A Novel and Intelligent Call Admission Control Scheme using Simulated Annealing

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Abstract—**Next Generation Wireless Systems (NGWS) is expected provide a variety of services to mobile users, including high-speed data and real-time multimedia services. In order to realize this objective, there are several challenges posed by heterogeneous wireless networking environments within NGWS. Among these challenges, a unified handoff management is one of the key issues to support global roaming of mobile users among different network architectures. In this paper, a new call admission control scheme, Simulated Annealing-based Call Admission Control (SA_CAC), is proposed for NGWS. The SA_CAC scheme applies simulated annealing algorithm to achieve high network utilization, minimum cost, minimum handoff latency and to guarantee QoS requirements. A Markov Decision model is developed to derive the optimality equations for best performance with the minimum cost. The simulated annealing algorithm optimizes these equations for the final handoff decision. Performance analysis is provided to assess the efficiency of the proposed SA_CAC scheme. Simulation results show a significant improvement in handoff latencies and costs over the heuristic approach and other call admisson control (CAC) schemes.**

Index Terms—**Next Generation Wireless Systems, Call Admission Control, handoff management, Simulated Annealing, Markov Decision Model.**

I. Introduction

Next Generation Wireless System (NGWS) will realize the objective of a wide range of services including high-speed data and real-time applications to mobile users. The mobile user will be able to communicate through different wireless networking architectures and to roam within these architectures [1]. Hence, there is a need for a unified handoff management scheme, which can address admission control as well as architectural heterogeneities for roaming mobile users. Intelligent algorithms are an efficient way of solving this problem.

Among the various artificial intelligence techniques, simulated annealing (SA), which is a probabilistic search method, have been used in a wide variety of optimization tasks, including numerical optimization and combinatorial optimization problems as well as admission control in wireless systems. The advantage of using simulated annealing is its ability to operate with large-scale problems and its robustness towards achieving local optima convergence [7], [10]. There are several schemes proposed for admission control issue using SA for specific wireless network architectures [4], [9]. Although these schemes are promising, they do not specifically consider admission control policies as a means to provide a unified scheme for maximum network utilization, minimum handoff latency, and QoS. The recently proposed admission control scheme, genetic-based admission control scheme (GAC) provides such a unified solution using genetic algorithms (GAs) [5]. However, this scheme can also be improved using different artificial intelligent techniques in terms of handoff latency, cost and providing certain level of QoS requirements.

In this paper, SA algorithm is applied to the call admission control (CAC) scheme to achieve the best performance with low cost and low handoff latency. The SA_CAC also achieves near-linear speed-up and better performance than GAC. The objective of the scheme is to achieve maximum wireless network utilization while satisfying the mobile terminal's QoS requirements and significantly reduce handoff latency. To fulfill this objective, the bandwidth and power requirements of the channel, as well as the signaling and switching parameters of the wireless architecture are captured in the handoff algorithm. These parameters are fed into a cost function developed based on the Markov Decision Process, which is then optimized using SA. As a result, the algorithm determines which network architecture the mobile terminal would complete handoff with respect to the minimum cost.

The remainder of the paper is organized as follows: The modeling and analysis of the SA_CAC scheme is presented in Section II. The overall system solution is given in Section III. The performance of the scheme along with the effects of the SA_CAC algorithm on the network performance and latency are then discussed in Section IV. Conclusions are provided in Section V.

II. Modelling and Analysis

Dynamic factors should be considered for effective network resources usage. There are different constraints such as bandwidth, latency and power consumption of the network. Let each state in the final action of the Markov Decision Process [11] represent different wireless network architecture. The collection of these states consists different wireless architectures.

$$\begin{aligned} Cost\ function &\Rightarrow (Real\ Cost)_N \\ &= \mathcal{F}(Bw_N, Pw_N, Sig_N, Sw_N) \quad (1) \end{aligned}$$

where

Bw is bandwidth of the network,
Pw is the power consumption of the network,
Sig is the signaling to set-up a handoff,
Sw is the switching, rerouting of traffic during the handoff, and
N is the index, $N = 1...n$ where n is the number of different wireless architectures.

The set of actions is basically the call admission decisions for the corresponding mobile terminals. It can be 1 for "accept" or 0 for "reject". The set of actions can be defined as a binary decision variable.

Each parameter in the cost function depends on the wireless network architecture in the system. Power consumption cost, Ψ_{Pw} is fixed with a coefficient such as

$$\Psi_{Pw}(N) = c_{Pw} \tag{2}$$

The bandwidth cost ψ_{Bw} is assumed that it depends linearly on the overall capacity of the network architecture and inversely with the available capacity as follows

$$\psi_{Bw}(N) = c_{Bw} \cdot \frac{C_N}{C(t)} \tag{3}$$

where C_N is the total capacity of the channel of the network and $C(t)$ is the available capacity of the channel at time t. t is the time of the handoff (i.e. if the available capacity of resource is C_N for the corresponding network architecture, then the cost will be only the bandwidth coefficient). c_{Bw} is the bandwidth cost coefficient per capacity.

Both signalling and rerouting cost coefficients change with respect to the next network architecture that the handoff occurs. Hence, the network decision function can be defined as

$$f_N(N_c, N_x) = \begin{cases} 0 & , N_c = N_x \\ 1 & , N_c \neq N_x \end{cases}$$

where N_c is the current network and N_x is the next network, which the mobile terminal would roam. $f_N(N_c, N_x)$ determines whether the next cell, where the mobile terminal roams, is the same network or not.

$$\Psi_{Sig}(N) = c_{Sig}[1 + f_N(N_c, N_x)] \tag{4}$$

$$\psi_{Sw}(N) = \sum_{1}^{\delta} c_{Sw}[1 + f_N(N_c, N_x)] \tag{5}$$

where c_{Sig} and c_{Sw} are the signalling and switching cost coefficients respectively, and δ is the number of connections.

The states in the theory would represent each different network architecture for the proposed solution [11]. The cost functions for the Markov Decision Process (MDP) theory have been defined above. The optimization objective is to find a policy π^* such that

$$\nu^{\pi^*}(N) = \inf_{\pi \in \Pi} \nu^{\pi}(N) \tag{6}$$

The optimization problem is formulated using Continuous Time Markov Decision Process (CTMDP). The optimal decision policy can be found by solving the related optimality equations for each network architecture in the system [11]. We assume that the handoff requests arrive according to a Poisson process with rate λ and the request durations are exponentially distributed with rate μ. The optimality equations can be written as

$$\nu(N) = \min_{a \in A} \left\{ r(N,a) + \left(\frac{\lambda + \mu}{\lambda + \mu + \alpha}\right) \sum_{j \in N} p(j|N,a)\nu(j) \right\} \tag{7}$$

where $r(N, a)$ is the cost expectation of a handoff between two cells, $0 \leq \alpha < 1$ is discount factor and $p(j|N, a)$ is the state transition probability that the system occupies state (network) j at the subsequent decision, given that the system is in state (network) N at the earlier decision and action a is chosen.

After deploying the cost expectation, $r(N, a)$ and state transition probabilities, the final optimality equations are given for $j = 0$ and $j = i + 1$ respectively as follows

$$\begin{aligned} \nu(N) &= min\Big\{c_{Sig}\big[1 + f_N(N_c, N_i)\big] + c_{Pw} + \\ &+ \Big[\frac{\frac{c_{Bw}.C_N}{C(t)} + \sum_1^{\delta} c_{Sw}\big[1 + f_N(N_c, N_i)\big]}{(\alpha + \lambda + \mu)}\Big] + \\ &+ \big(\frac{\lambda + \mu}{\alpha + \lambda + \mu}\big)\big(\frac{\mu}{\mu + \lambda}\big)\Big\} \ for\ i = 0, \end{aligned} \tag{8}$$

$$\begin{aligned} \nu(N) &= min\Big\{c_{Sig}\big[1 + f_N(N_c, N_i)\big] + c_{Pw} + \\ &+ \Big[\frac{\frac{c_{Bw}.C_N}{C(t)} + \sum_1^{\delta} c_{Sw}\big[1 + f_N(N_c, N_i)\big]}{(\alpha + \lambda + \mu)}\Big] + \\ &+ \big(\frac{\lambda + \mu}{\alpha + \lambda + \mu}\big)\big(\frac{\lambda}{\mu + \lambda}\big)\Big\} \ for\ i > 0, \end{aligned} \tag{9}$$

where c_{Sig}, c_{Pw}, c_{Bw}, c_{Sw} are the signalling, power consumption, bandwidth and switching cost coefficients respectively, δ is the number of connections, $f_N(N_c, N_i)$ is the network decision function, N_c is the current, N_x is the next network, C_N is the total capacity of the channel of the network and $C(t)$ is the available capacity of the channel at time t.

These optimality equations for the values of $\nu^*(N)$ is then optimized using the simulated annealing in order to determine the final handoff decision. The numerical analysis is provided in Section IV.

III. SA_CAC: Simulated-Annealing Based Call Admission Control

A. System Solution

Different wide area types of wireless networks (i.e. 3G-pico, 3G-micro, 3G-macro, Satellite-LEO, Satellite-GEO) and WLAN networks exist in a typical urban scenario deployed by several service providers. Both wireless network architectures should be networked to each other in order to realize the inter-system handoff in the NGWS. This can be done in a way that, these wireless systems, heterogeneous architectures are connected to one another through a third party interconnection gateway system such as proposed in [3]. As given in the literature, gateway architecture, Network Mobility Gateway (NMG) proposed in [3] is also an example architectural element of the NGWS in our paper. NMG gateway sits in the Internet as shown in Fig. II.

NMG is capable of managing the handoffs among these different wireless network systems. The proposed SA_CAC scheme takes its place in this step of the system. It is deployed in NMG to manage all handoff management issues. For the inter-system mobility management, all of the controllers of the network architectures, base transceiver station (BTS), access point (AP), radio network controller (RNC) and fixed earth station (FES) are involved. These controllers propagate their system control and signaling messages through NMG. NMG propagates the messages needed for the functioning of the algorithm to SA_CAC itself. These messages consist of all the information of the wireless system related to the mobility management. This information is used by SA_CAC to evaluate the minimum total cost for each available wireless system at the same area of the corresponding mobile terminal. Then, the scheme determines which cell and which network

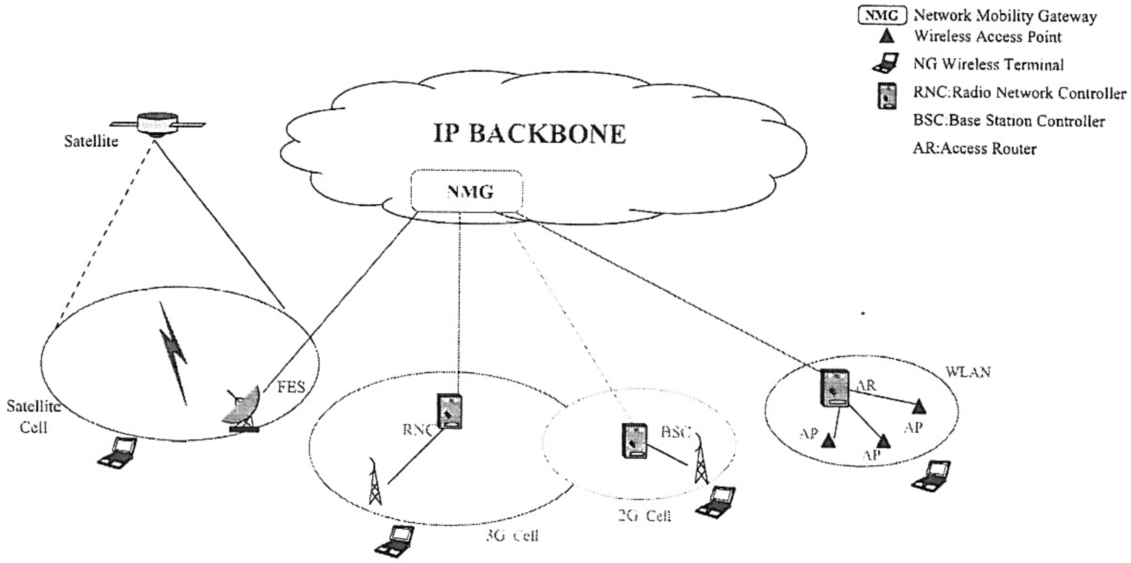

Fig. 1. Next Generation Wireless System Architecture.

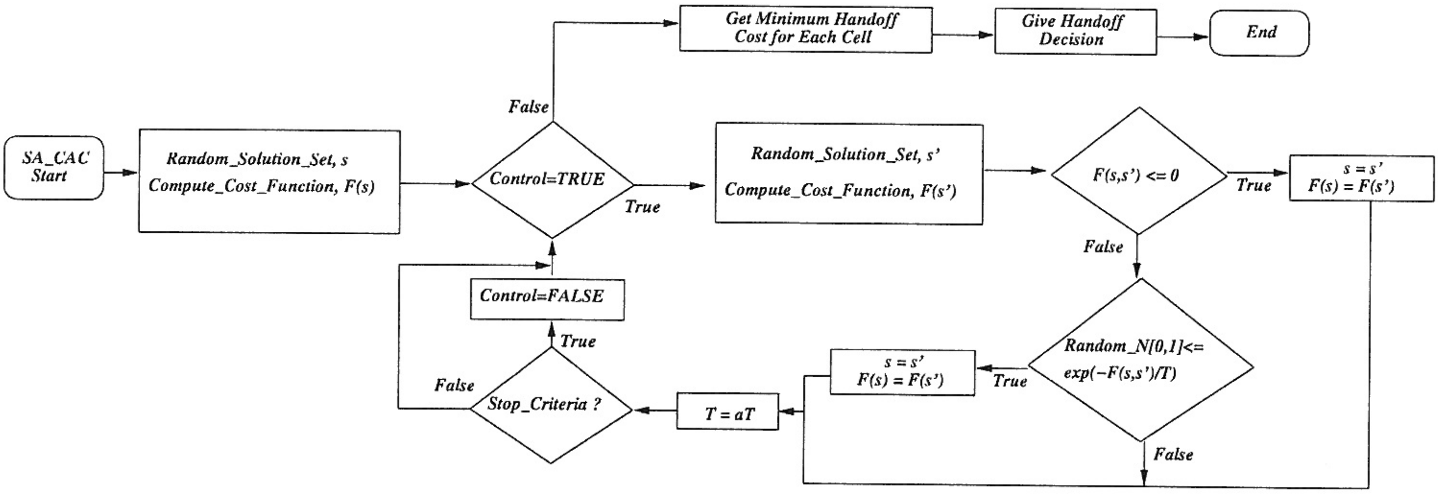

Fig. 2. SA_CAC operation flowchart.

architecture has the minimum total cost via implementing SA. The objective of using SA is to find the minimum cost for the wireless network system to provide maximum network utilization and minimum handoff latency and to fulfill QoS requirements. SA_CAC then informs NMG about the handoff decision. Accept or reject action is then deployed after the propagation of the decision to NMG.

B. Simulated Annealing

The simulated annealing (SA) algorithm is developed based on the annealing technique of the metals in chemistry. The implementation of CAC algorithm using simulated annealing (SA_CAC) is based on simple "stepped geometric decrease" type algorithm. Simulated annealing is a method of local searching algorithm, which sample the whole domain and improve the solution by recombination of the population in some form. Hence, the simulated annealing algorithm converges in faster manner for the optimization problems [10].

The simulated annealing algorithm first randomly initializes a set of solution. Then, it considers a neighboring value and evaluates its cost function for optimization. If the cost function for the neighboring value is reduced, the search moves to that point as a new solution and the process is repeated. However, if the cost function increases, the move to the neighbor point is not necessarily rejected; there is a small probability, p, that the search will move to the neighbor point and continue. The probability is a function of the change in the cost function, ΔE and a temperature parameter, T.

$$p = e^{\frac{-(\Delta E)}{T}} \tag{10}$$

The algorithm starts at a chosen temperature T, and runs for L steps with the same temperature. The temperature decreases at a constant factor, $a < 1$ with each iteration. The algorithm stops if there is no significant change in the cost function after number of steps. The completed SA_CAC flow-chart showing the detailed operation of the scheme is presented in Fig. 2.

IV. Performance Analysis

This section demonstrates the performance of SA_CAC scheme with some simulations and comparison with other

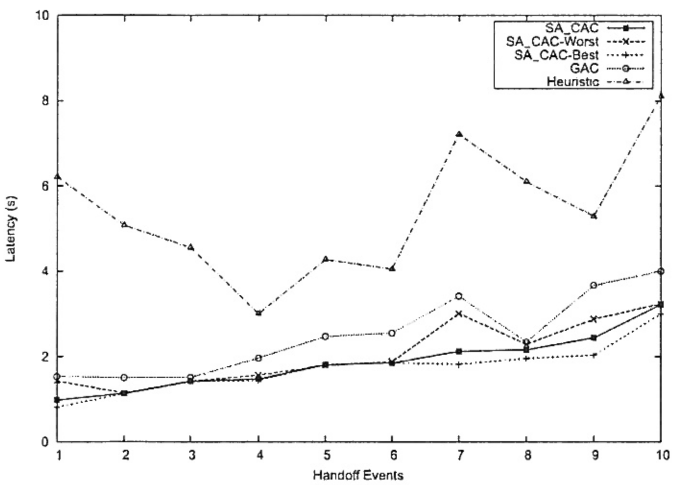

Fig. 3. The call admission control latency experienced with the SA_CAC scheme, traditional GAs and heuristic algorithm for varying handoff scenarios (T=50).

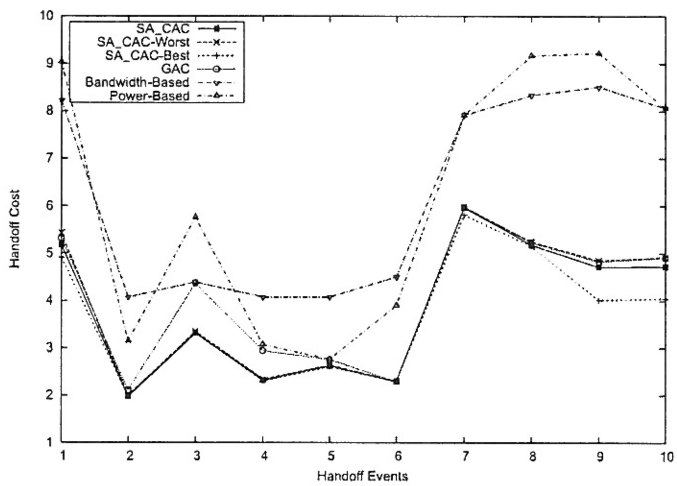

Fig. 4. Handoff cost experienced with the SA_CAC scheme, traditional GAs, bandwidth-based and power-based schemes for varying handoff scenarios (T=50).

algorithms. The performance is compared with the heuristic algorithm and other previously proposed CAC schemes.

In order to investigate the performance, SA_CAC is deployed for various handoff scenarios. These scenarios are shown in Table I. The simulation experiments are performed with the initial temperature, $T = 50$, temperature decrease factor, $a = 0.9$, number of steps for each iteration, $L = 100$, number of steps for the stopping criteria, $st = 10$ and the percentage decrease, $\varphi = 0.1$ unless otherwise specified. The algorithm stops if the objective cost function is decreased by less than φ percent for a number of steps of consecutive iterations of L steps. The other parameter values related to the final optimality function which determine the final cost coefficient values are shown in Table II. Sat_L represents Satellite LEO, Sat_G represents Satellite GEO, $3G_p$ represents $3G$ pico, $3G_p$ represents $3G_\mu$ micro, $3G_m$ represents $3G$ macro and WLAN represent wireless LAN networks in the table. These values are also used in the simulations of previously proposed wireless schemes [12], [13].The simulation experiments demonstrate the performance analysis of SA_CAC scheme with respect to handoff latency, cost and QoS.

The first simulation is designed to show the handoff latency performance of SA_CAC scheme over heuristic and traditional GAs based CAC schemes for various handoff scenarios in different wireless system architectures. As shown in Fig. 3, SA_CAC algorithm improves the handoff latency significantly compared to the other algorithms.

The second simulation is designed to show how the proposed scheme using simulated annealing utilizing network resources efficiently and finds the minimum handoff cost over other proposed admission control schemes. The experiments are performed for varying handoff scenarios as shown in Table I. For this case, the SA_CAC scheme is compared with different admission control algorithms based on available bandwidth and power consumption [2], [6]. The handoff cost also demonstrates the network resource usage while determining which wireless network architecture the mobile terminal should perform the handoff.

As shown in Fig. 4, for each handoff scenario, the total handoff cost using the SA_CAC scheme is much less than other algorithms. In one or two cases, the results are similar with the other schemes. This happens when there are similar wireless network systems around the corresponding MT.

Another critical requirement for NGWS is to provide a certain QoS level for the mobile terminal. This includes a successful connection admission percentage for a large number of terminals. This experiment is designed to illustrate how the SA_CAC scheme provides the required QoS level for different types of wireless network architectures and for an increasing number of terminals.

For this experiment, it is assumed that there are five different cells in the coverage area of the mobile terminal. These are $3G_p, 3G_\mu, Sat_L, WLAN\ and\ Sat_G$ with 100% available capacity at the start of the simulation and available for the mobile terminals. The results are shown in Fig. 5. In each iteration, the number of mobile terminals is increased by 50.

As demonstrated in Fig. 5, the scheme using simulated annealing is able to accommodate a higher number of MTs with greater admission percentages over other algorithms and the scheme using genetic algorithms. It is expected that as the number of roaming MTs increase, the percentage will decrease. However, even under such circumstances, the SA_CAC scheme still improves the admission percentage compared to other schemes.

V. Conclusions

Since there is no any admission control scheme in the literature that provides a single solution to address the heterogeneous architectures in the Next Generation Wireless System, SA_CAC scheme realizes this objective in a perfect sense. In order to develop a system solution, a Markov Decision model is deployed to derive the necessary equations for the best network performance with minimum cost. Then, the fast, reliable and accurate artificial intelligence technique, simulated annealing algorithm is used to optimize these equations and to provide high network utilization, minimum cost, minimum handoff latency and required QoS level with better performance than the other admission control schemes.

Experimental results show that SA_CAC scheme achieves very efficient resource utilization and low handoff latencies and costs in different heterogeneous wireless architectures. The scheme is shown to significantly improve resource utilization with very low handoff latency and very low cost over different previously proposed admission control schemes.

TABLE I

SIMULATION EXPERIMENTS OF DIFFERENT HANDOFF SCENARIOS FOR ROAMING AMONG HETEROGENEOUS WIRELESS ARCHITECTURES.

Scenario #	(N_1, N_2, N_3, N_4)	$(Av_{BW1}, Av_{BW2}, Av_{BW3}, Av_{BW4})$
1	$(3G_p, Sat_G, Sat_L, -)$	(70%,30%,40%,-)
2	$(3G_p, 3G_m, 3G_\mu, -)$	(50%,50%,50%,-)
3	$(WLAN, 3G_m, 3G_p, Sat_L)$	(20%,30%,40%,90%)
4	$(Sat_L, Sat_G, 3G_m, 3G_m)$	(100%,50%,50%,80%)
5	$(3G_\mu, WLAN, WLAN, Sat_G)$	(60%,30%,10%,60%)
6	$(3G_p, 3G_\mu, WLAN, -)$	(50%,80%,10%,-)
7	$(Sat_G, 3G_m, WLAN, -)$	(65%,55%,45%,-)
8	$(3G_m, 3G_\mu, Sat_L, WLAN)$	(50%,10%,80%,5%)
9	$(3G_p, 3G_m, Sat_L, -)$	(40%,50%,75%,-)
10	$(Sat_G, Sat_L, 3G_\mu, -)$	(75%,50%,25%,-)

TABLE II

COST COEFFICIENT PARAMETERS USED FOR THE FINAL OPTIMALITY EQUATION.

Coeff.	Sat_L	Sat_G	$3G_p$	$3G_\mu$	$3G_m$	WLAN
c_{sig}	(1,5)	(1,5)	(1,5)	(1,5)	(1,5)	(1,5)
$c_{pw}(W)$	(2,10)	(2,10)	(0.01,0.05)	(0.01,0.05)	(0.01,0.05)	(0.04,0.25)
$c_{bw}(\frac{1}{bw})$	(1.5,45)	(7.5,45)	(0.6,4.3)	(4.3,7.5)	(7.5,45)	(0.01,0.5)
c_{sw}	(1,5)	(1,5)	(1,5)	(1,5)	(1,5)	(1,5)

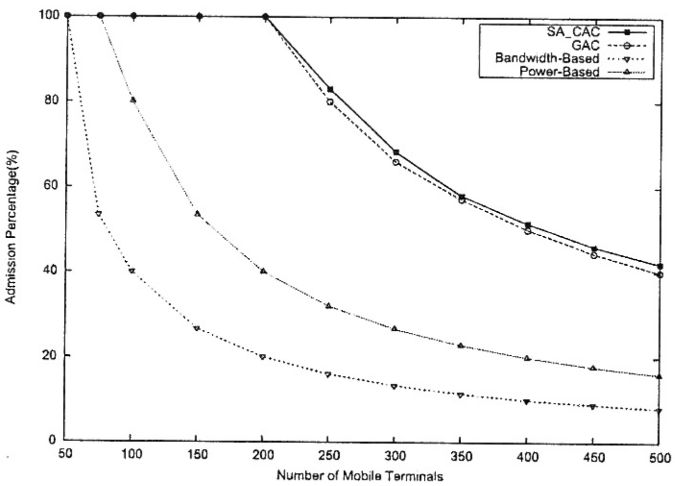

Fig. 5. Connection admission percentage experienced with the SA_CAC, traditional GAs, bandwidth-based and power-based schemes for varying number of mobile terminals (T=50).

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