Call Admission Control for Mobile Agent Based Handoff in Wireless Mesh Networks

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***Abstract*—In wireless mesh network (WMN), it is important to provide an efficient handoff scheme, due to the frequent user mobility. To address this issue, we propose a mobile agent (MA) based handoff approach, where each mesh client has a MA residing on its registered mesh router. To guarantee quality of service (QoS) and achieve differentiated priorities during the handoff, we develop a proportional threshold structured optimal effective bandwidth policy for call admission control (CAC) on the mesh router. Simulation study shows that our proposed CAC scheme can obtain satisfying tradeoff between differentiated priorities and statistical effective bandwidth in WMN handoff environment.**

I. INTRODUCTION

One of the most important issues in the design of wireless mesh network (WMN) [1], [2] is how to efficiently support mesh client handoff among different mesh routers, since wireless users in WMN are free to move to anywhere at anytime. To address this issue, we propose a mobile agent (MA) based handoff approach for WMN. In this approach, each mesh client has a MA residing on the attached mesh router. If a mesh client moves to a new location and changes its mesh router, the mobile agent migrates as well. Particularly, if the mesh client intends to make a handoff, the client MA will move to the new mesh router beforehand and pre-setup a new communication channel for the handoff call. Then, the mesh client will accomplish the handoff process and use the new channel to resume the call.

For the MA based handoff in WMN, it is very important to employ the call admission control (CAC) mechanism in the mesh router. First, call admission control is a critical step for the provision of QoS guaranteed service because it can prevent the system capacity from being overused. Second, call admission control can give handoff calls higher priority than new calls.

In this paper, we develop a proportional threshold structured optimal effective bandwidth policy for CAC on the mesh router, which adopts threshold structure and gives handoff calls and new calls different priorities. Since it is intractable to exactly locate this policy, genetic algorithm (GA) will be utilized as the fast computational approach to achieve a near-optimal solution. Moreover, the performance of our proposed CAC scheme is evaluated by extensive analysis and simulation study.

The rest of the paper is organized as follows. We first introduce the WMN handoff challenges in Section II. We then propose a mobile agent based handoff approach in Section III. In Section IV, we develop a proportional threshold structured optimal effective bandwidth policy as well as the corresponding GA approximation scheme. In Section V, we evaluate the performance of our proposed CAC scheme in WMN handoff environment through simulation study. In the end, Section VI concludes the paper.

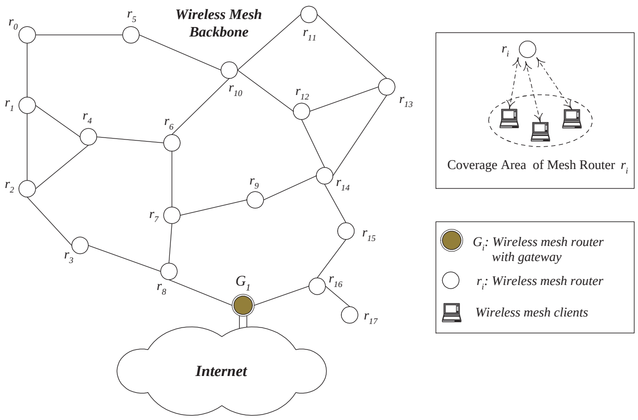

Fig. 1. An example of wireless mesh network.

II. HANDOFF CHALLENGES IN WIRELESS MESH NETWORK

As shown in Fig. 1, a WMN consists of two types of nodes: mesh routers and mesh clients. The mesh routers form an infrastructure of mesh backbone for mesh clients. In general, mesh routers have minimal mobility and operate just like a network of fixed routers, except being connected by wireless links through wireless technologies such as IEEE 802.11. We can observe from Fig. 1 that, the WMN can access the Internet through a gateway mesh router, which is connected to the IP core network with physical wires.

In WMN, every mesh router is equipped with a traffic aggregation device (similar to an 802.11 access point) that interacts with individual mesh clients. The mesh router relays aggregated data traffic of mesh clients to and from the IP core network. Typically, a mesh router has multiple wireless interfaces to communicate with other mesh routers, and each wireless interface works on one wireless channel.

Mesh clients achieve Internet access through mesh routers.

Handoff is indispensable for connection continuity, as a mesh client moves from the range of one mesh router to that of another. Ideally, the handoff should be completely transparent to mesh clients. That is, there should be no interruption in network connectivity, and the communication protocols involved should follow the standards deployed in regular wireless devices. In this paper, we define a WMN that offers above handoff function as seamless handoffed WMN.

While cellular networks solve the handoff problem [3] using signaling embedded in their low-level protocols, there are only limited studies on efficient seamless handoff in IEEE 802.11 based WMN. Most WMNs today require specially modified clients to transfer connectivity from one mesh router to another. Even though some of them give the appearance of continuous connectivity to a roaming client, the handoff delays can be as long as several seconds [4]. This delay is too long for real-time applications, such as interactive voice over IP or video conferencing.

This paper develops an MA based handoff scheme, which offers seamless and fast handoff to support VoIP and other real-time applications. In our new scheme, all the handoff and re-routing logics is done solely by the MA, and only standard MAC and IP protocols are used. Therefore, it is compatible with any 802.11 mobile device that supports DHCP regardless of the vendor or architecture. The entire mesh network is seen as a single and omnipresent access point, which gives the mobile clients the illusion that they are stationary.

III. MOBILE AGENT BASED HANDOFF IN WMN

A. Introduction to Mobile Agent

A mobile agent is an executing program that can migrate during execution from machine to machine in a heterogeneous network. In other words, the agent can suspend its execution, migrate to another machine, and then resume execution on the new machine from the point at which it left off. On each machine, the agent interacts with stationary agents and other resources to accomplish its task.

Mobile agents have several advantages in distributed information-retrieval applications. By migrating to an information resource, an agent can invoke resource operations locally, eliminating the network transfer of intermediate data. By migrating to the other side of an unreliable network link, an agent can continue executing even if the network link goes down, making mobile agents particularly attractive in mobile-computing environments. Most importantly, an agent can choose different migration strategies depending on its task and the current network conditions, and then change its strategies as network conditions change.

There are many mobile agent platforms currently existing, such as Aglets from IBM, Voyager from Recursion Software, Jumping Beans from Jumping Beans Inc., and so on [5]. It is an appropriate approach to deploy mobile agents in mobile ad hoc network and WMN, because they share the nature of "mobility". We outline below the solution of seamless handoff for WMN.

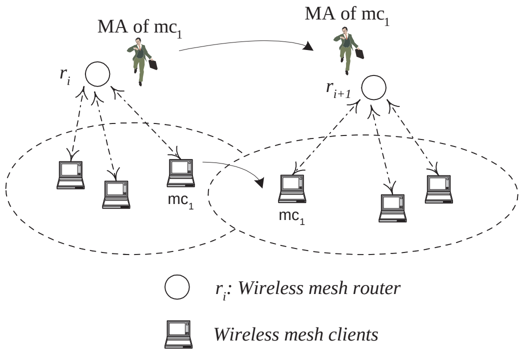

Fig. 2. Mobile agent based handoff in WMN.

B. Mobile Agent Based Handoff

To provide seamless handoff, we apply mobile agent technology to WMN. As shown in Fig. 2, in our solution each mesh client is assigned a "client MA". The mesh client places its client MA in the mesh router that it registers with. If the mesh client moves from the range of one mesh router to that of another mesh router, the client MA migrates too.

We study the scenario that a mesh client moves from the range of one mesh router to that of another mesh router during a call. When a mesh client intends to handoff, it will inform its current mesh router first. Then the current mesh router transfers the client MA of handoff mesh client to the mesh router in neighborhood. To achieve seamless handoff, the client MA will pre-setup a substitute session channel on the new mesh router. The session channel pre-setup usually involves resource reservation, network layer rerouting, and so on. Once the new session channel is established, the mesh client will be notified to accomplish the handoff process and resume the call on new channel.

In this paper, we assume that Session Initiation Protocol (SIP) is deployed in WMN to support QoS guaranteed multimedia communication. This assumption is motivated by the fact that many researchers advocate SIP as a feasible signalling solution for VoIP applications [6] and SIP has been selected as the call control protocol for 3G IP-based mobile networks. Specifically, we suppose the client MA in Fig. 2 is equipped with a SIP signaling module to support call handoff.

IV. CALL ADMISSION CONTROL SCHEME FOR WMN HANDOFF

It is a challenging task to provide mobile users with QoS guaranteed service, especially when the traffic load in WMN is heavy. Many researchers believe that CAC plays a critical role to overcome this challenge. Traditionally, CAC aims to maximize the number of admitted sessions or the amount of effective bandwidth while guaranteeing their QoS requirements. However, in WMN handoff environment we have to consider the issue of differentiated priorities as well. That is, handoff calls have to be given more preference than new calls in the CAC process, since users are much more sensitive to call dropping than to call blocking.

In the rest of this section, we design a proportional threshold structured optimal effective bandwidth policy, which adopts threshold structure to implement CAC, gives handoff calls and new calls different priorities, and offers high effective bandwidth.

A. System Model

A system model for the CAC in handoffed WMN can be formulated as follows. We assume there are M classes of traffic loads in the network. On a given mesh router, all the traffic loads share the overall B units of physical access bandwidth, and each class of traffic load consists of both new calls and handoff calls. With regard to the class i traffic, we assume that

(1) the requests arrive from a random process with an average rate λ_i^{nw} for new calls and λ_i^{hf} for handoff calls;

(2) the average connection holding time is $1/\mu_i^{nw}$ seconds for new calls and $1/\mu_i^{hf}$ seconds for handoff calls;

(3) the bandwidth requirement of a connection are fixed to $b_i^{nw} = b_i^{hf} = b_i$, where b_i^{nw} and b_i^{hf} represent the bandwidth requirements of class i new call and handoff call respectively;

Then, the CAC on mesh router is responsible to accept or reject connection requests based on the state information, the type of connections (new call or handoffed call), and the QoS requirements of connections.

Let the bandwidth requirement vector be

$$\begin{aligned}\vec{b} &= (b_1, b_2, ..., b_M, b_{M+1}, b_{M+2}, ..., b_{2M}) \\ &= (b_1^{nw}, b_2^{nw}, ..., b_M^{nw}, b_1^{hf}, b_2^{hf}, ..., b_M^{hf})\end{aligned}, \tag{1}$$

the traffic intensity vector be

$$\begin{aligned}\vec{\rho} &= (\rho_1, \rho_2, ..., \rho_M, \rho_{M+1}, \rho_{M+2}, ..., \rho_{2M}) \\ &= (\frac{\lambda_1}{\mu_1}, \frac{\lambda_2}{\mu_2}, ..., \frac{\lambda_M}{\mu_M}, \frac{\lambda_{M+1}}{\mu_{M+1}}, \frac{\lambda_{M+2}}{\mu_{M+2}}, ..., \frac{\lambda_{2M}}{\mu_{2M}}) \\ &= (\rho_1^{nw}, \rho_2^{nw}, ..., \rho_M^{nw}, \rho_1^{hf}, \rho_2^{hf}, ..., \rho_M^{hf}) \\ &= (\frac{\lambda_1^{nw}}{\mu_1^{nw}}, \frac{\lambda_2^{nw}}{\mu_2^{nw}}, ..., \frac{\lambda_M^{nw}}{\mu_M^{nw}}, \frac{\lambda_1^{hf}}{\mu_1^{hf}}, \frac{\lambda_2^{hf}}{\mu_2^{hf}}, ..., \frac{\lambda_M^{hf}}{\mu_M^{hf}}),\end{aligned} \tag{2}$$

and the system state vector be

$$\begin{aligned}\vec{n} &= (n_1, n_2, ..., n_M, n_{M+1}, n_{M+2}, ..., n_{2M}) \\ &= (n_1^{nw}, n_2^{nw}, ..., n_M^{nw}, n_1^{hf}, n_2^{hf}, ..., n_M^{hf}),\end{aligned} \tag{3}$$

where n_i^{nw} and n_i^{hf} are the numbers of class i new calls and handoff calls on the mesh router respectively. We define the ith traffic load as the traffic load characterized by parameter set (b_i, ρ_i, n_i). Clearly, the ith traffic load belongs to new call traffic if $1 \le i \le M$, belongs to handoff traffic if $M+1 \le i \le 2M$. Moreover, both the ith and $M+i$th traffic loads are categorized into class i traffic.

Based on above discussions, we can further define Ω_{CS} as the set of all possible system states, which can be expressed as $\Omega_{CS} = \{\vec{n} | \vec{n} \cdot \vec{b} \le B\}$. Under this definition, the subscript CS stands for “complete sharing”, which means that an incoming connection will be accepted if sufficient bandwidth resources are available in the system. We can now define a CAC policy, denoted by Ω, as an arbitrary subset of Ω_{CS}. Given Ω, a connection request will be accepted if and only if the system state vector remains in Ω after the connection being accepted.

B. Proportional Threshold Structured Optimal Effective Bandwidth Policy

1) Requirement of Differentiated Priority: Call admission control for high-speed wired networks has been intensively studied in previous works [7], [8]. Due to user mobility, CAC becomes much more complicated in wireless networks. An accepted call that has not completed in the range of current mesh router may have to be handed off to another mesh router. During the process, the call may not be able to gain a session channel in the new mesh router to continue its service because of the limited resource in WMN, and this will lead to the call dropping. Thus, the new calls and handoff calls have to be treated differently in terms of resource allocation. In other words, handoff calls are usually assigned higher priority over the new calls, since users tend to be much more sensitive to call dropping than to call blocking.

2) Requirement of Maximal Statistical Effective Bandwidth: In general, mesh clients want to maximize the network throughput and have the Internet access of broadest bandwidth. Therefore, they prefer a CAC policy that has the maximal *statistical effective bandwidth*. For a given CAC policy Ω, we define the statistical effective bandwidth that it can achieve as

$$B_E(\Omega) = \sum_{\vec{n} \in \Omega} (\vec{n} \cdot \vec{b}) P_\Omega(\vec{n}), \tag{4}$$

where $P_\Omega(\vec{n})$ is the steady state probability that the system is in state $\vec{n}$.

It is noted that, if a policy Ω satisfies the coordinate convex condition and the arrival and service processes are both memoryless, then $P_\Omega(\vec{n})$ can be calculated by (as shown in [9])

$$P_\Omega(\vec{n}) = \frac{1}{G(\Omega)} \prod_{i=1}^{2M} \frac{\rho_i^{n_i}}{n_i!}, \qquad \vec{n} \in \Omega \tag{5}$$

where

$$G(\Omega) = \sum_{\vec{n} \in \Omega} \prod_{i=1}^{2M} \rho_i^{n_i} / n_i! \tag{6}$$

and $\mu_1^{nw} = \mu_1^{hf}$.

Moreover, the blocking probability of the ith traffic load $(1 \le i \le 2M)$ is

$$Pb_i(\Omega) = \frac{G(\Omega_i^b)}{G(\Omega)}, \tag{7}$$

where $\Omega_i^b = \{\vec{n} | \vec{n} \in \Omega \ \&\ \vec{n} + \vec{e}_i \notin \Omega\}$ and $\vec{e}_i$ is a $2M$-dimension vector of all zeros except its ith element, which is one.

3) Tradeoff Between Differentiated Priorities and Maximal Statistical Effective Bandwidth: As stated above, handoff requires differentiated priorities while mesh clients requires maximal statistical effective bandwidth. To balance above two requirements, we propose a proportional threshold structured optimal effective bandwidth policy. This policy adopts proportional threshold structure, which can be defined in two steps. In the first step, we apply threshold vector $\vec{N}_{th} = (N_1^{th}, N_2^{th}, ..., N_M^{th}, N_{M+1}^{th}, N_{M+2}^{th}, ..., N_{2M}^{th})$ where $N_i^{th} \leq B/b_i$ as the upper bound to system state vector $\vec{n}$, so that $n_i \leq N_i^{th}$ $(i = 1, 2, ..., M, M+1, ...2M)$. In the second step, to give handoff calls more priority than new calls, we introduce the following proportional threshold constraint

$$N_i^{th} = \min\{B/b_i, x\frac{\rho_i}{\rho_{M+i}}N_{M+i}^{th}\} \qquad (i = 1, 2, ..., M), \tag{8}$$

where $0 \leq x \leq 1$ is the proportional factor.

Once x is determined by the network administrator, there are a set of proportional threshold structured policies, and each policy is associated with a certain threshold vector $\vec{N}_{th}$. Then, the proportional threshold structured optimal effective bandwidth policy is the proportional threshold structured CAC policy that produces maximal statistical effective bandwidth.

C. Genetic Algorithm for Near-Optimal Solutions

Any proportional threshold structured CAC policy can be determined by and only by the second half of threshold vector $\vec{N}_{th}$, which is denoted by $\vec{N}_{th}^{hf} = (N_{M+1}^{th}, N_{M+2}^{th}, ..., N_{2M}^{th})$. In this respect, the set of all possible proportional threshold structured CAC policies can be described as a space of all possible $\vec{N}_{th}^{hf}$. As a result, the task of finding the proportional threshold structured optimal effective bandwidth policy can be modeled as a optimization problem, whose goal is to optimize the value of $\vec{N}_{th}^{hf}$ so as to achieve optimal statistical effective bandwidth. To solve this optimization problem, a straightforward method is to employ brute-force search. However, the method of brute-force search usually has tremendous computational complexity, although it can obtain the exact optimal solution. Correspondingly, we employ genetic algorithm (GA) to search for the near-optimal solution [10].

A genetic algorithm is an adaptive heuristic search program that applies the principles of evolution found in nature. Genetic algorithm combines selection, crossover, and mutation operators with the goal of finding the solution of best fitness to a problem. Here, fitness is a special GA term, which refers to the objective function of the optimization problem. In our application, fitness is defined as the statistical effective bandwidth function in Eq. 4.

A genetic algorithm searches for the optimal solution until a specified termination criterion is met. The solution to a problem is called a chromosome. A chromosome is made up of a collection of genes which are simply the parameters to be optimized. A genetic algorithm creates an initial population (a collection of chromosomes), evaluates this population, then it evolves the population through multiple generations using the genetic operators in the search for a good solution for the problem at hand.

Considering the CAC policies of proportional threshold structure, the searching space can be described by a vector of M variables $\vec{N}_{th}^{hf} = (N_{M+1}^{th}, N_{M+2}^{th}, ..., N_{2M}^{th})$, which also serves as the chromosome in the perspective of genetic algorithm. In fact, $(N_{M+1}^{th}, N_{M+2}^{th}, ..., N_{2M}^{th})$ is only the second half of $\vec{N}_{th}$. However, the first half of $\vec{N}_{th}$, i.e., $(N_1^{th}, N_2^{th}, ..., N_M^{th})$ can be derived from $(N_{M+1}^{th}, N_{M+2}^{th}, ..., N_{2M}^{th})$ by the proportional threshold constraint. In addition, the searching space of $\vec{N}_{th}$ follows the scope of $N_i^{th} \leq B/b_i$.

To solve the statistical effective bandwidth optimization problem above, we define genetic operators as follows:

1) *Selection Operator*: “Roulette” is chosen as the selection operator for statistical effective bandwidth optimization. In “Roulette”, the chance of a chromosome getting selected is proportional to its fitness. This is where the concept of survival of the fittest comes into play.

2) *Crossover Operator*: “one point crossover” is employed for statistical effective bandwidth optimization. The “one point crossover” randomly selects a crossover point within a chromosome then interchanges the two parent chromosomes at this point to produce two new offspring. Consider the following two parents which have been selected for crossover. The “|” symbol indicates the randomly chosen crossover point.
   - Parent a: $(N_{M+1}^{th}(a), |N_{M+2}^{th}(a), ..., N_{2M}^{th}(a))$
   - Parent b: $(N_{M+1}^{th}(b), |N_{M+2}^{th}(b), ..., N_{2M}^{th}(b))$

   After interchanging the parent chromosomes at the crossover point, the following offsprings are produced:
   - Offspring a: $(N_{M+1}^{th}(a), |N_{M+2}^{th}(b), ..., N_{2M}^{th}(a))$
   - Offspring b: $(N_{M+1}^{th}(b), |N_{M+2}^{th}(a), ..., N_{2M}^{th}(b))$

3) *Mutation Operator*: We utilize “Gaussian Mutation” for statistical effective bandwidth optimization. “Gaussian Mutation” adds a unit Gaussian distributed random value to the chosen gene. The new gene value is clipped if it falls outside of the user-specified lower or upper bounds for that gene. To make it clear, an example is given below:
   - Before Mutation: $(N_{M+1}^{th}, N_{M+2}^{th}, ..., N_{2M}^{th})$
   - After Mutation: $(N_{M+1}^{th} + \text{offset}, N_{M+2}^{th}, ..., N_{2M}^{th})$, where “offset” is Gaussian random variable.

4) *Termination Method*: We use “Fitness Convergence” as the termination method, which stops the evolution when the fitness is deemed as converged.

V. PERFORMANCE EVALUATION

In this section, we present numerical results to demonstrate the performance of our CAC scheme in WMN handoff environment. As shown in Table I, we assume that five classes of traffic share a total of $360Mbps$ physical access bandwidth on a mesh router, and each traffic class includes both new calls and handoff calls.

Using the genetic algorithm discussed in Section IV-C, we first demonstrate the performance of our CAC scheme in Fig. 3 and Fig. 4, while varying proportional factor $0 \leq x \leq 1$. Here, each numerical result (statistical effective bandwidth and blocking probability) is achieved from a near-optimal solution when the genetic algorithm reaches convergence. Moreover, Fig. 3 and Fig. 4 utilize the concepts of normalized statistical

TABLE I
TRAFFIC LOAD CONFIGURATION ON A MESH ROUTER

	Bandwidth Requirement	Arrival Rate of New Calls	Arrival Rate of Handoff Calls	Service Time
Traffic Class 1	64Kbps	1100 (calls/hour)	400 (calls/hour)	25 (min./call)
Traffic Class 2	200Kbps	350 (calls/hour)	100 (calls/hour)	1 (hours/call)
Traffic Class 3	500Kbps	550 (calls/hour)	100 (calls/hour)	25 (min./call)
Traffic Class 4	1500Kbps	150 (calls/hour)	50 (calls/hour)	25 (min./call)
Traffic Class 5	2500Kbps	16 (calls/hour)	8 (calls/hour)	1 (hours/call)

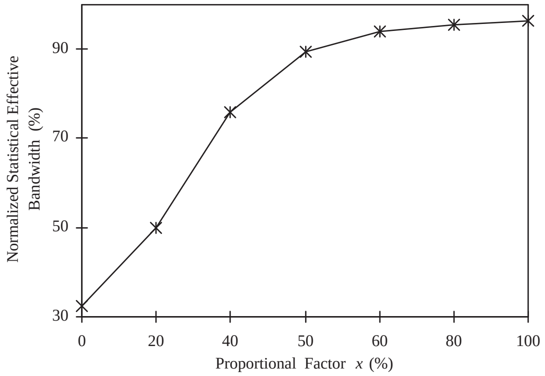

Fig. 3. Statistical effective bandwidth while varying proportional factor x

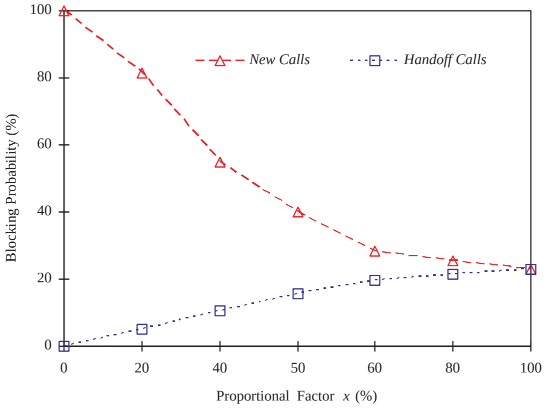

Fig. 4. Average blocking probability of new calls and handoff calls while varying proportional factor x

effective bandwidth and average blocking probability of new calls and handoff calls, which are defined as follows.

Normalized statistical effective bandwidth of policy Ω:

$$B_E^N(\Omega) = B_E(\Omega)/B. \tag{9}$$

Average blocking probability of new calls:

$$Pb_{Avg}^{nw}(\Omega) = \frac{\sum_{i=1}^{M} b_i \rho_i Pb_i(\Omega)}{\sum_{i=1}^{M} b_i \rho_i}. \tag{10}$$

Average blocking probability of handoff calls:

$$Pb_{Avg}^{hf}(\Omega) = \frac{\sum_{i=M+1}^{2M} b_i \rho_i Pb_i(\Omega)}{\sum_{i=M+1}^{2M} b_i \rho_i}. \tag{11}$$

As illustrated in Fig. 3 and Fig. 4, when $x = 0\%$, our scheme gives handoff calls overwhelming preference over new calls, yielding a solution of good differentiated priorities but the lowest statistical effective bandwidth. In fact, when x is equal to zero, the system accepts only handoff calls whereas all new calls are blocked. By contrast, when $x = 100\%$, our scheme gives new calls and handoff calls the same priority, yielding a solution of the highest statistical effective bandwidth but the worst differentiated priorities. As a result, to balance the considerations of differentiated priority and statistical effective bandwidth, we should choose an appropriate value for x, such as $x = 50\%$.

VI. CONCLUSION

In this paper We propose a mobile agent based handoff approach for WMNs. In our approach, each mesh client has a MA residing on its registered mesh router. If a mesh client makes a handoff to another mesh router, the mobile agent moves with it too. To further improve the performance of mobile agent based handoff, we develop a proportional threshold structured optimal effective bandwidth policy for the CAC on mesh router. Numerical results show that our CAC scheme can give handoff calls and new calls different priorities, while achieving high statistical effective bandwidth.

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