# An MDP-Based Handover Decision Algorithm in Hierarchical LTE Networks

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***Abstract*—Hierarchical macrocell and femtocell networks aim to provide seamless roaming and improve network capacity. UEs moving in such networks may experience frequent handovers. In this paper, a handover decision algorithm considering data arrival, handover delay and signaling cost is proposed based on Markov decision processes. The expected total reward seeks a balance between transmission latency and handover signaling overhead, under dynamic traffic arrivals. A typical scenario is simulated, where a UE roams in a macrocell, passing through an array of femtocells with different connection capacities, and the simulation experiment indicates the effectiveness of the proposed algorithm.**

## I. INTRODUCTION

The demand for higher data rates in wireless cellular networks is increasing, and has triggered the development of femtocells. Femtocells are small base stations transmitting at low power, meant to be placed in individual home/office and backhauled onto operators network via conventional digital subscriber line (DSL) or cable broadband access (or, when available, fiber) [1]. Due to their short transmit-receive distance, femtocells can greatly reduce transmit power, prolong handset battery life, and achieve a high signal-to-interference-plus-noise ratio (SINR) [2].

The deployment of femtocells changes the architecture of conventional macrocellular networks. The new network architecture is divided into the macrocell tier and the femtocell tier. The macrocell tier is composed of long range base stations (macrocells) that provide cellular coverage to mobile users, while the femtocell tier is comprised of short-range access points (femtocells) that offer high throughputs [3]. The emerging hierarchical macrocell and femtocell networks in LTE system have been playing a crucial role in providing better service quality for the users. In order to achieve high quality, handover support is key. Cell handover enables the UE to transfer its service seamlessly from its serving cell to the target cell without terminating the service [4]. There are three types of handover in hierarchical networks: 1) femto-to-macro handover; 2) macro-to-femto handover; and 3) femto-to-femto handover [5].

The handover decision involves selecting the target point of attachment and the time of handover. Handover criteria such as received signal strength, network connection time, power consumption, velocity of the mobile terminal, user preferences may need to be taken into consideration to maximize user satisfaction [6]. Many handover algorithms for hierarchical networks have been studied in the literature recently. In [7], the authors combined the values of received signal strength from the serving macrocell and the target femtocell, considering the large asymmetry in the transmit powers of the two tiers. In [8], the authors proposed two handover decision algorithms considering mobile terminal's velocity as well as received signal strength in the two-hierarchy networks. In [9], the authors proposed a novel handover decision algorithm based on dynamic programming, taking into consideration UE location and mobility. In [10], the authors introduced a handover decision algorithm that optimizes a combined cost function involving battery lifetime of mobile terminals and load balancing among access points. In [11], the authors proposed an MDP-based handover decision for maximizing the expected total reward of a connection based on the information of available bandwidths and delays from different networks. To evaluate handover performance, the total reward combines a link reward function and a signaling cost function. In [12], the authors formulated the handover decision problem for 4G wireless networks as a constrained MDP with the objective of maximizing the expected total reward of a connection subject to the expected total access cost constraint. The model considers connection duration, QoS metrics, mobility/location information, network access cost, and signaling cost incurred on the network.

The aforementioned handover decision algorithms generally neglect the issue of bursty data arrivals. The arrived data packet size, handover delay and transmission rate altogether determine the amount of data transmitted in a decision period. Therefore, the joint effect of these factors needs to be properly combined and balanced, and there exists a tradeoff between data transmission and handover signaling cost. Furthermore, the inherent stochastic nature of bursty data arrivals needs to be adaptively treated and exploited in the handover decision process. For these purposes, we utilize Markov decision processes (MDP) [13] as the modeling tool, which has been extensively used in the literature due to its capability of yielding optimal solutions for sequential decision making problems involving stochastic processes. The main idea of the proposed MDP-based handover decision algorithm is to combine data arrival, transmission rate, and handover

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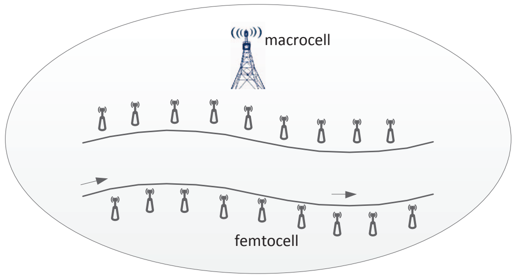


Fig. 1. Hierarchical macrocell/femtocell networks.

signaling overhead to derive a handover criterion, and we introduce a tradeoff factor to enable a tunable combination of transmission reward and handover cost. We perform extensive numerical experiments and the results indicate that the proposed algorithm is effective.

The remaining part of this paper is organized as follows. In Section II, we describe the hierarchical LTE network environment. In Section III, we present the MDP model formulation, the handover decision algorithm, the optimality equations, and the value iteration algorithm. In Section IV, we exhibit numerical experiments, presenting detailed simulation setup, numerical results and discussions. Finally, Section V concludes the paper.

## II. Network Model

As shown in Figure 1, imagine that there is a road within the coverage of a macrocell, and assume that a number of houses are distributed along sides of the road. Adjacent houses are close and lined with equal distance. Suppose that each house has an active femtocell operating in open access mode [4]. A UE moves along the road and passes through a series coverage areas of femtocells; also note that the macrocell is always available.

According to conventional handover decision algorithms, the UE would handover to the cell which would provide the highest transmission rate. Though this strategy is beneficial for transmitting continuous data, in the presence of a series of femtocells, the UE would experience a successive series of handovers during its connection lifetime, thus incurring a perhaps undesirably high handover signaling cost.

In our proposed MDP-based algorithm, several factors have impact on handover decision making, listed as follows:

### A. Network Situation

Network situation is represented by transmission rate, handover delay and signaling cost, from one network to another. A handover incurs delay and signaling overhead, which vary with the type of handover. During handover, there is a disruption to the call during which time data transmission cannot be serviced. Meanwhile, the transmission rates provided by macrocell and femtocell networks are different. Therefore, it is necessary that we take both the achieved QoS and the signaling load incurred on the network into account when making handover decision.

### B. Data Packet Size

In the proposed model, an arriving data packet first reaches into a buffer of infinite size. A segment of data in the buffer is fetched at each decision epoch to update the amount of data to be transmitted, and we denote the size of transmitted data segment as $Q$. If the size $Q$ is usually small as would be typically encountered for bursty data arrivals, deciding handover to a cell with higher capacity may be uneconomic. We hence need to make the handover decision taking into account the data packet size.

### C. User Preference

User preference describes the UE's experience of transmitting data via different networks. Some conventional handover decision algorithms enforce the UE to frequently handover seeking for high transmission rate. However, such frequent handovers for highly mobile UEs is likely to lead to handover failure and dropped calls, and furthermore the network may consequently become overloaded. Under this consideration, unless necessary, the UE may tend to continue its current connection which may provide a possibly lower transmission rate than other candidate networks.

## III. Handover Decision Algorithm

In this section, the MDP model is used to formulate the handover decision problem. An MDP model consists of five elements: 1) decision epochs; 2) states; 3) actions; 4) transition probabilities; and 5) rewards [11]. In the following, we describe how the handover decision problem in hierarchical networks can be formulated as an MDP to obtain the optimal policy.

### A. Decision Epochs

The decision epoch $t$ is the time at which a UE leaves or enters the coverage area of a femtocell. In our model, update occurs before decision-making in a sufficiently short time so that we view update and decision-making to happen simultaneously. The interval between two successive decision epochs is the residence time of the UE in the coverage of a femtocell. For simplicity of description, we assume that the interval length is a constant, denoted as $t_{dec}$, so that we have $t = \{0, t_{dec}, 2t_{dec}, 3t_{dec}, ...\}$ as the decision epochs; it is possible to extend our model and algorithm to the case where the interval length is variable.

### B. States

Considering the situation of the candidate network and the amount of data to be transmitted, which both influence the decision making at a given decision epoch, we denote the system state at each decision epoch as a multi-dimensional vector. The state space $S$ is defined as

$$S = \{1, 2\} \times Q \times C^1 \times C^2 \times T,$$

where $\{1, 2\}$ represents the set of available networks that the UE can connect to: "1" represents macrocell and "2" represents femtocell; $Q$ denotes the amount of data to be transmitted at the decision epoch; $C^m$ is the capacity of the network $m$ ($m = 1, 2$) and we assume that the capacity of a network is a constant during each decision period; $T$ represents handover delays.

Let $D$ be an independent and identically distributed (i.i.d.) random variable denoting the amount of data arriving the buffer in each decision period, let $d_j$ be its value in the $j$th decision period, and let $q_j$ be the amount of data which is updated before the $j$th decision epoch. When UE handovers from network $m$ to network $n$, we have

$$q_{j+1} = [q_j - C_{n,j} \cdot (t_{dec} - \tau_{mn,j})]^+ + d_j, \qquad (1)$$

where $[x]^+ \equiv max\{x, 0\}$, $C_{n,j}$ is the capacity provided by the network $n$ in the $j$th decision period, and $\tau_{mn,j}$ is the handover delay from network $m$ to network $n$ in the $j$th decision period. The product term $C_{n,j} \cdot (t_{dec} - \tau_{mn,j})$ denotes the maximum amount of data that can be transmitted when UE handovers from network $m$ to network $n$ in the $j$th decision period. In this paper, for simplicity, We assume that $C_{n,j}$ is deterministic; it is possible to extend the model and algorithm to the case where $C_{n,j}$ is i.i.d. random. We assume that $\tau_{12,j}$, $\tau_{21,j}$, $\tau_{22,j}$ are i.i.d. random variables depending on network topology and configuration. Since in our model we consider only one macrocell, $\tau_{11,j}$ is equal to zero. At the $j$th decision epoch, the state of the MDP is $s = [m, q_j, C_{1,j}, C_{2,j}, \tau_{m1,j}, \tau_{m2,j}]$.

### C. Actions

At each decision epoch, the handover decision algorithm instructs the UE to take an action based on the current state information. The action is to decide whether to connect to the current network or to handover to another network. We use $A = \{1, 2\}$ to represent the set of possible actions. The UE is allowed to connect to only one of the networks simultaneously.

### D. Transition Probabilities

In MDP, the next state only depends on the current state and the decision maker's action but not on the previous states [13]. The transition probability from the current state $s$ to the next state $s' = [n, q_{j+1}, C_{1,j+1}, C_{2,j+1}, \tau_{n1,j+1}, \tau_{n2,j+1}]$ at the $(j+1)$th decision epoch is the joint probability of the state transition at each dimension under the chosen action $a$. Thus

$$\begin{aligned}
& p[s'|s, a] \\
\overset{(a)}{=}\ & p[n, q_{j+1}, \tau_{n1,j+1}, \tau_{n2,j+1} | m, q_j, \tau_{m1,j}, \tau_{m2,j}, a] \\
=\ & p[q_{j+1}, \tau_{a1,j+1}, \tau_{a2,j+1} | q_j, \tau_{m1,j}, \tau_{m2,j}, a] \\
\overset{(b)}{=}\ & p[q_{j+1} | q_j, \tau_{m1,j}, \tau_{m2,j}, a] \cdot p[\tau_{a1,j+1} | q_j, \tau_{m1,j}, \tau_{m2,j}] \\
& \cdot p[\tau_{a2,j+1} | q_j, \tau_{m1,j}, \tau_{m2,j}] \\
\overset{(c)}{=}\ & p[q_{j+1} | q_j, \tau_{m1,j}, \tau_{m2,j}, a] \cdot p[\tau_{a1,j+1} | q_j] \cdot p[\tau_{a2,j+1} | q_j] \\
\overset{(d)}{=}\ & p[D = d_j] \cdot p[\tau_{a1,j+1}] \cdot p[\tau_{a2,j+1}], \qquad (2)
\end{aligned}$$

where (a) follows from the modeling assumption that $\{C_{n,j}\}$ is deterministic, (b) follows from the fact that $q_{j+1}$, $\tau_{a1,j+1}$ and $\tau_{a2,j+1}$ are independent, (c) follows from the fact that $\tau_{12,j}$, $\tau_{21,j}$, $\tau_{22,j}$ are i.i.d. random variables, and (d) is based on utilizing (1).

### E. Rewards

For any action that the UE takes at each decision epoch, there is a reward. Given the current state $s$ and the chosen action $a$, the total reward function $r(s, a)$ depends on a data reward function and a signaling cost function which are respectively defined below.

*1) Data Reward Function:* It is desirable that the data transmission is completed the soonest with handover, but handover will bring latency, which in turn prolongs the data transmission time. The networks which the UE can connect to in each decision period provide different capacities. So the data reward function is used to represent the amount of data that the UE transmits by choosing action $a$ in state $s$ in the $j$th decision period:

$$r_{1,j}(s, a) = \max\{q_{j-1}, C_{a,j-1} \cdot (t_{dec} - \tau_{m,a})\} / D_{max}, \qquad (3)$$

where $D_{max}$ denotes the maximum amount of data that can be transmitted in a decision period, used to normalize the data reward function.

*2) Signaling Cost Function:* The normalized signaling cost function of the $j$th decision period is defined as

$$r_{2,j}(s, a) = K_{m,a} / \max_{m,n} K_{m,n}, \qquad (4)$$

where $K_{m,n}$ is the handover signaling overhead from the current network $m$ to the target network $n$ [11].

Finally, as mentioned in Section II, the total reward function between two successive handover decision epochs is defined as follows:

$$r(s, a) = r_{1,j}(s, a) - \omega r_{2,j}(s, a), \qquad (5)$$

where $\omega \in [0, 1]$ is a tradeoff factor that depends on the preference of the UE [12].

### F. Optimality Equations

Let $v^\pi(s)$ denote the expected total reward, given the policy $\pi$ and an initial state $s$. In order to maximize the expected reward given by (5), we choose the expected total discounted reward optimality criterion to obtain the MDP optimal policy $\pi^*$. Let $v(s)$ denote the maximum expected total reward with the initial state $s$; that is,

$$v(s) = \max_{\pi \in \Pi} v^\pi(s).$$

We seek an $\varepsilon$-optimal policy $\pi^*_\varepsilon$, that is, for a given $\varepsilon > 0$, a policy satisfying

$$v^{\pi^*_\varepsilon}(s) + \varepsilon \geq v(s).$$

The optimality equations are given by

$$v(s) = \max_{a \in A} \left\{ r(s, a) + \beta \sum_{s' \in S} p[s'|s, a] v(s') \right\}. \qquad (6)$$

The solutions of the optimality equations correspond to the maximum expected total reward $v(s)$ and the $\varepsilon$-optimal policy. There are various algorithms available to solve the optimization problem. We obtain the $\varepsilon$-optimal policy and the maximum expected total reward using the value iteration algorithm (VIA) [13].

TABLE I
SYSTEM PARAMETERS

| Value | Parameter |
|---|---|
| $P_m = 43$ dBm | Tx power of macro BS |
| $P_f = 15$ dBm | Tx power of femto BS |
| $PL_m = 28 + 25\log_{10} d$ | Path loss model for macrocell |
| $PL_f = 38.5 + 20\log_{10} d$ | Path loss model for femtocell |
| $W = 6$ dB | Wall loss for femtocell |
| $\sigma_m = 8$ dB, $\sigma_f = 6$ dB | Shadowing for macrocell and femtocell |
| 10 Mbit/s, 30 Mbit/s, 50 Mbit/s | Transmission rate of macrocell |
| 20 Mbit/s, 40 Mbit/s, 60 Mbit/s | Transmission rate of femtocell |
| $t_{dec} = 0.5$ s | Decision period |

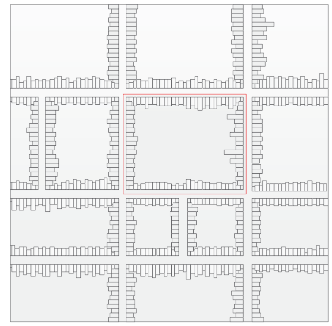

Fig. 2. Simulation scenario. The UE's route is indicated.

## IV. Simulation And Discussions

### A. Simulation Setup

Numerical results are investigated by using the scenario shown in Fig. 2 and the parameters listed in Table I. The scenario is a residential area covered by one macrocell and around 700 femtocells. As described in Section II, the distance between two adjacent femtocell base stations located at the same side of the road is 30 meters. The width of the road is 60 meters. The UE moves forward along the inner side of the predefined path, repeatedly. The macrocell base station is located in the center of the scenario. The path is covered by 100 femtocells within the coverage of the macrocell.

For conceptual clarity, we assume that the UE is always in E-UTRAN RRC_CONNECTED state [14]. We assume that each handover is successful and there is no call drop. Transmission links experience log-normal shadowing with mean zero and variance $\sigma_m^2$ and $\sigma_f^2$, respectively. In fact, the capacity provided to the UE by the network is changing constantly as a result of moving of the UE and the interference, fading, shadowing, load balancing and other factors. For simplicity, the capacities of femtocell and macrocell are quantified into three levels, respectively. All the femtocells share the same subchannels. The UE requests one subchannel for downlink transmission at each decision epoch.

For the handover delays $\tau_{12,j}$, $\tau_{21,j}$, $\tau_{22,j}$, we assume that they are uniformly selected from the set {20 ms, 40 ms, 60 ms, 80 ms}. The size of an arriving data packet, denoted by $d$, is a constant. At most one packet arrives in each decision period and the probability that one packet arrives is $P[D = d_j] = P[D = d] = P_d$. Thus Equation (2) is simplified into

$$p[s'|s,a] = \begin{cases} \frac{1}{4}P_d, & a = 1 \\ \frac{1}{16}P_d, & a = 2. \end{cases} \tag{7}$$

From (7) we can see that the transition probability is related to the data arrival probability and the chosen action. By varying the current state $s$ according to (1), the transition probability matrix can be obtained in a simulation-based manner. The switching costs are $K_{1,1} = 0$, $K_{1,2} = K_{2,1} = 0.8$ and $K_{2,2} = 1$. In the expected total discounted reward, the discount factor $\beta$ is set as 0.975; for the VIA, $\varepsilon$ is chosen to be $10^{-3}$.

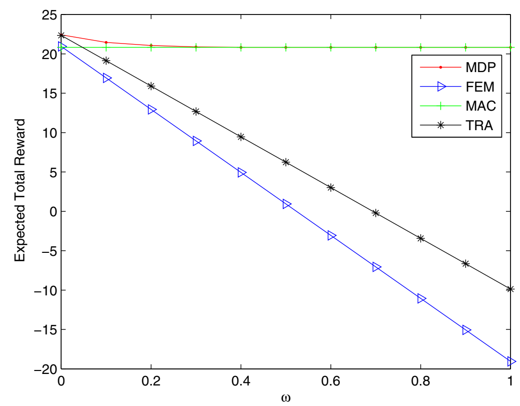


Fig. 3. Expected total reward under different trade-off factor $\omega$ when $D = 15$M (bits) and $P_d = 1/2$.

### B. Results and Discussions

In this section, we present and discuss the simulation results. To the best of our knowledge, there has been no previous proposals considering the impact of transmission time and data arrivals for handover in hierarchical LTE networks. Therefore we compare the performance of our proposed MDP-based handover decision algorithm with three other heuristic policies. In the first policy denoted by TRA, which is essentially a greedy algorithm, the network to be selected at each decision epoch is the one possessing the highest capacity. In the second policy denoted by MAC, the UE connects to the macrocell all the time and hence no handover is performed. In the third policy denoted by FEM, the UE always connects to the femtocell with the highest capacity.

Figure 3 shows the expected total reward versus the tradeoff factor $\omega$. The policy from the MDP algorithm gives the highest expected total reward for all values of $\omega$. When $\omega$ exceeds 0.3, the increase of signaling overhead becomes significant and the UE tends not to handover to the femtocell, so the expected total reward of the MDP policy coincides to that of MAC. Also as we can see, as $\omega$ increases, the expected total rewards of FEM and TRA both descend straightly down, because the handover signaling cost is not considered in these two policies.

From Figure 3, the tradeoff factor $\omega$ provides the network operators with more options. Small values of $\omega$

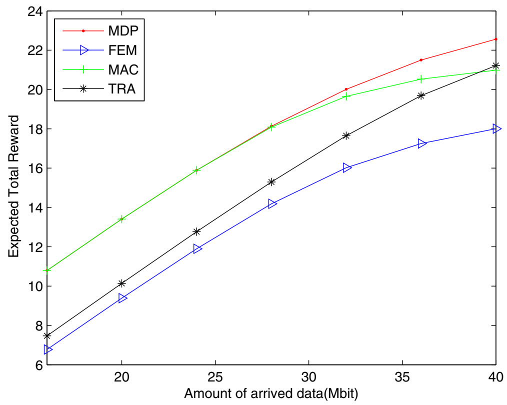


Fig. 4. Expected total reward under different amount of arriving data packet $D$ when $\omega = 0.1$ and $P_d = 1/2$.

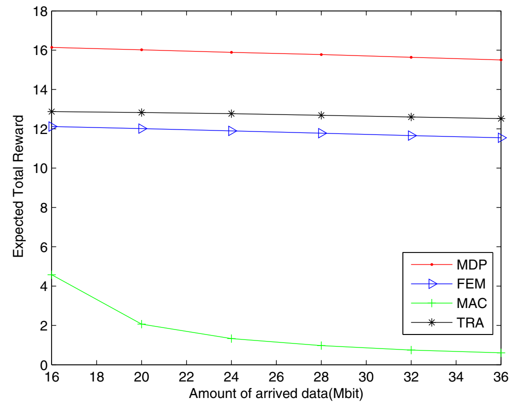


Fig. 5. Expected total reward under different amount of arriving data packet $D$ when $\omega = 0.1$ and the product of $D$ and $P_d$ is 12M (bits).

can be set when the networks load is light, in order to get better QoS parameters; large values of $\omega$ can be set for heavily loaded networks in order to refrain the UE from performing frequent handovers.

Figure 4 shows the expected total reward versus the size of the arriving data packets. When $D$ varies from 16M to 40M, the MDP algorithm gives the highest expected total reward. As we can see from the figure, when $D \leq 28$M, the expected total reward of the MDP policy is equal to that of MAC. This is because the MDP policy chooses to connect to the macrocell in this regime. The expected total reward of TRA converges to that of MDP as $D$ increases. The reason is that the majority of the weight is placed on the data reward function when the amount of arrived data is large.

Figure 5 shows the expected total reward versus the packet size, under a fixed average data arrival rate in each decision period. The expected total reward of the MDP algorithm gives the highest expected total reward, and decreases as the the packet size increases. Therefore, for a fixed data arrival rate, it may be beneficial to use a relatively small packet size in order to achieve a high reward.

## V. Conclusions

In this paper, a handover decision algorithm is proposed for hierarchical LTE networks. Effects of bursty data arrival, handover delay, network capacity, and the handover signaling overhead are taken into consideration for improving the decision. The algorithm is formulated as an MDP with the objective of maximizing the expected total reward, balancing between a data reward function and a signaling cost function. The total reward function thus offers a compromise between data transmission and handover signaling cost. Simulation experiments indicate that the proposed MDP algorithm is effective and outperforms heuristic handover policies.

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