Analysis and Optimization of a Transparent Multicast Mobility Support in Cellular Systems

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***Abstract*—In this paper we review a multicast mobility support for cellular systems acting in a transparent way, by means of multicast agents placed at each base station. This architecture makes prediction about user movements and performs a resource reservation in advance, where the multicast tree creation is made before the radio handover. In this paper, we propose a simple analytical model useful to compute the two basic performance indexes: the handover latency and the resource utilization time. This analysis has been used to set the optimal threshold parameters involved in the multicast and radio handovers.**

I. INTRODUCTION

In a multicast environment with mobility over a cellular network, when a Multicast Mobile Host (MMH) is moving between cells served by different multicast routers, it must wait both for the multicast tree update and the traffic flood, before receiving the requested multicast packets. We have identified this problem in [1] and called the relative time performance index *handover latency*, h_l.

To avoid the handover latency, with the relative packet loss, we have designed and implemented an agent-based architecture [1], where each Base Station (BS) integrates a Multicast Agent (MA). BS and MA work together to predict the MMH movements and to perform the multicast join to those groups needed by MMH, when necessary. This happens when the next visited cell is served by a multicast router having not still active join to one or more of the MMH multicast groups. The multicast join in a new cell, called multicast handover, is performed in advance with respect to the radio handover, by permitting to reduce the handover latency.

When the multicast tree is created in the new cell, MA waits for the MMH radio handover before starting the packets broadcasting (regarding new multicast groups interesting MMH) on the radio interface. This strategy allows to avoid the waste of the wireless bandwidth.

Due to the absolute transparency of this mobility support to the MMH operating system, to the MMH energy consumption and to the wireless resource occupation, we called this system Transparent Mobile Multicast [1].

Three different power thresholds are considered: H for the multicast handover in advance, H_r for the radio handover and H_o to perform a soft multicast handover, i.e., to wait for a certain amount of time before release a joined group after a cell change, creating a redundant multicast packet flood to multiple MAs. In the following we assume these threshold expressed in dB.

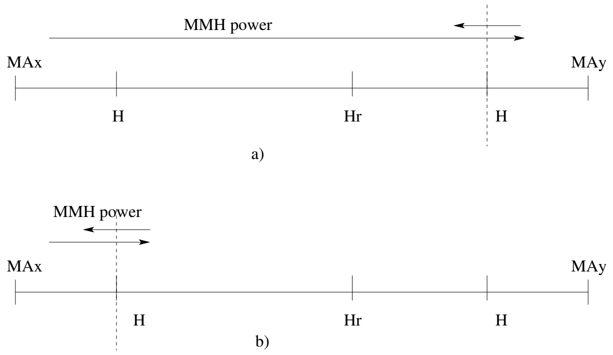

Fig. 1. Multicast ping pong effects involving MA_x (a) and MA_y (b).

To clarify the role of these thresholds, let us review the discussion in [1] by considering a generic MMH moving between $\mathrm{cell_x}$ with base station $\mathrm{BS_x}$ and $\mathrm{cell_y}$ with base station $\mathrm{BS_y}$. Let $P_x(\cdot)$ and $P_y(\cdot)$ be the received power (expressed in dB) at $\mathrm{BS_x}$ and $\mathrm{BS_y}$, respectively, functions of the distance between the MMH and the two BSs.

By supposing that the generic MMH is actually linked to $\mathrm{cell_x}$, MA of $\mathrm{cell_y}$, MA_y, performs the multicast groups join (multicast handover) if:

$$P_y(\cdot) \geq P_x(\cdot) - H$$

BS_y performs the radio link handover if:

$$P_y(\cdot) \geq P_x(\cdot) + H_r$$

Under the constraint that $H > -H_r$, it follows that the multicast handover is always performed before the radio one.

The packet flood of groups joined by the MMH performing the handover to $\mathrm{cell_y}$ is stopped by MA_x only if no other MMHs in $\mathrm{cell_x}$ use them, and if we have a low probability that the MMH is coming back. This last condition, introduced to avoid a multicast ping pong, referred to as the $\mathrm{cell_x}$ for the sake of simplicity due to the the geometry symmetry, is checked by means of:

$$P_y(\cdot) \geq P_x(\cdot) + H + H_o$$

where H_o plays the role of a security threshold with respect the multicast handover.

Let us discuss why we have selected the condition $P_y(\cdot) \geq P_x(\cdot) + H + H_o$. When the multicast handover is performed, i.e., when $P_y(\cdot) \geq P_x(\cdot) - H$, MA_y activates the join for the MMH's multicast groups. A possible condition of multicast join release in the $\mathrm{cell_x}$ could be $P_y(\cdot) \geq P_x(\cdot) + H$. Unfortunately, if this last condition is verified and the MMH immediately comes back, i.e., $P_y(\cdot)$ return to be lesser than $P_x(\cdot) + H$, the MA_y starts a multicast handover to $\mathrm{cell_x}$ (in force of the condition $P_y(\cdot) \leq P_x(\cdot) + H$) by causing a multicast ping pong (i.e., successive joins and unjoins in the same cell). The ping pong effect may be neglected by considering the new threshold H_o above introduced. This condition avoid similar ping pong effects, but involving MA_y, present when MMH is moving to $\mathrm{cell_y}$. A graphic presentation of the two multicast ping pong effects above described is reported in Figure 1

This paper introduce a simple mathematical model that describes the role of the different thresholds on the system performance. This model allows to select the optimal H parameter, taking into account both the handover latency, h_l, and a new parameter, t_{on}, called resource utilization time, described in the following. This simple analytical model, based only on the path-loss propagation phenomenon without consider shadowing and multipath fading, is discussed in Section II.

In Section III we use the developed model to obtain an optimal H value, by minimizing h_l, without accounting for t_{on}; while, the joint optimization is reported in Section IV where a metric taking into account both the terms is shown. Finally, in section V, some conclusions are given.

II. System Model and Performance

Consider cells with radius r, so that the inter-BS distance is $x_f = 2r$. Let move MMH with a linear walking model and a constant velocity v, without any stop or any change in the velocity. In Figure 2 this reference situation is depicted.

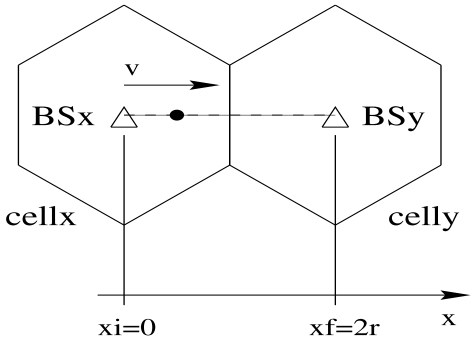

Fig. 2. MMH moving between two cells.

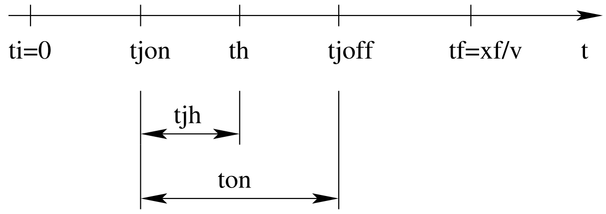

Fig. 3. Relation between join, handover and unjoin times.

To compute the received powers into two adjacent cells, let us model the path-loss by using the COST-231 HATA model [2] [3]. By considering transmitter and receiver at distance x, the received power is $P(x) = P - P_l(x)$, where P is the MMH transmitted power and $P_l(x) = A + B\log(x)$ is the path loss, with $B = 44.9 - 6.55\log(h_{BS})$ and h_{BS}, the BS antenna height, fixed to 30m.

We are interested to investigate three time instants: $t_{j_{on}}$, the time in which MA activate the MMH join; t_h, the time in which the radio handover is performed; and $t_{j_{off}}$, the time in which the join is released by MA. In Figure 3 a possible time evolution, with the three times underlined, is reported.

We define the resource utilization time, t_{on}, as the total time in which MA maintains active the join, so that $t_{on} = t_{j_{off}} - t_{j_{on}}$. Furthermore, let us call t_{j_h} the time in which the join is active in both cells before the radio handover, so that $t_{j_h} = t_h - t_{j_{on}}$.

Now we proceed to evaluate these characteristic times.

The radio handover is performed at distance x_h from BS_x, where x_h may be computed from $P_y(x_h) = P_x(x_h) + H_r$. Noting that $P_y(x_h) = P - P_{ly}(x_f - x_h)$ and $P_x(x_h) = P - P_{lx}(x_h)$ it follows that:

$$x_h = x_f\left(10^{-\frac{H_r}{B}} + 1\right)^{-1}$$

which can be re-written, on the basis of the linear walk assumption, as a function of the times t_h and x_f/v:

$$t_h = \frac{x_f}{v}\left(10^{-\frac{H_r}{B}} + 1\right)^{-1} \tag{1}$$

We can compute in a similar way the $t_{j_{on}}$ and $t_{j_{off}}$ times, relative to the the start and the end of the multicast handover. By observing that the space break points in these cases can be derived by $P_y(x_{j_{on}}) = P_x(x_{j_{on}}) - H$ and $P_y(x_{j_{off}}) = P_x(x_{j_{off}}) + H + H_o$, we have:

$$\begin{aligned} t_{j_{on}} &= \frac{x_f}{v}\left(10^{\frac{H}{B}} + 1\right)^{-1} \\ t_{j_{off}} &= \frac{x_f}{v}\left(10^{-\frac{H+H_o}{B}} + 1\right)^{-1} \end{aligned} \tag{2}$$

By observing that $t_{j_{off}}$ increases, when H growths, in a monotonic way, while $t_{j_{on}}$ has an opposite trend, the natural condition $t_{j_{off}} \geq t_{j_{on}}$ forces H to assume its minimum value $H_{min} = -H_o/2$ when $t_{j_{off}} = t_{j_{on}}$.

By remembering the condition $H > -H_r$, it follows also that $t_{j_{on}} \leq t_h$.

$t_{j_{on}}$, $t_{j_{off}}$ and t_h are reported in Figure 4 as a function of H, with $r = 3.5$Km, $v = 100$Km/h and $H_o = H_r = 8$dB. Note that, as expected, $t_{j_{on}} = t_{j_{off}}$ if $H = -4$dB and that t_h is constant, since it does not depends on H. Furthermore, it

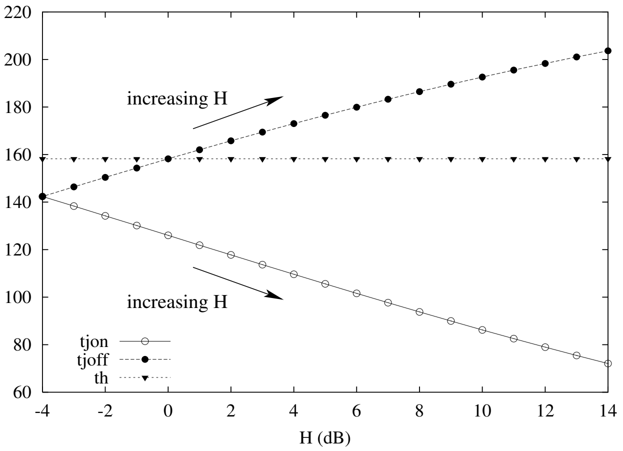

Fig. 4. $t_{j_{on}}$, t_h and $t_{j_{off}}$ as a function of H.

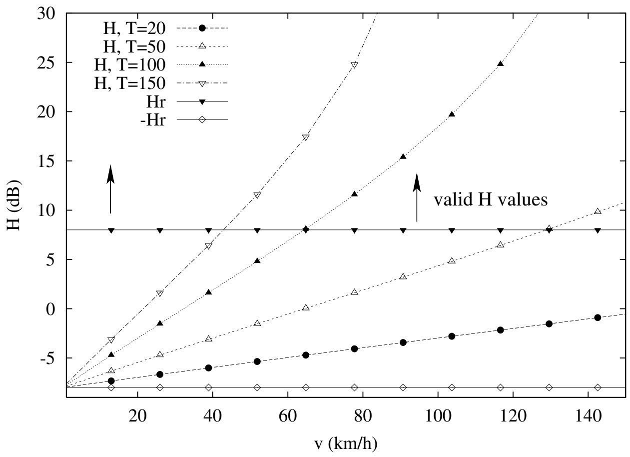

Fig. 5. Minimum H value to obtain $h_l = 0$.

should be $t_{j_{off}} \geq t_h$, to avoid the group unjoin before the radio handover, i.e., $H \geq H_r - H_o$. This leads, with the assumed parameter values, to the constraint $H \geq 0$, corresponding to the cross point between the t_h and $t_{j_{off}}$ curves.

Due to that by increasing H, $t_{j_{on}}$ decreases, the multicast handover latency h_l decreases; on the other hand, t_{on} increases and then also the core network load growths, due to the maintenance of multiple multicast trees.

To compute the handover latency, h_l, i.e. the time from the radio handover to the reception of multicast packets, we introduce the overall multicast delay, T, defined as the time from a multicast IGMP request to the beginning of the multicast packet reception. This time depends on many factors: the join request time, the multicast tree update, the flooding time throughout the multicast tree in the core network and the time to deliver the packet using the radio interface.

By considering a steady-state core network, and by fixing a given multicast topology (i.e., transmitter located at the same distance from MAs) we can consider T as a deterministic value.

The h_l is:

$$h_l = \max[T - t_{j_h}, 0] = \max[T - t_h + t_{j_{on}}, 0]$$

which has maximum value $h_{l_{max}} = T$, corresponding to the case without mobility support.

t_{on} directly descends from Eq. (2) and its maximum, $t_{on_{max}}$, by observing Figure 4, is:

$$t_{on_{max}} = t_{j_{off}}(H_{max}) - t_{j_{on}}(H_{max})$$

where H_{max} is the maximum value assumed for H.

III. Optimal H Value by Minimizing h_l

In order to have no handover latency, i.e., $h_l = 0$, when MMH moves from a cell to an adjacent one, it must be $t_{j_h} \geq T$, i.e., the time from the multicast join in the new cell to the radio handover must be higher or equal to the overall multicast delay. By substituting Eq. (1) and (2) in $t_{j_h} = t_{j_{on}} - t_h \geq T$ we obtain:

$$H \geq B \log \frac{a + ab + b}{1 - a - ab}$$

where $a = Tv/x_f$ and $b = 10^{-H_r/B}$.

Since we are interested to the lowest value of H giving $h_l = 0$, results:

$$H = \max \left[B \log \frac{a + ab + b}{1 - a - ab}, H_r - H_o \right]$$

This equation gives the optimal value of H, having only considered the handover latency. In Figure 5 we report the optimal H values as a function of the velocity v, for the following system parameters: $r = 3.5$Km, $H_o = H_r = 8$dB, T in the set $\{20\text{s}, 50\text{s}, 100\text{s}, 150\text{s}\}$ and v spanning from 0 to 150Km/h.

With the selected parameters, the minimum possible H value is zero (due to $H_r - H_o = 0$). The H parameter increases both with T and v, since they are playing the same role in the H expression in force of their multiplicative presence in the a parameter.

IV. Optimal H Value by Jointly Minimizing h_l and t_{on}

In order to choose the H value guaranteeing optimal values for both h_l and t_{on}, let us start the study of the dependency of these two parameters on H. By considering the previously derived expression of h_l and t_{on} and the previously discussed constraint on H, we can derive the trends, reported in Figure 6, for the same system parameters of Figure 5 and with $T = 100$s. As expected, with the H increase, h_l decreases and t_{on} increases.

In Figure 7 h_l and t_{on} are shown, having normalized them to $h_{l_{max}}$ and to $t_{on_{max}}$, respectively, where $h_{l_{max}}$ and $t_{on_{max}}$ have been introduced in Section II, and having fixed $H_{max} = 20$dB.

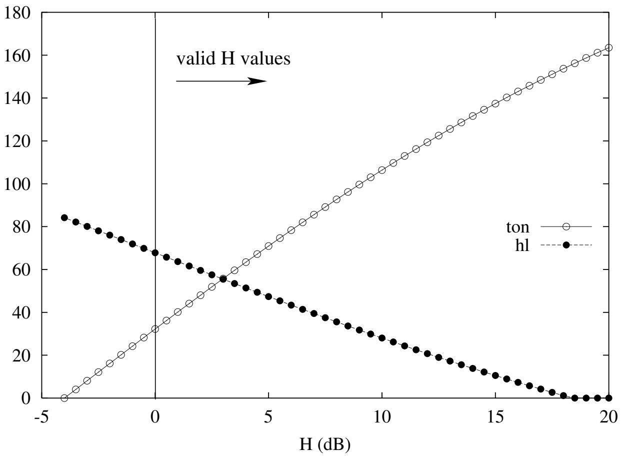

Fig. 6. h_l and t_{on} as a function of H for $T = 100$s.

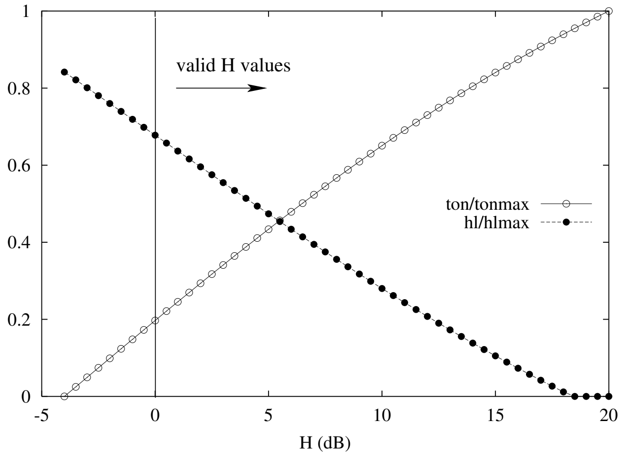

Fig. 7. Normalized h_l and t_{on} as a function of H.

Due to the opposite trend of h_l and t_{on} by varying H, the joint optimization requires the introduction of a cost function able to weight the two effects. Considering that can be interesting modulate the weight to be applied to the handover latency or to the resource utilization time, we propose a balancing between these two effects as a function of a suitable setting parameter α.

Furthermore, to enhance the sensibility to the combining parameters, we propose a quadratic combination of $\frac{h_l}{h_{l_{max}}}$ and $\frac{t_{on}}{t_{on_{max}}}$. By calling α the combination parameter, we have:

$$f_c(\alpha, H) = \alpha \left(\frac{h_l}{h_{l_{max}}} \right)^2 + (1-\alpha) \left(\frac{t_{on}}{t_{on_{max}}} \right)^2, \quad 0 \leq \alpha \leq 1$$

Once all parameters in the set $\{v, r, H_r, H_o, T\}$ are fixed, we can find the optimal H value, by minimizing $fc(\alpha, H)$ for a given α. We underline that the α parameter is set to drive the optimization, in order to differently weight h_l and t_{on}. So, $\alpha = 0$ means that the H choice does not depend on the handover latency but only on t_{on}. The opposite set, $\alpha = 1$, allows to minimize h_l as discussed in Section III.

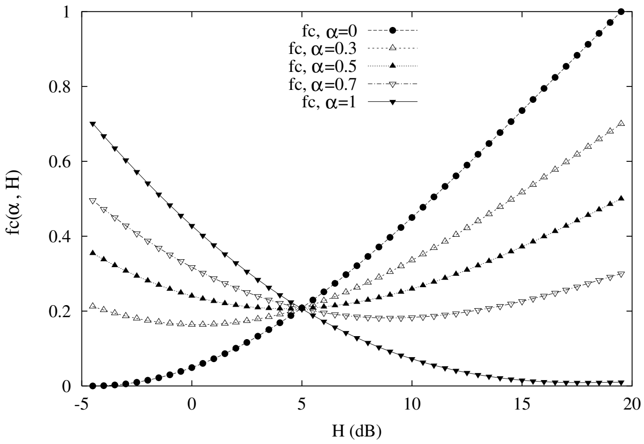

Fig. 8. Cost function $f_c(\alpha, H)$ as a function of H for $\alpha = \{0, 0.3, 0.5, 0.7, 1\}$.

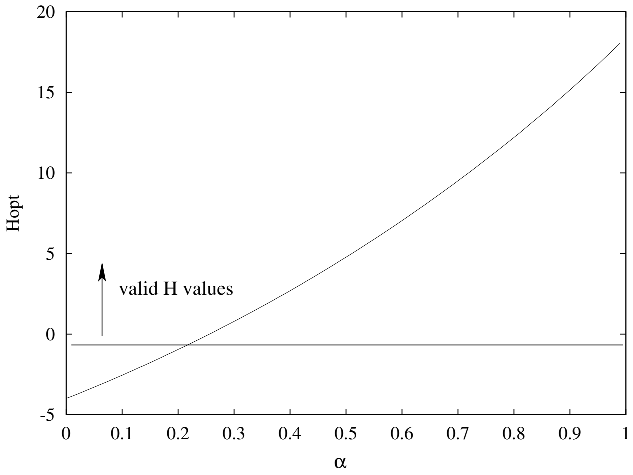

Fig. 9. Optimal H as a function of α.

The cost function $fc(\alpha, H)$ as a function of H for different α values is reported in Figure 8. Note that a unique cross point exists by varying α, corresponding to the case $h_l = t_{on}$. The $fc(\alpha, H)$ minimization gives the H optimum, which is reported as a function of α, having reported the H validity region, in Figure 9. It is interesting to observe that for the considered parameters, a linear dependence between the optimal H and α is verified.

In Figure 10 the value of optimal H is reported both as a function of α and v.

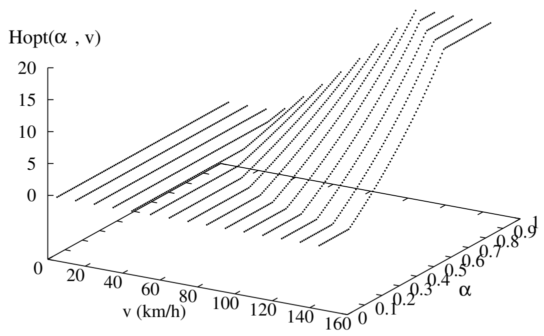

Fig. 10. $H_{opt}(\alpha, v)$.

V. Conclusions

By introducing a simple analytical model, we have derived a method to choose threshold parameters for the multicast mobility support solutions presented in [1] by considering both the handover latency (h_l) and the redundancy in the network resource utilization (t_{on}).

Let us observe that, in this model, we have not accounted for propagation effects such as shadowing and multi-path fading. Further investigations should take into consideration these effects.

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