

Hybrid Model of Least Squares Handover Algorithms in Wireless Networks

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Abstract—An adaptive handover algorithm for wireless communication systems is addressed in this paper. Moving from the Generalized Extended Least Square handover algorithm proposed in [1], we model the handover mechanism as a hybrid system, and we include it in a dynamic optimization problem which is solved through the use of a trellis diagram. The objective function takes into account the parameters that influence the handover mechanism. The optimal solution of the program allows to evaluate performance of the handover in terms of the probability of handover and probability of outage.

I. INTRODUCTION

The coexistence of a multiplicity of heterogeneous high capacity wireless systems has pushed the investigation of efficient handover algorithms. The handover process, the mechanism of transferring the connection between a mobile station (MS) and a base station (BS) or access point (AP) to another BS or AP, is strongly dependent on the wireless access technology, as well as on the particular radio propagation environment. Therefore, handover algorithms should adapt to the environment, e.g., macro-cellular, micro-cellular, overlay systems [2]. We mainly concern with microcellular systems since they appear to be the most effective mean of increasing the capacity of a cellular system even if they require a stronger radio resource management since the number of handover per cell is increased by an order of magnitude and the time to make an handover is reduced with respect to a macrocellular environment. Moreover microcells encounter a propagation phenomenon known as *corner effect*. This is characterized by a sudden drop in signal strength when a mobile turns around a corner, since the line of sight (LOS) from the serving BS to the MS is lost. The propagation of a signal in this environment has to be considered in two separate regions, subdivided with a breakpoint, each having different inverse power laws, [3], [1].

There is a long history of studies concerning handover (see e.g. [1], [2], [4], [5], [6], [7], [8], [9], [10]) Some of these papers are strongly differentiated on the basis of the choice of the handover decision parameter, e.g. the received signal strength from the serving and the neighbouring BSs, the distance from BSs, the bit error rate.

In this paper, we extend the Generalized Extended Least Square (GELS) handover algorithm proposed in [1], thus

assuming as decision criterium the signal strength measurement. The GELS algorithm has been developed in order to generalize the environment in which the least square path loss approach proposed in [1] could be applied. In particular, we investigate the optimal performance of the handover by posing the GELS as an optimal control problem for a hybrid system. We illustrate the performance of the approach by numerically solving the problem for an example scenario. Our approach differ from the relevant contributions in [2] - [10], since we include in the hybrid model the optimal design of the path loss filter provided by the GELS algorithm. Furthermore, we extend previous work in [1] by providing the optimal decision rule for handover.

II. SYSTEM MODEL

Without loss of generality, our system model consists of two base stations (or access points), BS_0 and BS_1 which are separated by D meters. A mobile station (MS) is supposed to move from BS_0 to BS_1 with constant speed v and on a straight line. The MS measures the strength of the signal coming from the two BSs at a constant time interval T . We are considering a wireless environment with path loss and log-normal fading (shadowing). Therefore, the signal strengths (in dB) coming from the base stations and measured by the MS at time nT , are given by [7]

$$p_s(n) = \alpha_s - \beta_s \log[d_s(n)] + u_s[d_s(n)],$$

$$s = 0, 1 \quad n = 1, \dots, N \quad (1)$$

where $d_s(n)$ represents the distance of the MS from BS_s , and N is the maximum number of measurements of signal strengths given by $N = \lfloor D/(vT) \rfloor$. Moreover, we have

- the term $\alpha_s - \beta_s \log[d_s(n)] \triangleq a_s[d_s(n)]$ denotes the path loss;
- the term $u_s[d_s(n)]$ models the shadow fading processes which is assumed to be a zero-mean stationary Gaussian process (in dB), and is characterized by the following autocorrelation function [11]:

$$\tilde{r}_{u_s}(\Delta) = E[u_s(d)u_s(d - \Delta)] = \sigma_{u_s}^2 e^{-|\Delta|/\bar{d}} \quad s = 0, 1 \quad (2)$$

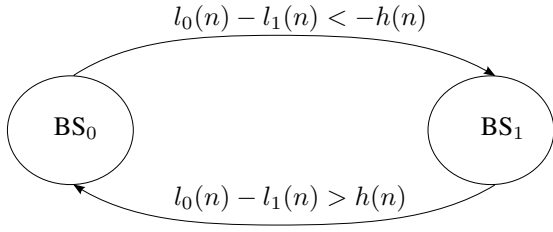


Fig. 2. Hybrid model of handover mechanism

Therefore, the filter coefficients are given by:

$$G_s(n, i) = A_s(n, i) - B_s(n, i) \log d_s(n) \quad (22)$$

IV. HYBRID SYSTEM

We believe that a useful representation for the GELS algorithm in the most generic environment can be given through the use of discrete hybrid automata as presented in [12]. For the simplified scenario considered in this paper we assume to model the GELS algorithm through a discrete time hybrid system, which is a simplification of a DHA and whose state is given by:

$$S(n+1) = A(n)S(n) - f(d(n+1), d(n)) + W(n) \quad (23)$$

where:

$$S(n) = [p_0(n), p_1(n), l_0(n), l_1(n)]^T \quad (24)$$

$$A(n) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ G_0(n+1) & 0 & 1 & 0 \\ 0 & G_1(n+1) & 0 & 1 \end{bmatrix} \quad (25)$$

$$f(d(n+1), d(n)) = \begin{bmatrix} \beta_0 \log \left(\frac{d_0(n+1)}{d_0(n)} \right) \\ \beta_1 \log \left(\frac{d_1(n+1)}{d_1(n)} \right) \\ G_0(n+1) \beta_0 \log \left[\frac{d_0(n+1)}{d_0(n)} \right] \\ G_1(n+1) \beta_1 \log \left[\frac{d_1(n+1)}{d_1(n)} \right] \end{bmatrix} \quad (26)$$

$$W(n) = \begin{bmatrix} u_0(n+1) - u_0(n) \\ u_1(n+1) - u_1(n) \\ G_0(n+1)[u_0(n+1) - u_0(n)] \\ G_1(n+1)[u_1(n+1) - u_1(n)] \end{bmatrix}, \quad (27)$$

and

$$d(n) = [d_0(n) \ d_1(n)]^T \quad (28)$$

The switching of the BSs after an handover decision is taken can be described by the following update equation for the discrete variable $b(n)$:

$$b(n) = \mathbf{1}_{\mathcal{E}(n)}, \quad (29)$$

where $b(n)$ is 1 when the MS is connected to the BS₁, and 0 when it is connected to the BS₀. It has to be remarked that the input variable of the system is the hysteresis $h(n)$, which determines the values of $\mathcal{E}(n)$. Fig. 2 shows the described hybrid system with the switching conditions on the edges.

V. OPTIMAL HYBRID CONTROL

The aim of this section is to find the optimum values of the system input $h(n)$ to be used in order to achieve good performance of the handover algorithm. We express performance in terms of the outage probability, and handover probability. Defining with β the outage probability threshold, the outage probability can be expressed as follows:

$$\begin{aligned} P_0(n) &= P[p_0(n) < \beta | b(n) = 0] \cdot P[b(n) = 0] + \\ &P[p_1(n) < \beta | b(n) = 1] \cdot P[b(n) = 1] \\ &= P[\{p_0(n) < \beta\} \cap \bar{\mathcal{E}}(n)] + \\ &P[\{p_1(n) < \beta\} \cap \mathcal{E}(n)]. \end{aligned} \quad (30)$$

The computation of Eq.(30) requires knowledge of the joint probability distribution of $p_0(n)$ and $y(k)$, $\forall k < n$. The same observation apply to $p_1(n)$. These computations are not a difficult task. However, in order to keep light the computations, we make the following approximation. Under the hypothesis that correlation is negligible between non time-contiguous events, it is possible to approximate the events (9) and (10) as follows:

$$\begin{aligned} \mathcal{E}(n) &\approx \{y(n) < -h(n)\} \cup \\ &\{y(n) < h(n), y(n-1) < -h(n-1)\} \end{aligned} \quad (31)$$

$$\begin{aligned} \bar{\mathcal{E}}(n) &\approx \{y(n) \geq h(n)\} \cup \\ &\{y(n) \geq -h(n), y(n-1) \geq h(n-1)\} \end{aligned} \quad (32)$$

Using (31) and (32), we have

$$\begin{aligned} P\{p_0(n) < \beta, \bar{\mathcal{E}}(n)\} &= \\ &P\{p_0(n) < \beta, y(n) \geq h(n)\} + \\ &P\{p_0(n) < \beta, y(n) \geq -h(n), y(n-1) \geq h(n-1)\}, \end{aligned} \quad (33)$$

$$\begin{aligned} P\{p_1(n) < \beta, \mathcal{E}(n)\} &= \\ &P\{p_1(n) < \beta, y(n) < -h(n)\} + \\ &P\{p_1(n) < \beta, y(n) < h(n), y(n-1) < -h(n-1)\}, \end{aligned} \quad (34)$$

Equations (33) and (34) can be computed knowing the correlation between $y(n)$ and $p_i(n)$.

The handover probability is defined as

$$\begin{aligned} P_H(n) &= P[b(n) = 0, b(n-1) = 1] \cdot \mathbf{1}_{b(n-1)=1} + \\ &P[b(n) = 1, b(n-1) = 0] \cdot \mathbf{1}_{b(n-1)=0} \\ &= P[\bar{\mathcal{E}}(n), \mathcal{E}(n-1)] \cdot \mathbf{1}_{b(n-1)=1} + \\ &P[\mathcal{E}(n), \bar{\mathcal{E}}(n-1)] \cdot \mathbf{1}_{b(n-1)=0} \end{aligned} \quad (35)$$

Under previous approximations, it is possible to see that

$$\begin{aligned} \mathcal{E}(n) \cdot \bar{\mathcal{E}}(n-1) &= \{y(n) < -h(n), y(n-1) \geq h(n-1)\} + \\ &+\{y(n) < -h(n), y(n-1) \geq -h(n-1), y(n-2) \geq h(n-2)\}. \end{aligned} \quad (36)$$

and:

$$\begin{aligned} \bar{\mathcal{E}}(n) \cdot \mathcal{E}(n-1) = & \{y(n) \geq h(n), y(n-1) < h(n-1)\} + \\ & + \{y(n) \geq h(n), y(n-1) < h(n-1), y(n-2) < -h(n-2)\}. \end{aligned} \quad (37)$$

The simultaneous minimization of the outages and handovers can be achieved defining the cost function:

$$J = \sum_{n=1}^K \alpha \cdot P_H(n) + (1 - \alpha)P_O(n), \quad (38)$$

where α is a parameter introduced to tradeoff the performance in term of outages or handoff, and K is the time horizon. Note that the cost function depends on the hysteresis value $h(n)$. systems. Thus, an optimization problem can be expressed as

$$\begin{aligned} \min_{h(n)} \quad & J \\ \text{s.t.} \quad & S(n+1) = A(n)S(n) - f(d(n+1), d(n)) + W(n) \\ & b(n) = \mathbf{1}_{\mathcal{E}(n)} \end{aligned} \quad (39)$$

The cost function can be optimized with dynamic programming techniques, thus getting the optimal input $h(n)$ of the hybrid system.

The dynamic programming approach is based on the possibility to estimate the fading parameters over a time horizon, and then on the optimization of the input at a given time n over all the possible future states and inputs. In actual situation, however, a prediction of the wireless parameters can be done only on a short time scale. Furthermore, even though the inputs assume only discrete values [1], the combination of all possible future states and inputs would have an exponential growth as function of the time horizon. Therefore, we consider that the optimization is carried out for a time horizon of few time instants \bar{K} (according to the decorrelation time of the fading, and the sampling time of the processes) from the current time n , and that the input is the same over such a time horizon.

Under these assumptions, the dynamic programming optimization can be performed with the help of a trellis structure, where each stage of the trellis is associated to a time instant and the possible values that the state of the system assume. The starting stage of the trellis is associated with the state of the system at the time $n-1$, and the ending stage with the states of the system at the time $n+\bar{K}$. Details about the implementation of this strategy is discussed in the next section.

VI. IMPLEMENTATION

In this section we report on the implementation of the optimization problem described in the previous section.

The optimization is only needed in a region which is close to the cells boundaries, so we take into account a path of Dis= 500 m, whose left side is 750 m far from BS₀, as shown in figure 4. The coherence interval is assumed to be $\bar{d} = 20$ m, which implies that predicted values of the wireless channel coefficients are valid only up to 20 meters far from the starting point. This means that, if the current BS and the hysteresis value

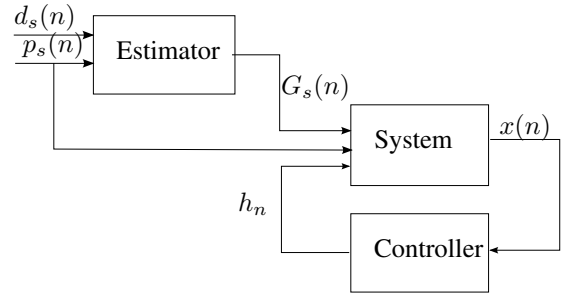


Fig. 3. Control scheme.

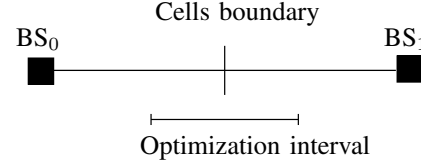


Fig. 4. Optimization scheme

are assumed to be known at time $n-1$, future values of these parameters can be predicted up to the time instant $n+3$. In fact, assuming a sampling distance $d_c = v \cdot T_c = 6.24$ m, where $v = 13$ m/s and $T_c = 0.48$ s are the speed of the MT and the sampling interval, respectively, it follows that the number of prediction stages (and thus the number of stages of the trellis diagram) is:

$$\frac{\bar{d}}{d_c} = 4 \quad (40)$$

In figure 5 we report the trellis corresponding to the possible future states. The optimization algorithm is as follows:

- 1) we assume that at distance 750 meters the system is at the generic time instant $n-1$ where the MT is still connected to BS₀ with the maximum value of the hysteresis margin;
- 2) since the channel coefficients are valid up to 4 samples from this starting point, we compute through dynamic programming the costs of each reverse path as a function of the hysteresis which is assumed to be the same for each path of the four stages of the trellis;
- 3) for any path starting from $b(n-1)$ and ending to one of the possible values of $b(n+3)$, we compute the objective function as a function of the hysteresis;
- 4) for each path we then compute the hysteresis value that minimize the cost function corresponding to the path;
- 5) once the hysteresis levels are known, it is possible to compute numerically the objective function associated to each path, and thus the actual cost path;
- 6) the values of $b(n)$ and $h(n)$ are computed selecting the

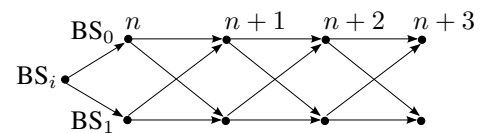


Fig. 5. Trellis scheme.

path with the minimum cost;

- 7) the system goes in the next state, when a new value of the fading parameters is produced. The trellis is updated removing the last stage, and adding a new one.

The procedure described above is performed a number of times given by $\text{Dis}/d_c = 80$.

VII. CONCLUSION AND FUTURE WORKS

In the framework of the analysis of linear handover algorithms, the GELS algorithm proposed in [1] has been modelled through the use of hybrid systems theory and an optimization problem has been posed in order to find the optimal decision rule for the handover procedure. The optimization problem can be implemented through the use of a trellis representation and of dynamic programming for the simplified scenario described.

Future work is concerned with progresses along two major directions. The first one deals with further formal enhancement of the hybrid model for the GELS algorithm through the more general framework of DHA, [12]. The second research line is intended to explore the solution of the optimization problem for a more realistic scenario which includes an higher number of BSs as well as multiple access interference.

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