On Enhancement of Handover Decision in Femtocells

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Abstract— **Deployment of femtocells with open or hybrid access into mobile networks leads to problems with handling handover of mobile users. In this paper we discuss two important aspects that can be considered and exploited in a design of innovative handover procedure for scenario with femtocells. The first aspect is related to varying quality and limited capacity of femtocell's backbone. Further, an accuracy of determination of a time spent by users in a femtocell is analyzed in this paper with purpose to exploit it for elimination of redundant handovers. The implementation aspects of proposed enhancements in handover decision algorithm are discussed as well.**

Keywords-femtocells, mobility, handover, backbone, estimation, Time in Cell

I. Introduction

New entity, denoted as femtocell, is introduced in standards for wireless networks. The femtocell, represented by Femto Access Point (FAP), is small base station connected to the operator's network typically via a cable connection. The femtocells are designed to improve indoor signal quality, to enable new services, or to offload macrocells. One of the major requirements on the FAP is its low cost since the FAPs are supposed to be owned by users.

Large amount of FAPs is assumed to be deployed in next years. However, dense deployment leads to several problems, such as interference or mobility management, that need to be solved to ensure high Quality of Services (QoS) for all users. In this paper, the problem of handover is tackled as it is crucial for ensuring user's seamless mobility. If only limited group of users can access the FAP (i.e., closed access is provided by the FAP), handover to this cell occurs very rarely since only small amount of users can access the FAP. The handover decision procedure is important especially for open or hybrid access FAP as all users can perform handover to any of these FAPs.

By deployment of femtocells with small radius, the number of initiated handovers can rise rapidly. Consequently, the users spend relatively short time in the femtocells. Thus, handover is performed frequently and an overhead due to handover management increases as well. Further, QoS is also decreased due to handover interruption. Utilization of conventional techniques for elimination of redundant handovers in scenario with femtocells (e.g., hysteresis or timers) is double-edged. Although these techniques can eliminate majority of handovers, it is only at the cost of significant drop in throughput gain introduced by open access femtocells [1][2]. Several papers exploit the knowledge of distance between a User Equipment (UE) and its neighboring femtocells (for example, see [3]). However, the femtocell's position is not known in the most cases since the FAP can be deployed indoor without ability to receive GPS signal for localization. Further, all MBSs are interconnected via a backbone offering very high quality, high capacity, and high stability in the conventional wireless networks. Therefore, the parameters of backbone are typically not taken into account in the proposals on advanced handover algorithms (see [3]–[5]). Nevertheless, the backbone of FAP is typically provided by a connection of low rate and variable delay.

In this paper, we outline an enhancement of handover decision by FAP's backbone characteristics. Further, we discuss an accuracy of prediction and estimation techniques for determination of a time spent by users in the area covered by FAPs. This can improve conventional ways for elimination of redundant handovers in networks with femtocells.

II. Enhanced Handover Decision in Femtocells

For advanced handover procedure, FAP's backbone quality must be considered during handover decision. Further, estimation and prediction techniques can be exploited efficiently as the radius of femtocells is very small. Note that the handover to a FAP can be profitable only for low speed users (such as pedestrians) due to low cell radius. High speed users do not spent enough time in the area covered by FAP to take advantage of higher quality of the connection. Thus, we assume only low speed users performing handover to a FAP.

A. *Backbone quality*

The FAP is typically connected to the Internet via a backbone of lower quality (e.g., xDSL). On that account, the backbone's parameters can fluctuate significantly in time. Handover is influenced by two backbone parameters: delay and capacity. To cope with the delay constrain, the next condition must be fulfilled before performing handover to a target FAP:

$$D_T^b \leq max\{ D_S^i \}; \qquad i = 1,2,...n \tag{1}$$

where D_T^b is the backbone delay of the target FAP and it expresses the packet delay from the FAP to the destination side of a transmission chain (that is either a server or other user), D_S^i stands for the maximum acceptable delay of *i-th* service currently experienced by the UE, and n is the total amount of services currently used by the UE for the multiservice case.

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The second parameter, backbone capacity, should be at least equal to the sum of all requests from all services experienced by the user as defined by the next equation:

$$C_T^b \geq \sum_{i=1}^{n} C_S^i ; \qquad i = 1,2,...n \tag{2}$$

where, C_T^b and C_S^i is the backbone capacity provided by the target FAP and the capacity required by *i-th* service currently experienced by the user respectively.

Each FAP is aware of its backbone quality as it needs this information to schedule users' data through backbone. Information on quality must be delivered to the MBS, which is supposed to take control over handover decision. The reporting of backbone quality (available capacity and packet delay) can be included in control information for coordination of MBSs and FAPs. The information on backbone delay can be provided in form of range of delays related to the experienced service class. It means, the delay is reported as an index representing appropriate range of delays. Its size is only several bits. For example, 4 bits enables to distinguish 16 classes, which is sufficient number. The information on capacity should be expressed as an absolute amount of available resources. The number of bits required for this information depends on accuracy of reporting information. Sufficient amount is 16 bits as it enables to distinguish 2^{16} levels of available capacity.

The transmission of information on backbone quality can be either triggered by a handover request or periodical. The drawback of handover triggered one is additional delaying of handover due to delivering information on backbone status to the MBS. However, the overhead is negligible since only few additional bits are transmitted per a handover. Contrary, the periodic reporting does not delay handover but it increases overhead. The maximum size of overhead generated during the periodical reporting is derived as follows. Bit rate necessary for reporting is expressed as ratio of the size of reported information and the interval between two reports. The maximum size of a report is 16+4 bits as stated before. The minimum reporting period is supposed to be equal to the frame duration, which is 10 ms in LTE-A. Then the maximum reporting overhead is 2 000 bps. This overhead is negligible comparing to the expected backbone capacity in Mbps.

Except both above mentioned backbone constrains, radio interface quality as in conventional macrocell networks must be considered as well. Then, the handover to a FAP is initiated only if subsequent formulas are fulfilled:

$$\begin{aligned} & min\{ C_T^r , C_T^b \} \geq \sum_{i=1}^{n} C_S^i ; \qquad i = 1,2,...n \\ & D_T^r + D_T^b + D_T^p \leq max\{ D_S^i \} ; \qquad i = 1,2,...n \end{aligned} \tag{3}$$

where C_T^r and D_T^r corresponds to the capacity and delay of the radio interface of the target FAP respectively, and D_T^p represents additional delays, such as processing delay or queuing delay, introduced by the target FAP.

B. Derivation of Time in Cell

Since the femtocells are of low radius, it is expected to reach more precise estimation of the time spent by users in the femtocell (denoted as Time in Cell, t_c) comparing to the case of macrocells. The t_c of a FAP is defined as the time when the FAP provides higher channel quality (s_f) than channel of MBS (s_m). The definition of t_c is depicted in Fig. 1.

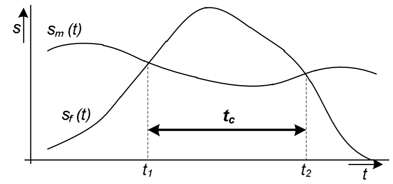

Figure 1. Definition of the Time in Cell for a FAP

Next, we derive maximum dispersion of t_c in femtocells. The minimum and maximum t_c can be determined as follows. Let distance covered by *j-th* user in a femtocell is defined as:

$$d_{f,j} = d_{f,avg} \pm \Delta_{d,j} \tag{4}$$

where $d_{f,avg}$ is average distance covered by all users in the FAP's area, and $\Delta_{d,j}$ represents distance deviation of *j-th* user.

Further, the speed of *j-th* user is defined as:

$$v_j = v_{j,avg} \pm \Delta_{v,j} \tag{5}$$

where $v_{j,avg}$ is the average speed of pedestrians and $\Delta_{v,j}$ stands for the speed variation of *j-th* user. Since only pedestrians are admitted to FAPs, the mean speed of users is normally distributed along $1.34\ ms^{-1}$ with deviation of $\Delta_{v,j,max} = 0.37ms^{-1}$ (see [6]). Then, the speed of *j-th* user is in interval $v_j = \langle 1.34 - 0.37 ; 1.34 + 0.37 \rangle ms^{-1}$. In compliance with above mentioned, average t_c is calculated as:

$$t_{c,j,avg} = d_{f,avg} / v_{j,avg} \tag{6}$$

Let define a scenario for determination of the lower and upper limits of t_c. The most common case of infrastructure deployment is represented by a single direct street (see Fig. 2.)

According to (4), (5), and (6), the real t_c of individual user is limited from lower boundary to:

$$t_{c,min} = \left(d_{f,avg} - \Delta_{d,j} \right) / \left(v_{j,avg} + \Delta_{v,j,max} \right) = \left(d_{f,avg} - \Delta_{d,j} \right) / 1.71 \tag{7}$$

Equation (7) corresponds to a movement of the fastest pedestrian along the shortest path. The $t_{c,min}$ depends on the position of a street in relation to the FAP's radius. The street is of the width Δ_w and its borders are in distances D_2 and D_1 from

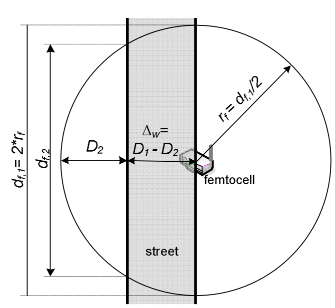

Figure 2. Notation for determination of t_c limits

the cell edge. Assuming the direct movement on the street, $t_{c,min}$ corresponds to the user's movement along the direct path, which is in distance D_2 from the cell edge. The distance $d_{f,2}$ covered by the user in the femtocell along the path distanced D_2 from the cell edge is determined as:

$$d_{f,2} = 2\sqrt{r_f^2 - (r_f - D_2)^2} \tag{8}$$

Therefore, the $t_{c,min}$ as a function of D_2 is:

$$t_{c,min} = d_{f,2} / (v_{j,avg} + \Delta_{v,j,max}) = 2\sqrt{r_f^2 - (r_f - D_2)^2} / 1.71 \tag{9}$$

The upper bound for t_c is derived analogically. The $t_{c,max}$ corresponds to a movement of the slowest user along the longest path. In this case, the trajectory covered by a user following the path distanced D_1 from the cell edge is equal to $d_{f,1} = 2r_f$ (see Fig. 2). Then, $t_{c,max}$ is derived as follows:

$$t_{c,max} = (d_{f,avg} + \Delta_{d,j}) / (v_{j,avg} - \Delta_{v,j,max}) = 2r_f / 0.97 \tag{10}$$

A dependence of $t_{c,min}$ and $t_{c,max}$ on D_2 is shown in Fig. 3. This figure is depicted for condition $D_1 = r_f$, which represents the maximum achievable $d_{f,1}$ (i.e., $d_{f,1} = 2r_f$) and thus it is the worst case scenario. As Fig. 3 shows, the variation of t_c is up to roughly *2.1* multiple of cell radius. This maximum variation of the t_c appears if the area of user's movement (that is, a street or a sidewalk) stretch over at least a half of the cell diameter (i.e., street width $\Delta_w = r_f$. Still, the variation of t_c is significantly lower than in the case of conventional macrocells since:

$$t_{c,max}^{mcro} = 2.1 \times r_B \text{ ; } t_{c,max}^{femto} = 2.1 \times r_f \text{ ; and } r_B >> r_f \tag{11}$$

where r_B and r_f represents radius of femtocell and macrocell respectively. Thus we can declare $t_{c,max}^{femto} << t_{c,max}^{macro}$.

In more realistic situation, the users are not limited to the direct movement. Their movement is influenced by other factors such as a deployment of streets in the cell, points of interests, users' behavior, etc. These factors can be represented by ξ. The t_c is also affected by a probability *TC* that the user will stay longer in the cell, e.g., due to a stop. Therefore, *TC* is related to the ξ. Neither ξ nor *TC* can be determined easily. However, both are clearly proportional to the cell radius since larger cell can cover more complex infrastructure lay-out (e.g., more street crosses, more points of interests, etc.). Hence, the probability *TC* is significantly higher for larger cells:

$$TC_{r_B} = f(\xi); \xi = f(r_B) >> TC_{r_f} = f(\xi); \xi = f(r_f) \tag{12}$$

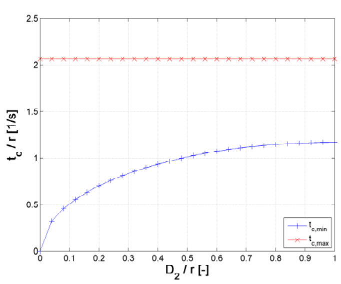

Figure 3. Deviation of $t_{c,min}$ and $t_{c,max}$ over relative distance of users' path from the FAP's position

Above mentioned shows that dispersion of minimum and maximum time in cell is significantly lower for cells with low radius. Thus, it can be included in handover in femtocells.

C. *Proposed enhancement of handover algorithm*

With relation to the conventional handover, the new algorithm considers backbone quality and t_c parameter.

If conventional handover criteria are met, the requirements on backbone are confronted with the parameters provided by the FAP. Subsequently, typical t_c for the FAP is compared with threshold $t_{c,Thr}$. The $t_{c,Thr}$ should be set up according to the FAP's load and according to user's services. Increasing $t_{c,Thr}$ lowers the amount of performed handovers. Only fulfillment of all conditions leads to handover initiation. If any of these criteria is not satisfied, handover is not performed.

Exchange of information on delay and capacity is only modification needed to implement proposed modifications to the current wireless networks as discussed in Section IIA.

III. CONCLUSION

This paper proposes enhancement of handover procedure taking advantage of low cell radius and considering FAP's backbone quality. Before performing handover to a FAP, the FAP's backbone capacity and delay must be confronted with user's requirements. The handover is performed only if FAP's backbone is able to satisfy the user. As the analysis of the time in cell shows, the variation of this parameter in femtocells is very low. Thus, time in cell can be used for handover to FAPs. Both aspects require only minor modification in backbone management communication among FAPs and MBSs.

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