Intra-cell Handover in OFDMA-based Wireless Access Networks

Kiril M. Kassev[1] and Boris P. Tsankov[2]

Abstract – **OFDMA-based wireless access networks employ Adaptive Modulation and Coding at physical layer that results in different bit rate per radio transmission unit at different location in the cell. The cell is decomposed into regions. The mobile users encounter intra-cell handover at the border between two neighbour regions. The paper considers the intra-cell handover influence over system performance. An analytical method is proposed and numerical results are reported.**

Keywords – **Adaptive modulation and coding, intracell handover, OFDMA.**

I. INTRODUCTION

In order to satisfy the customer demands for access to a wide variety of multimedia applications over wireless communication networks, significant research efforts are being put in development of next generation mobile networks (NGMN), also referred to as 4G, based on all-IP environment. This can be achieved by employing the OFDMA technique at the air interface, which is immune to intersymbol interference and frequency selective fading, due to the time-varying nature of the wireless channel. As a consequence, OFDMA-based systems have become a popular choice, and have been adopted in several standards towards NGMN [1], [2].

In contrast to the traditional channelized multiple access systems, where each user is assigned a fixed amount of bandwidth during the whole connection time, in wireless networks the channel capacity of a wireless link is time-varying, and thus the quality of service (QoS) requirements may not be satisfied, even though a large amount of resource (i.e. bandwidth) is allocated to a certain connection. This is especially true when a mobile station (MS) is located at the cell edge area. The Adaptive Modulation and Coding (AMC) within the OFDMA based cell means to choose the best Modulation and Coding Scheme (MCS) for given channel quality. AMC is a powerful tool to enhance the overall wireless access network performance [3], [4].

Due to the AMC implementation the OFDMA-based cell is subdivided on concentric rings, each ring characterized by particular modulation and coding scheme depending on the radio channel condition [5]. A MS during its movement might cross the ring border with consequent intra-cell handover (HO). The intra-cell HO leads to a change of resource amount placed to the connection disposal.

The main observation of this paper is the intra-cell HO influence to the overall cell performance. The mobility is mostly related to multimedia services and voice services in particular. The analytical model proposed and the numerical examples considered are based on voce like services with constant bit rate and corresponding QoS parameters.

The rest of the paper is organized as follows: Some related papers are listed in the Section II. The analytical model for teletraffic evaluation of the impact of intra-cell HO is presented in section III, followed by the numerical studies in Section IV. We conclude the paper and present possible suggestions for further study in Section V.

II. STATE OF THE ART

The interaction of analytical framework for evaluation of teletraffic performance characteristics of the system under consideration at the data link layer with AMC at the physical layer provides a base for interesting and realistic design work. This topic is covered by a number of excellent papers describing in depth the essence of the underlying problems. Reference [6] investigates the performance of transmission over wireless links, in case an interaction between a finite-length queuing and different AMC schemes are taken into consideration. The Erlang capacity of WiMAX systems with fixed modulation schemes is calculated in [7], considering two traffic classes – streaming and elastic. An interesting approach for evaluation of Erlang capacity of a multi-class TDMA system with AMC by separating the calculation of blocking and outage probabilities is proposed by the authors of [8].

Interestingly, a similar problem in GSM networks has been considered for full-rate and half-rate transmission, depending on the radio conditions [9-11]. In this case, there only exist two cell areas with different radio channel characteristics.

III. SYSTEM MODEL AND PERFORMANCE ANALYSIS

We will restrict our considerations to voice-like real time traffic with constant bit rate and the following assumptions:

- MSs and their traffic are uniformly distributed over the cell;
- MS's movement direction is uniformly distributed over $[0, 2\pi]$;
- New call arrival follow a Poisson process with rate λ;
- The call holding time is exponentially distributed with mean $1/\mu$.

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The employment of the AMC scheme at the physical layer results in splitting-up the cell into non-overlapping cell areas (rings), as shown on Fig. 1. The total cell capacity is *C* resource units (time slots). A call to (from) a MS in ring *l* requires exactly d_l resource units in order to be served. The rings are numbered starting with the most inner being number *l* to the most outer cell ring being number *L*. Therefore, $d_x > d_y$, if $x > y$.

The system state is defined by the set $N\{n_1, n_2, ..., n_L\}$, where n_l is the number of calls (number of active MSs) in ring *l*, ($l = \overline{1, L}$).

The 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.

Intracellular HO calling rate from ring l to ring $l+1$ is

$$\lambda_l^{h+} = n_l \delta_l^+.$$

$1/\delta_l^+$ is mean dwell time of calls that handover outward of ring *l*. By analogy, the intracellular HO calling rate from ring l to ring $l-1$ is

$$\lambda_l^{h-} = n_l \delta_l^-.$$

We use notation $\{n_l\}$ for any state $N_l\{..., n_l, ...\}$, where the number of calls in ring *l* is equal to n_l.

The possible transition out of any state $\{n_l\}$ and into the same state $\{n_l\}$, due to changes in ring *l*, are shown on Fig. 2. Therefore, in a condition of statistical equilibrium there is

$$\begin{aligned} &P_{\{n_l\}}[\lambda_l d_l + n_l \mu d_l + n_l \delta_l^+ (d_{l+1} - d_l) + n_l \delta_l^- (d_l - d_{l-1}) + \\ &+ n_{l-1}\delta_{l-1}^+ (d_l - d_{l-1}) + n_{l+1}\delta_{l+1}^- (d_{l+1} - d_l)] = \\ &= P_{\{n_l - 1\}}[\lambda_l d_l + n_{l-1}\delta_{l-1}^+ (d_l - d_{l-1}) + n_{l+1}\delta_{l+1}^- (d_{l+1} - d_l)] + \\ &+ P_{\{n_l + 1\}}[(n_l + 1)\mu d_l + (n_l + 1)\delta_l^+ (d_{l+1} - d_l) + \\ &+ (n_l + 1)\delta_l^- (d_l - d_{l-1})], \qquad l = 2, ..., L-1. \end{aligned} \tag{1}$$

It is obvious that

$$\delta_1^- = 0, \tag{2}$$

and that δ_L^+ is the call handover rate from ring *L* to another cell.

Therefore, for $l = 1$

$$\begin{aligned} &P_{\{n_1\}}[\lambda_1 d_1 + n_1 \mu d_1 + n_1 \delta_1^+ (d_2 - d_1) + n_2 \delta_2^- (d_2 - d_1)] = \\ &= P_{\{n_1 - 1\}}[\lambda_1 d_1 + n_2 \delta_2^- (d_2 - d_1)] + \\ &+ P_{\{n_1 + 1\}}[(n_1 + 1)\mu d_1 + (n_1 + 1)\delta_1^+ (d_2 - d_1)]. \end{aligned} \tag{3}$$

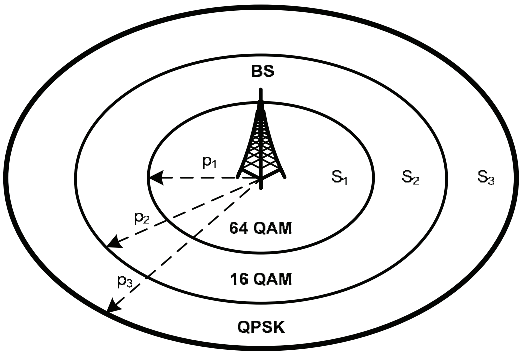

Fig. 1. OFDMA-based cell with AMC scheme employed

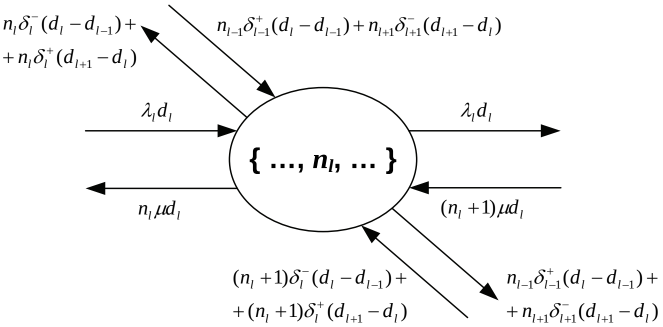

Fig. 2. System state transitions for ring *l*

For $l = L$

$$\begin{aligned} &P_{\{n_L\}}[\lambda_L d_L + n_L \mu d_L + n_L \delta_L^+ d_L + n_L \delta_L^- (d_L - d_{L-1}) + \\ &+ n_{L-1}\delta_{L-1}^+ (d_L - d_{L-1}) + \lambda_h d_L] = P_{\{n_L - 1\}}[\lambda_L d_L + \\ &+ n_{L-1}\delta_{L-1}^+ (d_L - d_{L-1}) + \lambda_h d_L] + P_{\{n_L + 1\}}[(n_L + 1)\mu d_L + \\ &+ (n_L + 1)\delta_L^+ d_L + (n_L + 1)\delta_L^- (d_L - d_{L-1})]. \end{aligned} \tag{4}$$

Where λ_h is the incoming inter-cell handover traffic from the other cells. At the same time λ_h is also outgoing inter-cell handover traffic to the outer cells:

$$\lambda_h = \lambda_L^{h+} = n_L \delta_L^+. \tag{5}$$

For cellular networks [12], [13] the relation between fresh call traffic λ and handover cell traffic λ_h is equal to the relation between mean call holding time $1/\mu$ and mean cell dwell time $1/\delta$, that is

$$\frac{\lambda_h}{\lambda} = \frac{\delta}{\mu}. \tag{6}$$

The radius r_l is the outer radius of ring l normalized to the cell radius. The ratio p_l of the ring l area to the entire cell area is given by

$$p_l = \frac{r_l^2 - r_{l-1}^2}{r_L^2}. \quad (7)$$

The radius r_l is actually the distance covered by MCS_l.

The value of p_l also represents the probability of an active MS being located in ring l.

The average dwell time in a cell is taken to be in direct proportion to the cell radius and in inverse proportion to the average MS speed [13], [14].

IV. NUMERICAL RESULTS

Following the assumption stated in Section III, the system parameters that were used in the analytical evaluation are as follows. The cell has a capacity of 6 resource units, which are shared among both new voice calls, arriving at each ring, and intra-cell handover calls when MSs move across inner boundaries (rings). We apply a 3-ring cell with the corresponding MCS (Fig. 1). The bandwidth, in terms of a number of resource units, required to maintain a voice call depends on the location of a MS within the cell area, and it is assumed $d_1 = 1$, $d_2 = 2$, $d_3 = 3$. The average service rate is assumed to be $\mu = 0.0167$ s^{-1}, while the new voice call intensity λ_{MCS_l} in the cell area with the modulation scheme of highest order (64QAM) is varied from 0.001 to 0.01 s^{-1}. The intra-cell HO rates δ_l are mainly related to the MSs average speed, rings area and MSs distribution within the cell [13], [14]. We assume uniformly distributed MSs.

Typical spectral efficiency values for different MCS are shown on Table I [5]. We use the following relations between the distances covered by a particular MCS, depicted on Fig. 3 [15]. As a consequence, the following conclusions can be drawn:

- For constant coding rate (e.g. ¾) the relation between modulation and resources necessary for a given CBR service is

$$d_{64QAM} : d_{16QAM} : d_{QPSK} = 1:2:3. \quad (8)$$

- In case of the same coding rate, it follows that

$$r_{64QAM} : r_{16QAM} : r_{QPSK} \approx 2r : 3r : 4r. \quad (9)$$

According to (7), the following relation between the ring surfaces can be derived:

$$p_{64QAM} : p_{16QAM} : p_{QPSK} = 4r^2 : 5r^2 : 7r^2. \quad (10)$$

The relation between the ring's new incoming call rates is

$$\lambda_{64QAM} : \lambda_{16QAM} : \lambda_{QPSK} = 4r^2 : 5r^2 : 7r^2.$$

The performance measures under interest are new voice call blocking probability as well as handover dropping probability, which are depicted on Figs. 4 – 6, for different values of users' mobility.

TABLE I
MCS SPECTRAL EFFICIENCY (SE)

Modulation	Coding	SE (bps/Hz)
QPSK	1/2	0.7
QPSK	3/4	1
16 QAM	1/2	1.4
16 QAM	3/4	2.1
64 QAM	2/3	2.8
64 QAM	3/4	3.15

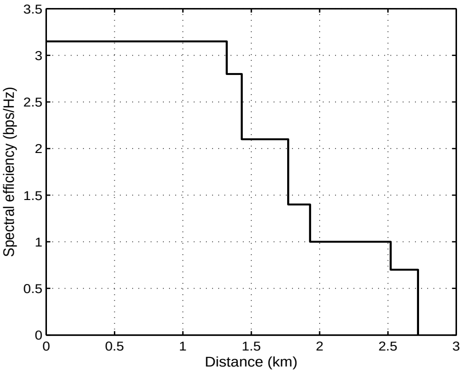

Fig. 3. Distance covered by a specific MCS in an OFDMA-based cell

A comparative study has been carried out for a case when MSs do not cross the inner boundaries - Intra-cell HO does not occur. The numerical results obtained are reasonable, especially for the MSs located in the Ring 3 area (Fig. 6), which are served by the most inefficient MCS (the most resource units per call are required). Thus, more new and HO calls exist in Ring 3, more call blocking/dropping probabilities are increased.

The performance metric studied include the total resource unit utilization under different traffic loads (including both new and HO arrivals) – Fig. 7. Results illustrate that the available resource can be better utilized, but there is a trade-off that the QoS parameters, such as new calls/HO blocking/dropping probabilities approach unacceptable levels.

On the other hand, since the wireless resource is scarce and expensive, a crucial task of further investigations is to guarantee the target QoS metrics while fully utilizing the scarce bandwidth. This is tightly coupled with the necessity of development of an appropriate resource management strategy.

V. CONCLUSION

An analytical model to study the intra-cell handover influence on system performance in terms of QoS metrics, such as call blocking/dropping probability, and resource unit utilization has been proposed. A comparative study for a case when intra-cell HO does not occur has been carried out. Some drawbacks have been identified and directions for future research have been drawn, which aim at looking for an optimal solution between target QoS measures and scarce resource utilization.

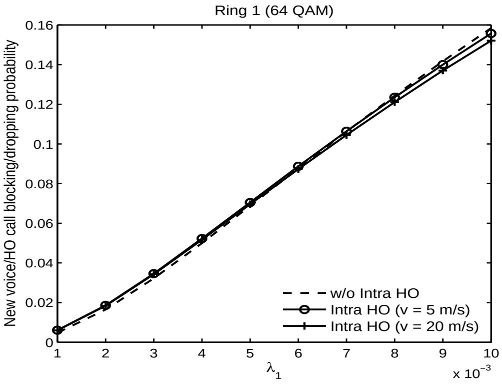

Fig. 4. Performance measures for traffic stream offered to Ring 1

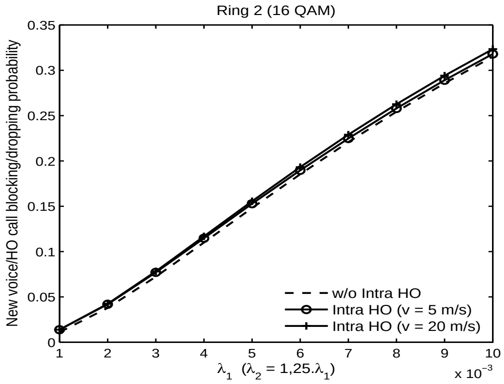

Fig. 5. Performance measures for traffic stream offered to Ring 2

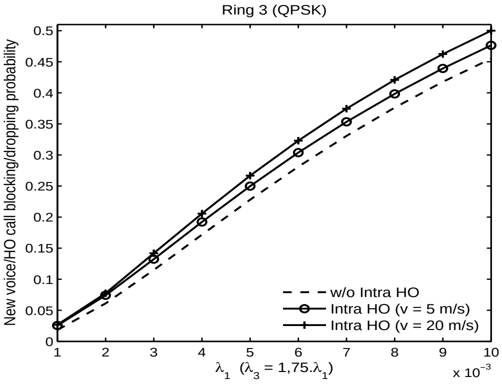

Fig. 6. Performance measures for traffic stream offered to Ring 3

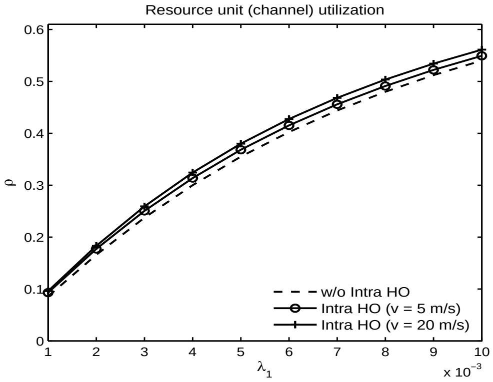

Fig. 7. Average utilization ρ of resource unit vs. traffic load

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