Performance Analysis of an Intra-cell Handover Management Policy in Wireless Access Networks

Kiril Kassev

Abstract – **The scarce nature of the bandwidth of wireless links is a key issue for QoS provisioning in next generation wireless systems. In the presence of mobile users willing to access to a rich variety of services, advanced mobility management is needed such that these services are provided seamlessly. From teletraffic point of view, bandwidth demands of active connections could fluctuate due to movement of mobile stations within a cell coverage. The transmission rate adjustment is based on the adaptive modulation and coding (AMC) technique employed. The resulting intra-cell handover has a major impact on the system performance. In the context of resource management, the problem is directly related to the issue of resource reservation and admission control. This paper aims at developing a threshold-based bandwidth management policy for QoS guarantee in next generation wireless access networks. The policy prioritizes connections according to their QoS requirements and the cell area of a call origin.**

Keywords – **Adaptive modulation and coding, Bandwidth allocation, Call admission control, Intra-cell handover**.

I. INTRODUCTION

For efficient usage of limited resources, wireless communications systems employ the cellular concept. In such a multicell environment new problems arise. The following two aspects could be distinguished – inter-cell interference management and handover management. In this paper, the attention is paid to a handover management policy, which maintains target QoS of active connections, over new ones. It aims at balancing the QoS of both handover and new calls (connections) arrivals. This is done by an appropriate resource reservation and admission control.

Wireless resource management policies should be capable of determine the optimal use of limited resources, according to the wireless channel state information and specific QoS requirements. Since bandwidth is a fundamental wireless resource, from teletraffic point of view, it may be considered as a transmission capacity of the wireless medium, which is shared by multiple users.

In order for the emerging wireless access systems to overcome the limitation of wireless communications environment, significant research efforts have been put towards development of technologies for enhancing the spectral efficiency. AMC has been well adopted as an advanced physical layer technology [1]. In legacy wireless access systems each active connection is assigned a fixed amount of bandwidth independently of the mobile station (MS) location within a cell. The quantity of resource consumption depends on the traffic source characteristics.

Initially, handover management for single-service wireless access systems had been extensively studied. A number of prioritization policies that handle the handover traffic has been proposed and analyzed [2], [3]. The basic mechanism is to suitably partition the available resource in a cell to a different traffic types (new and handover call arrivals). The investigations are made under the assumption of conversational services, such a voice, occupying a fixed number of resource units (channels) per call.

A common feature of admission policies is their ability to use the target cell information only (i.e., the number of occupied channels). It would be more beneficial some additional information of the adjacent cell to be used. Since handover decision is solely based on the availability of a free channel without taking into consideration the signal quality, [4] extends the well-known “guard channel” (GC) policy. This is done by combining the mobile assisted handover technique (available at GSM cellular system) and GC. A more efficient handover management scheme is proposed in [5]. The future behavior of an active call can be estimated more precisely, based on the mobility (location and velocity) of each MS. A channel reservation message can be sent to the approaching cell, allowing adaptive resource reservation.

In [6], a novel analytical method for performance analysis of GC policy is proposed. The commonly accepted assumption for Markovian arrival and departure processes is omitted. Performance metrics of interest are derived in presence of self-similar traffic.

One of the challenges in handover management schemes is towards efficient sharing of limited resources among multiple traffic classes. In general, the following approaches can be distinguished – complete partition (*reservation* of a bandwidth exclusively for each traffic class); complete sharing (sharing of available bandwidth among all traffic classes). For a particular traffic class, it is possible a *limitation* level to be set; hybrid schemes. A comparative study of the first two schemes is carried out in [7]. It is shown the advantage of complete sharing to complete partition scheme for efficient use of scarce resource in case of two traffic classes with different bandwidth requirements. The potential of movable boundaries allocation strategies, that can adjust the number of channels for each traffic class, has been investigated in [8]. The proposed scheme extends the GC by introducing different admission thresholds for different traffic classes. It is assumed each traffic class requires one channel per connection. A further extension of bandwidth allocation schemes has been presented in [9]. Authors sketch the design tradeoffs of known solutions and propose as well as study the performance of a

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policy that supports traffic flows with variable bandwidth requirements.

Considering the importance of the problem, a great extent of research work has been devoted to development of handover management policies applied for the case of inter-cell handover only. Having interested in performance analysis of emerging wireless access technologies, the application of above-mentioned methods may be inaccurate. In AMC-enabled systems (cells) the bandwidth demands of active connections may fluctuate due to movement of mobile stations within cell coverage. This is true for services requiring constant transmission capacity. As a consequence, the resulting intra-cell handover and its influence on the system performance should be taken into consideration.

This topic is covered by [10] in terms of physical layer performance. An interference avoidance technique based on the use of intra-cell handover in OFDMA femtocells is proposed. Authors apply the concept of intra-cell handover in GSM networks to OFDMA subchannels selection, in order to mitigate the interference between macro- and femtocell tiers.

The rest of the paper is organized as follows: The traffic model and resource management strategy are described in Section 2. Numerical studies in Section 3 reveal the impact of the both intra-cell handover and applied resource management policy on the system performance. Some conclusion remarks and suggestions for future work are presented in Section 4.

II. SYSTEM MODEL AND PERFORMANCE ANALYSIS

We consider a cell with a fixed amount of capacity. Independently of the multiple access technology employed, the cell capacity could be represents in terms of effective bandwidth. Thus, the total cell capacity is C resource units (bandwidth units).

The threshold-based bandwidth management policy is based on the complete sharing approach (Fig. 1). Both new calls (NC1) and handover calls (HO1) incoming in the cell area served by the highest modulation and coding scheme (MCS), get the highest priority (full access to the available cell resources). These calls are more profitable for the network operator, because they are allocated the smallest amount of resources per active call. This area is referred to as “Ring 1”, linked with the 64-QAM modulation scheme. The new calls (NC2) and handover calls (HO2) offered to “Ring 2” area compete for the remaining resource. This is done by setting the threshold levels T_0 and T_1, in terms of maximum number of resource units. Since dropping a handover connection (HO2) is not considered acceptable, $T_1 > T_0$. The policy aims at adjusting the threshold levels, in order to satisfy the handover dropping probabilities, keeping reasonable values of new calls blocking probabilities.

A call, with certain traffic characteristics, to (from) a MS in Ring l (l = 1, L) simultaneously requires d_l resource units in order to be guaranteed desired QoS.

A new call arrival in both rings follows a Poisson process with mean rate λ_l (l = 1, L). Both new call duration and Ring l dwell time are assumed to be negative exponentially distributed random variables with mean $1/\mu$ and $1/\delta_l$, respectively.

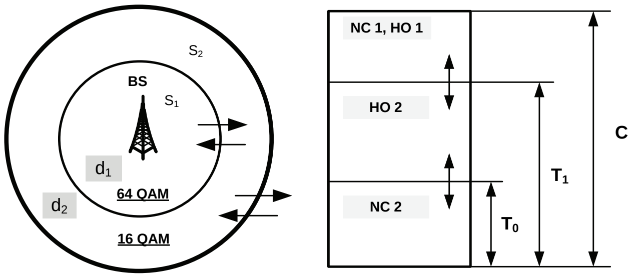

Fig. 1. An AMC-enabled cell with a handover management policy

Intracellular handover calling rate from Ring l to Ring l + 1 is $\lambda_l^{h+} = n_l \delta_l^+$. $1/\delta_l^+$ denotes the mean dwell time of handover calls outward of Ring l. The handover calling rate λ_l^{h-} from Ring l to Ring l - 1 can be estimated in a similar manner, where n_l denotes the number of both new and handover calls (active MSs) in Ring l.

In case of the most outer cell Ring L consideration, the incoming inter-cell handover rate from adjacent cells is defined by $\lambda_h = \lambda_L^{h+} = n_L \delta_L^+$. For cellular networks, the value of λ_h can be estimated by a relation derived from [11]. The average Ring l dwell time is in direct proportion to the cell radius and inverse proportion to the average speed v of MSs [12], [13].

Under the assumptions we stated above, the handover management policy can be modeled as a multi-dimensional Markov process. The multidimensional random variable depends on the number of rings L in a cell. Since we are interested in the steady state probabilities estimation, the challenge is to solve the system of linear equation for such a process. Based on the possible state transitions (Fig. 2), the topic under consideration faces the problem of irreversibility (i.e., the underlying Markov process is non-reversible). Thus, the steady states probabilities cannot be calculated by using product form solutions. A common approach is towards a direct method application, which requires a matrix inversion technique to be used. Depending on the structure of the coefficient matrix, an appropriate numerical method (algorithm) for solving simultaneous linear equations is required. This could limit the application of the method to relatively small state-spaces. The same could be true for a specific class of recursive methods for solving non-Markovian processes [14]. Although the method is well-adopted [9], [15], the limitation could arise in case a system with large state space and number of state transitions is investigated.

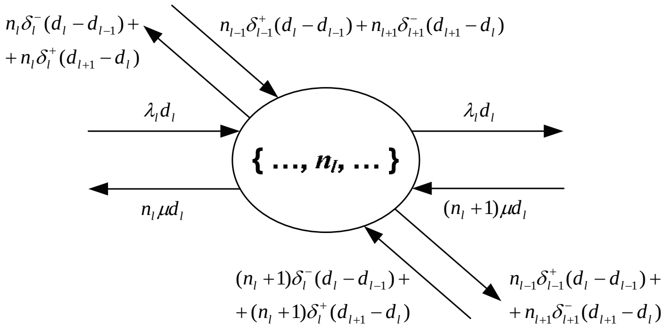

Fig. 2. System state transition for Ring l

In order to fully exploit the advantages of certain recursive methods applied to reversible Markov processes, a challenging work is to construct a reversible Markov chain that well approximate the non-reversible system under consideration (in a manner similar to [16]).

Since $L = 2$, the call (connection) level performance measures of interest are obtained by solving a two-dimensional non-reversible Markov process.

The state of the system (a cell) is defined by the set:

$$s = \{n_1, n_2, ..., n_l, ..., n_L\}.$$

Let the set of allowable states (determined by the resource sharing policy in use) is denoted by S. Therefore, $s \in S$ if and only if the following conditions are satisfied:

$$S = \{s : 0 \le n_2 \cdot d_2 \le T_0 \le T_1;\ 0 \le \sum_{i=1}^{2} n_i \cdot d_i \le C\}. \qquad (1)$$

We introduce the notation $s_l^+ = \{n_1, n_2, ..., n_l + 1, ..., n_L\}$.

Both new and handover calls offered to Ring 1 share the entire available cell resource. The call blocking (NC1)/dropping (HO1) probabilities are equal and can be derived as:

$$P_{NC1,HO1} = \sum_{s \in BD^+_{NC1,HO1}} P(s), \qquad (2a)$$

$$\begin{aligned} BD^+_{NC1,HO1} &= \{s \in S \mid s_1^+ \notin S\} \\ &= \{s \in S \mid d_1 + \sum_{j=1}^{2} n_j \cdot d_j > C\}. \end{aligned} \qquad (2b)$$

Let us introduce the subset $\hat{S} \in S$, defined by the threshold level T_0. The cell resource is completely shared by all types of calls offered from both rings. Thus, the blocking probability P_{NC2} for new calls offered to Ring 2 is given by:

$$P_{NC2} = \sum_{s \in B^+_{NC2}} P(s), \qquad (3a)$$

$$\begin{aligned} B^+_{NC2} &= \{s \in S \mid s_2^+ \notin \hat{S}\} \\ &= \{s \in S \mid d_2 + n_2 \cdot d_2 > T_0 \vee T_0 < n_2 \cdot d_2 \le T_1 \vee \\ &\vee d_2 + \sum_{j=1}^{2} n_j \cdot d_j > C\}. \end{aligned} \qquad (3b)$$

The dropping probability P_{HO2} for handover calls offered to Ring 2 is given by:

$$P_{HO2} = \sum_{s \in D^+_{HO2}} P(s), \qquad (4a)$$

$$\begin{aligned} D^+_{HO2} &= \{s \in S \mid s_2^+ \notin S\} \\ &= \{s \in S \mid d_2 + n_2 \cdot d_2 > T_1 \vee d_2 + \sum_{j=1}^{2} n_j \cdot d_j > C\}. \end{aligned} \qquad (4b)$$

III. NUMERICAL RESULTS

We assume the total cell capacity of 20 resource units. Based on a particular resource management policy, it is shared by both new call arrivals from each ring, and intra-cell handover arrivals, as a result of MSs movement across inner cell boundaries (rings). The intra-cell handover rates δ_l are related to the MSs average speed, rings area, and the MSs distribution within the cell [12], [13]. We suppose uniformly distributed MSs.

It is assumed a cell radius $r = 2$ km. The relation of the outer radius of Ring 1, linked to a MCS of the highest order (64-QAM), to the cell radius is denoted by p. This proportion depends on the wireless environment propagation conditions and statistical characteristics. The distance covered by a MCS is also governed by a set of target performance measures at physical level. Based on a relation between MCSs and resources necessary for constant transmission capacity provisioning, we assume $d_1 = 1$, $d_2 = 2$ resource units per call [17]. The new call arrival rate λ_l at Ring l is tightly coupled with the ratio of the Ring l area S_l to the entire cell area. The average service rate of MSs distributed over the cell is assumed to be $\mu = 0.0167\ \text{s}^{-1}$.

For complete sharing scenario both type of traffic flows offered from Ring 2 area experience higher losses compared to traffic arrivals from Ring 1 (Fig. 3). Connections with lower bandwidth requirements have a better chance at occupying the bandwidth than those with higher bandwidth requirements. In case handover limitation threshold T_1 is set to 16 resource units, it is shown that significant improvement of the performance measures cannot be reached. It is more likely Ring 2 handover dropping probability to get increased. For this reason, the rest of investigations are carried out for $T_1 = 20$ resource units. Fig. 4 depicts the impact of users' (MSs) mobility on the system performance. The resource management policy has low efficiency for high mobility users, compared to low mobility ones, as a result of increased intra-cellular handover rates. The threshold level T_0 has to be carefully set, such that Ring 2 new call blocking meet QoS.

The influence of the Ring 1 region area is illustrated on Fig. 5 (in terms of the parameter p). For low mobility users, an efficient point of operation of the management policy can be distinguished at $p \approx 0{,}6$. A good resource management scheme has to balance the tradeoffs between new call blocking and handover dropping probabilities in order to meet target QoS requirements.

The policy operation under certain dynamic range of new call arrival rates in both rings is depicted on Fig. 6. Again, the policy takes effect on low mobility users. When the new call arrival rate is high, no matter how parameters are adjusted, the policy cannot guarantee QoS.

IV. CONCLUSION AND FUTURE WORK

In this paper, a threshold-based intra-cellular handover management policy has been proposed and studied. Numerical analysis shows that important performance metrics can be improved as well as some tradeoffs have been identified.

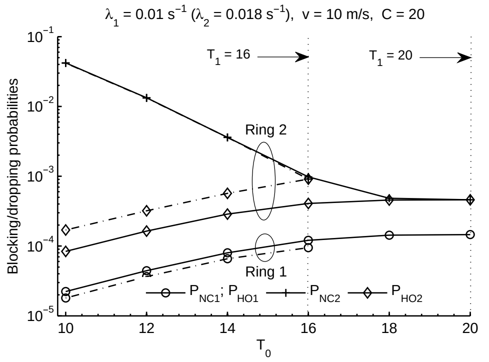

Fig. 3. Influence of Ring 2 limitation thresholds on QoS metrics

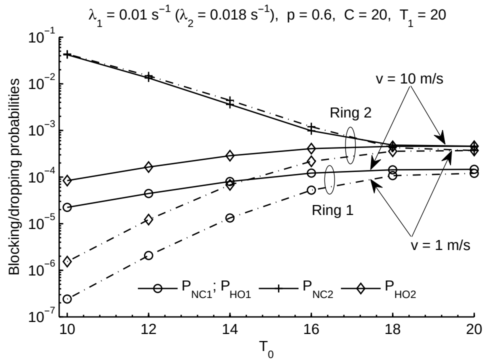

Fig. 4. Influence of MSs mobility on the system performance

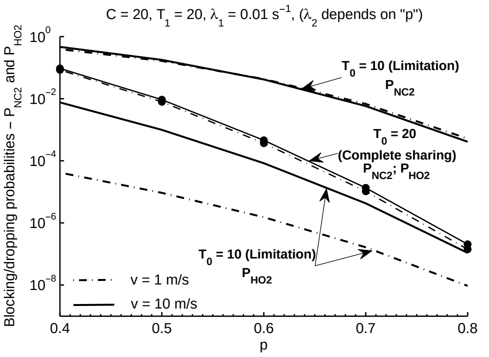

Fig. 5. Ring 1 region influence on system performance

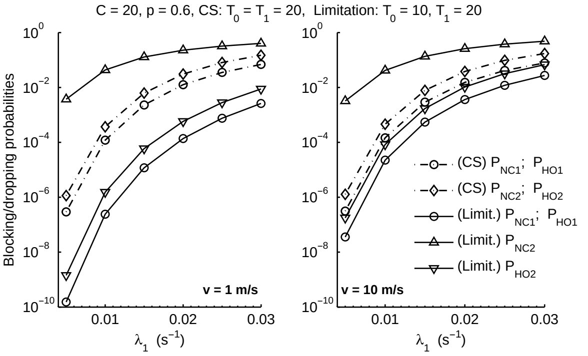

Fig. 6. Call-level QoS parameters vs. new call arrival rate dynamic

The future work will focus on methods for reversible Markov chains construction, which well approximate the non-reversible system investigated. This will enable us to use attractive recursive methods (e.g., Kaufman-Roberts) that can be applied to realistic systems with large state-space.

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