAB} = 0$ holds at the limiting value $T_{Cl} = 1$, since the aggregate bandwidth occupied by all the connections active on a cluster is always less than the cluster bandwidth $B_{Cl} = D_{Cl} \cdot B_{BS}$: consequently $P_{ncB} = P_{ncAB} + P_{cCD} - P_{ncAB}P_{cCD} = P_{cCD}$. Namely, the new connection blocking probability converges to the cell dropping probability, as illustrated in the highlighted bold continuous line in the graph of Figure 2.

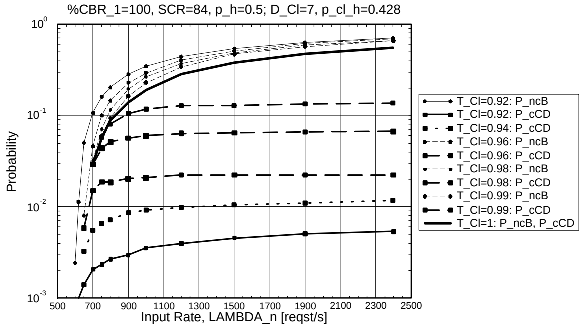

Figure 2: Cl_1 CAC: P_{fcT} vs. T_{Cl}

5.1.2 P_{fcT} *vs. Cluster Dimension* D_{Cl}

In general, an increase of the cluster dimension determines a growth of the cluster bandwidth $B_{Cl} = D_{Cl} \cdot B_{BS}$, on which the CAC procedure executes admission to the cell cluster: statistic multiplexing of the connections is more efficient. Moreover, the probability of executing a cluster hand-off p_{cl-h} decreases (by 25% for cluster sizes from 7 to 16 cells) due to the greater cluster dimensions (the mobiles will remain inside their own cluster for a longer time), which will cause a significant improvement of P_{fcT}. In Figure 3 it is possible to appreciate the decrease of P_{fcT} as D_{Cl} increases. Therefore, by directly reducing p_{cl-h} through a cluster dimension increase, we are able to achieve a P_{fcT} improvement.

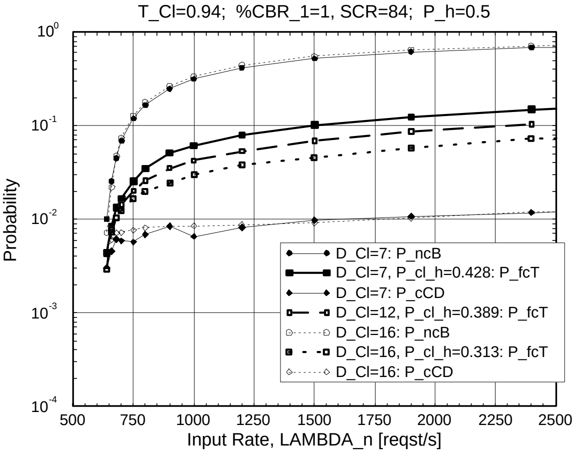

Figure 3: Cl_1 CAC: P_{ncB}, P_{fcT}, P_{cCD} vs. D_{Cl}

We may summarize the following aspects on Multiple-Cluster CAC with Single-Threshold schemes: on the positive side, we can highlight the saturation of P_{cCD} at the desired values as a function of the admission threshold T_{Cl} adopted (see Figure 2); on the negative side, we highlight the relatively high values of P_{fcT} that saturate above 10^{-1}; these values improve by adopting clusters with a greater dimension D_{Cl} even if not to the desired extent (see Figure 3).

5.2 MULTIPLE-CLUSTER CAC WITH DOUBLE-THRESHOLD (Cl_2)

The simplest solution to give admission priority to cluster hand-off connections consists in the adoption of Multiple-Cluster CAC with Double-Threshold scheme. A threshold $T_1 \equiv T_{Cl}$ is used to admit new connections to the clusters and a new threshold $T_2 > T_1$ is defined to admit cluster hand-off connections, so as to achieve $P_{hcAD} \ll P_{ncAD}$ and then reduce P_{fcT} to desired values.

Simulation results of the double threshold scheme are shown in Figure 4. The decrease of P_{fcT} (the curves shown with black squares ■ in the graph) compared with P_{fcT} for the single threshold scheme Cl_1, even if penalized by a slight deterioration of P_{ncB}, is found to be significant even for the threshold values $T_2 = 94.03\%$, $T_2 = 94.06\%$, and $T_2 = 94.09\%$, marginally above the T_1 threshold, set at 94%.

Such an improvement in P_{fcT} is a direct consequence of the decrease in P_{hcAD} generated precisely by the double threshold mechanism and highlighted in the graph of Figure 5.

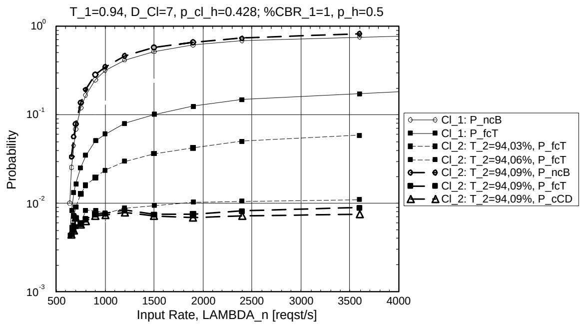

Figure 4: Cl_2 CAC: P_{ncB}, P_{fcT}, P_{cCD} vs. T_2

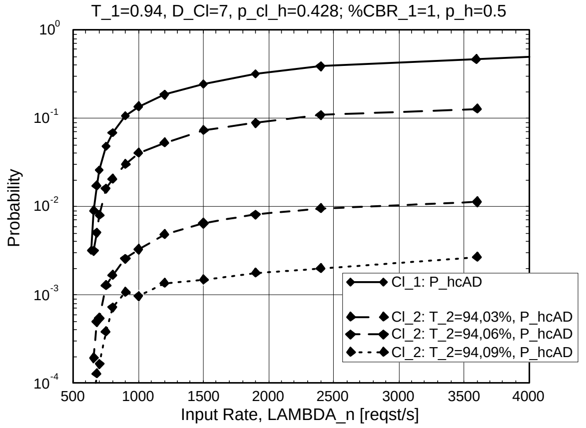

Figure 5: Cl_2 CAC: P_{hcAD}, P_{cCD} vs. T_2

6 CONCLUSIONS

Cell-Cluster based Connection Admission Control analysis has been developed in the framework of cellular networks. In general, Cluster CAC schemes are distributed and make the admission decision exploiting a kind of global information (the traffic on the cell cluster) compared to the strictly local information (the traffic on the cell) exploited by the traditional guard channel schemes. Moreover, Cluster CAC schemes are simple and consequently do not present significant difficulties for their realization. In fact, they are not based on complex algorithms that estimate terminal mobility. They are not dynamically adaptive to the congestion state of the network and therefore do not require complex monitoring procedures. They are not based on dynamic resource assignment to different network cells, which require heavy duty centralized control. Finally, Cluster CAC schemes conform to the structure of cellular networks, since they adapt well to the general architecture of cellular networks. In fact, cellular networks have normally several cells that refer to the same switch, which may be taken as the root of the cell cluster, where the admission procedure is executed before the routing function within the cluster and before the access function to the cell and to the medium (Figure 1).

In the performance analysis carried out in [3, 4, 6] dealing with networks loaded by real-time or data traffic in a proper mix it has been shown how cell cluster schemes are more efficient compared to guard channel schemes (taken as reference schemes) in terms of new connection blocking probability; in fact, executing the admission phase on a cluster of cells they achieve an improved traffic statistic multiplexing. Moreover, it has been shown how cluster admission simultaneously maintains under control the dropping probability (i.e., the access to individual cells) and hence also the forced termination probability at desired target levels.

All these works have been performed on a single-cluster architecture which does not consider hand-off events between different confining clusters. In this work we have developed the study of cluster schemes on more realistic multiple-cluster architecture.

We have shown how Cluster CAC schemes continue to operate well after a more realistic analysis based on a multiple-cluster architecture: cell dropping probability and forced termination probability saturate at desired target levels, by only giving priority to cluster hand-off connections compared to new connections. In fact, Cluster CAC schemes with double-threshold, besides having better new connection blocking probability due to *cluster admission* and maintaining *cell access* drop probability under control, are able to decrease cluster hand-off admission failure (with an appropriate second threshold) and consequently succeed in decreasing the forced termination probability.

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