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A NEW MODEL FOR BASE STATION POWER CALCULATION AS A CONSEQUENCE OF USER MOBILITY

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Abstract

In this paper we present a new model for base station calculation in various conditions of user mobility. It is proved that base station power is increased as a result of mobility for all users who do not need handover during a connection. Base station power is decreased for users, who are replaced by users from neighbouring cells after handover. As a final result, total base station power is not changed for initially uniformly distributed users. At the end of the paper model implementation is illustrated by several examples from practice which consider base station power in mobile cells with different position of great business centres or factories and with different constellations of mobility directions.

Keywords: user mobility, base station power, mobility distance, environment propagation coefficient, handover.

INTRODUCTION

User mobility plays a great role in the implementation of wireless (mobile) systems. Many problems appear as the results of mobility and it's mathematical and simulation analysis is pretty complex. References [1]-[6] are only a part of available literature. Among these references, [1] gives a survey of problems caused by user mobility. Reference [2] is a detailed analysis of practical problems in connection realization to allow user mobility. Reference [3] presents systems in which direction of user mobility is chosen randomly and is not changed in the considered base station (BS) cell during movement. In [4] additional moment of analysis is possibility to change directions of movement in a cell. The analysis of mobility in one practical system is presented in [5]. Reference [6] analyses problems connected to BS allocation and users movement in urban areas.

In this paper we present a new model for BS power calculation in various conditions of user moving. Section II explains how distance between BS and mobile user is calculated after user moving. After that, section III presents how distribution of BS power is changed after user moving as a function of various parameters, which have influence on BS power. Section IV considers total BS power as a result of users moving. Section V gives several examples from practice, where a new model may be implemented.

BASE STATION TO USER DISTANCE WHEN USER IS MOBILE

We can calculate the distance between BS and the user who is mobile in the area of base station cell by considering the model in Fig. 1.

Let us consider one base station cell, which is modelled by circle with a centre in point BS. We consider a group of users situated in the point designated by USER at a distance *r* from a BS (Fig. 1). From this point users start their moving in each direction with the same probability. Further, we suppose that the speed of user moving is constant and equal for each user. It means that, after some time, all users are situated at a circle with radius *d*, whose centre is in point USER. To perform our analysis, we shall divide all these users in groups of two of them, who are situated on the opposite sides of the presented circle. In the presentation in Fig. 1 we selected users on distance *r1* and *r2* from a BS (USER1 and USER2). These distances may be determined by the formulas:

$$r1 = \sqrt{r^2 + d^2 - 2 \cdot r \cdot d \cdot \cos(\alpha 1)} \quad (1)$$

$$r2 = \sqrt{r^2 + d^2 - 2 \cdot r \cdot d \cdot \cos(\alpha 2)} \quad (2)$$

It is satisfied that α1+α2=π, so equation (2) can be presented as

$$r2 = \sqrt{r^2 + d^2 + 2 \cdot r \cdot d \cdot \cos(\alpha 1)} \quad (3)$$

This method of calculation is satisfactory until users are situated in the area of considered BS cell after moving is realized. But, if some of distances *r1* and *r2* becomes greater than the cell radius (*R*), it is necessary to modify the method. The necessary modification can be explained by Fig. 2.

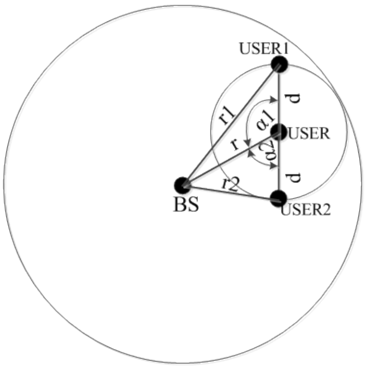

Fig. 1. *Illustration of user – BS distance calculation*

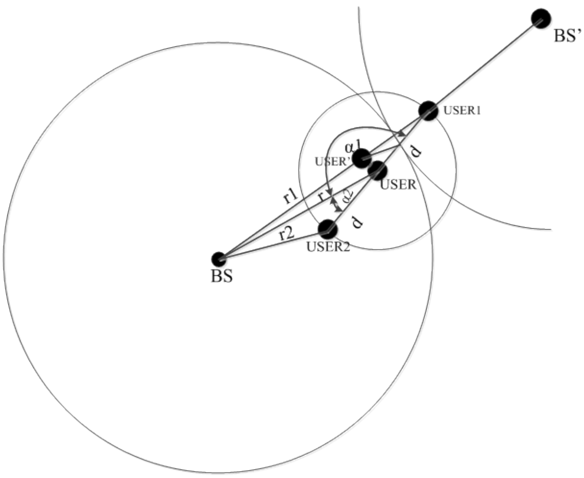

Fig. 2. *Illustration of user* – BS distance *calculation when user changes BS cell*

In Fig. 2 USER1 is (after moving) located at distance *r1* greater than cell radius *R*. That's why he is not any more under the control of base station BS, but under the control of neighbouring base station BS' (process of handover (handoff) at the cell rim, [3], [6]). USER1 is no more contributing to the BS power, but to BS' power. Instead of USER1, USER' is contributing to BS power. USER' behaves in relation to BS and BS' in the same way as USER1 in relation to BS' and BS. It means that, before moving, he was under the control of BS', but his mobility causes that he entered the BS cell area. The USER' distance from BS may be determined approximately as

$$r1' = 2 \cdot R - r1 \quad (4)$$

BASE STATION POWER DISTRIBUTION WHEN USERS START MOVING FROM ONE POINT

Base station power depends on several factors. First, it is determined in a different way for signalling channels and for traffic channels. When traffic channels are considered, in GSM systems there is difference whether the first carrier is considered, or some of other carriers are considered. When traffic channel is on the first carrier, its power does not depend on the distance between user and BS, i.e. it is always the same. On the other carriers, power of one traffic channel is variable, depending on the distance between BS and user. The power may be changed in 15 steps of 2dB difference between two adjacent steps. In this paper BS power is modelled as it is changed continuously in the function of distance, i.e.

$$P = k \cdot r^{\gamma} \quad (5)$$

where *r* is distance between BS and user, *γ* is propagation coefficient and *k* is coefficient of proportionality. Coefficient *γ* depends on environment conditions and its value may be $2 \le \gamma \le 5$, [2], [7]. In this paper we consider traffic channels, whose power depends on distance between user and BS.

Let us now group users, who start their moving from point USER in Fig. 1 into *m* groups, who are going on opposite sides. The first group consists of user subgroup, whose $\alpha 1=0$ and user subgroup, whose $\alpha 2=\pi$. The second group consists of user subgroup, whose $\alpha 1=\pi/m$ and user subgroup, whose $\alpha 2=(m+1)\cdot\pi/m$, and so on. The last group consists of user subgroup, whose $\alpha 1=(m-1)\cdot\pi/m$ and user subgroup, whose $\alpha 2=(2\cdot m-1)\cdot\pi/m$. Each subgroup consists of equal number of users.

Let us now compare the power, which is necessary for each group of users before moving (*Pnmove*) and after moving (*Pmove*). Before moving, the power for a group may be expressed as

$$P_{nmove} = 2 \cdot k \cdot r^{\gamma} \quad (6)$$

and after moving this power is (from (1), (3) and (5)):

$$P_{move} = k \cdot \begin{pmatrix} \left(\sqrt{r^2 + d^2 - 2 \cdot r \cdot d \cdot \cos(\alpha 1)}\right)^{\gamma} + \\ + \left(\sqrt{r^2 + d^2 + 2 \cdot r \cdot d \cdot \cos(\alpha 1)}\right)^{\gamma} \end{pmatrix} \quad (7)$$

The situation is specific if γ=2. From (7) it follows that

$$P_{move} = 2 \cdot k \cdot \left(r^2 + d^2\right) \quad (8)$$

i.e. the power does not depend on α1 and it is always greater than before moving.

For $2<\gamma\leq 5$ power for each group depends on α1 and it can be estimated (for integer value of γ) starting from (7) as:

$$\begin{aligned} P_{move} &> k \cdot \begin{pmatrix} \left(r^2 + d^2 \cdot \cos^2(\alpha 1) - 2 \cdot r \cdot d \cdot \cos(\alpha 1)\right)^{\frac{\gamma}{2}} + \\ + \left(r^2 + d^2 \cdot \cos^2(\alpha 1) + 2 \cdot r \cdot d \cdot \cos(\alpha 1)\right)^{\frac{\gamma}{2}} \end{pmatrix} = \\ &= k \cdot \left((r - d \cdot \cos(\alpha 1))^{\gamma} + (r + d \cdot \cos(\alpha 1))^{\gamma}\right) = \\ &= k \cdot \begin{pmatrix} r^{\gamma} - \binom{\gamma}{1} \cdot r^{\gamma-1} \cdot d \cdot \cos(\alpha 1) + \binom{\gamma}{2} \cdot r^{\gamma-2} \cdot d^2 \cdot \cos^2(\alpha 1) - \\ \ldots - d^{\gamma} \cdot \cos^{\gamma}(\alpha 1) + r^{\gamma} + \binom{\gamma}{1} \cdot r^{\gamma-1} \cdot d \cdot \cos(\alpha 1) + \\ + \binom{\gamma}{2} \cdot r^{\gamma-2} \cdot d^2 \cdot \cos^2(\alpha 1) + \ldots + d^{\gamma} \cdot \cos^{\gamma}(\alpha 1) \end{pmatrix} > \\ &> k \cdot 2 \cdot r^{\gamma} \end{aligned} \quad (9)$$

i.e. the power is also always greater than before moving. Its maximum value is reached for α1=0 and minimum value for α1= $\pi/2$.

The results of this analysis is illustrated by Fig. 3, for γ=4. The results are presented for three values of starting point distance from base station: $r=0.25\cdot R$, $r=0.35\cdot R$ and $r=0.55\cdot R$ and for users moving to a distance $d=0.3\cdot R$ from a starting point. Each point in the graph considers together two users: the first one, who moves in the direction at an angle α1 (USER1 in Fig. 1) and the second one, who moves at an angle α2=π-α1 (USER2 in Fig. 1). It is obvious that power increase is as greater as starting point is located nearer to the BS.

The conclusion on the base of the analysis is that BS power is always increased after users moving from one point, if they are not located in the area planned for handover by the neighbouring BS.

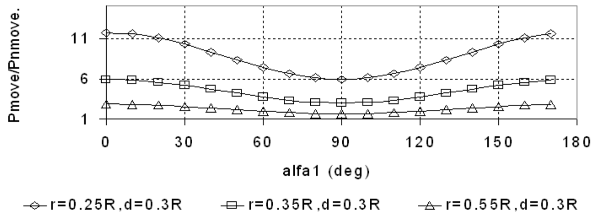

Fig. 3. *Ratio of BS power when users are mobile to BS power when they are located in one point as a function of mobility direction and distance between BS and user starting point (in the case when there is no handover)*

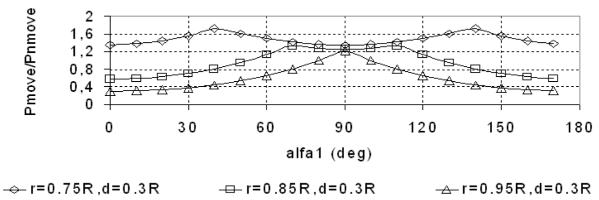

Fig. 4. *Ratio of BS power when users are mobile to BS power when they are located in one point as a function of mobility direction and distance between BS and user starting point (in the case when handover is necessary)*

Situation when users starting point is located in such a way that handover is necessary is presented in Fig. 4, also for γ=4. Characteristics are presented for three values of starting point distance from BS and for $d=0.3\cdot R$. When $r=0.75\cdot R$, not a great number of users are replaced by users from neighbouring cells. In this case is always greater power when users are moving (*Pmove*) in relation to power in their starting point (*Pnmove*), as it is when it is $r<0.7\cdot R$, i.e. when there is no handover at all. But, the shape of the curve is different than in the cases when there is no handover (Fig. 3). Its maximum is not at 0 and π. It is moving towards π/2, as the result of contribution of users with handover, who decrease power (between 0 and 40^0 and between 140^0 and π for this curve). If r is increased ($r=0.85\cdot R$ and $r=0.95\cdot R$), relation

Pmove/Pnmove depends on direction of user moving, i.e. on angle $\alpha 1$: it can be greater than 1 or smaller than 1. And the characteristic maximum is moving more and more to the central point π/2, as the number of users with handover is increased.

Fig. 5 presents BS power increase when distance between users starting and final point is altered, for γ=4. This distance is parameter in Fig. 5. Mobility distance is selected in such a way that there is no handover in any case. BS power increase significantly depends on the distance of user mobility.

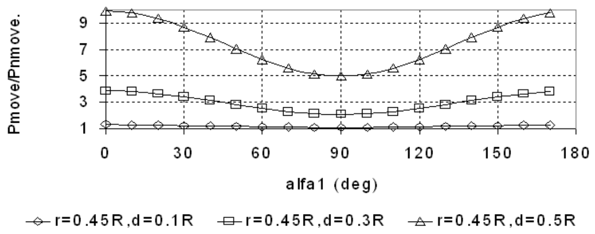

Fig. 5. *Ratio of BS power when users are mobile to BS power when they are located in one point as a function of mobility direction and distance of movement (in the case when there is no handover)*

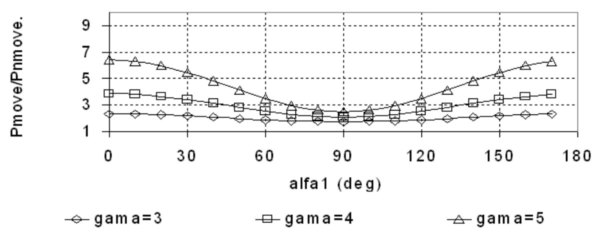

Fig. 6. *Ratio of BS power when users are mobile to BS power when they are located in one point as a function of mobility direction and coefficient γ (in the case when there is no handover)*

Influence of propagation coefficient γ is also significant and it is illustrated by graph in Fig. 6. Power increase after users moving is greater when γ is greater. Characteristics are presented for starting point at r=0.45·R and for moving distance d=0.3·R.

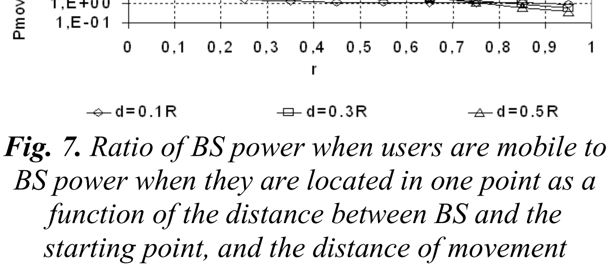

Fig. 7. *Ratio of BS power when users are mobile to BS power when they are located in one point as a function of the distance between BS and the starting point, and the distance of movement*

Fig. 7 presents ratio of BS power after user moving to the power when they are located in their starting point as the function of distance between BS and the starting point, for γ=4. Characteristics are presented for three values of moving distance. Power increase is very great when users are near BS and after that this power increase is reduced when distance between BS and starting point increases. The great power increase for users located before moving near BS is the consequence of multiple distance increase after moving and, relatively, great value of γ. At greater values of distance between BS and starting point the power after users moving becomes smaller than when they are located in their starting point, as a consequence of handover.

TOTAL BASE STATION POWER AS A RESULT OF USER MOBILITY

Until now we investigated only the power of user groups, located in some point in the BS cell area. When considering the graphic in Fig. 7, one could suppose that total BS power increases as the result of moving. But, this is not true for uniformly distributed users in the BS area. There are two reasons why BS power after users moving is not greater than before moving. The first one is that number of users, located near BS, is smaller than the number of distant users. The second one is that the necessary BS power for nearer users is smaller than necessary BS power for distant users. It means that, because of these two emphasized reasons, the part of total power, which is necessary for nearer users, is significantly smaller than for users located in the beginning at the greater distance. Although the power for nearer users is significantly more amplified, this power is only the small part of total BS power and this power amplification has not a great impact on total BS power.

Fig. 8 may be used to explain how we determine the probability that users are situated in some part of BS cell. Users are uniformly distributed in the whole area of BS cell. In that case this probability is equal to the ratio of the surface of considered BS cell part to the surface of the whole BS cell. For example, if we want to calculate probability that user is situated in the annulus with the outer radius r_n and the inner radius r_{n-1} (annulus n), Fig. 8, we will use the formula

$$\mathrm{Pr}_{ann} = \frac{\pi \cdot r_n^2 - \pi \cdot r_{n-1}^2}{\pi \cdot R^2} = \frac{r_n^2 - r_{n-1}^2}{R^2} \qquad (10)$$

When considering situation before users' movement, power is calculated for users in each annulus. It is, normally, supposed that the same power is necessary for each user in an annulus. The power for users in one annulus is dependent on the probability that users are situated in the considered annulus. Total power before movement (P_{tnmove}) is then obtained by summing values of power for users in each annulus.

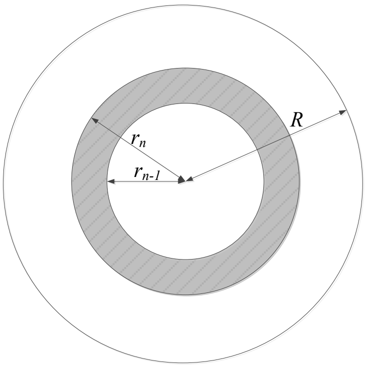

Fig. 8. *Method of determining number of users in part of BS cell (uniform users distribution)*

For users starting movement from some annulus, distance from BS is calculated depending on an angle (direction of movement) according to (1), or (2). This calculation is performed for each equally probable angle of movement. After that total BS power after movement (P_{tmove}) is calculated as the sum for users situated before movement in each annulus. Again power is dependent on the probability that user is situated in the considered annulus.

Table 1. *Ratio of total BS power after users moving to total BS power before moving as a function of moving distance*

d	P_{tmove}/P_{tnmove}
$0.1 \cdot R$	1.005
$0.2 \cdot R$	1.0048
$0.3 \cdot R$	0.9964
$0.4 \cdot R$	0.9795
$0.5 \cdot R$	0.9526

Table 1 presents ratio of the total BS power after users moving (P_{tmove}) to the total BS power before their moving (P_{tnmove}), when users are initially uniformly distributed, as a function of moving distance d. This ratio is nearly equal to 1 and it slightly decreases when d increases.

MODEL IMPLEMENTATION

Example 1: Let us consider a BS cell, in which there is one great business centre near BS. One half of mobile users in the BS cell are employs in this business centre, and the second half are users uniformly distributed in the BS cell area. After finishing their job, employs leave business centre and start travelling in all directions with equal probability and at the same speed. During travelling, they use mobile phones. Propagation coefficient is γ=4. What is the total BS power increase after employs pass distance $0.3 \cdot R$, $0.5 \cdot R$ and $0.8 \cdot R$?

Solution: Calculation in this case shows that total BS power is increased 2.3%, 15.6% and 112.8%, respectively, for users moving to distance $0.3 \cdot R$, $0.5 \cdot R$ and $0.8 \cdot R$ from business centre. So, the increase may be significant, although the influence of uniformly distributed users (who are not employs in business centre) is dominant to BS power.

Example 2: Let us consider a BS cell, where one great factory is situated approximately at half a radius of BS cell ($r=0.45 \cdot R$). All other parameters in a system are the same as in previous example. Workers in a factory finish their job and start their way home in all directions with equal probability and speed. What is the increase of BS power for $d=0.5 \cdot R$?

Solution: In this case total BS power increase is 67.9% for $d=0.5 \cdot R$, which is significantly more than 15.6% when business centre is located very near the BS. In this second example users from the factory are still in the originating BS, i.e. there is no handover.

Example 3: Let us consider together one business centre at distance $r=0.25 \cdot R$ and one factory at distance $r=0.65 \cdot R$ from BS. One quarter of mobile users are employs, who finish job in business centre. Further, the second quarter of mobile users is workers from factory, finishing their job. Remaining half of users are those, who are uniformly distributed in the BS cell. What is the increase in total BS power when mobile users from a business centre and a factory pass distance $d=0.3 \cdot R$?

Solution: Total BS power increase is 22.4%.

Example 4: Let us consider a business centre with similar characteristics as the factory in the example 2 (r=0.45·R, d=0.5·R, one half of mobile users in the considered cell are employs). The only difference is that business centre is located in one great, strait avenue, in which is also located a BS. What is the increase in total BS power when employs from a business centre leave their job?
Solution: As a business centre is located in a great avenue, employs are not travelling in all directions after finishing their activities in the business centre. Instead, they are using only the considered avenue and they are going with equal probability on both sides of an avenue. That's why we have to consider only one angle $\alpha 1$ in the model according to Fig. 1. As BS is located in the same avenue (on a distance from business centre), we choose $\alpha 1$=0. After their movement, mobile users are still located in the originating BS. The calculated total BS power increase after employs movement is now 95.2%, comparing to the moment of finishing the job. This increase is greater comparing to 67.9% in example 2, where all directions of users movement are equally probable.

CONCLUSION

In this paper we present a model of BS (total) power calculation as a consequence of user mobility. In this model we suppose that users start their moving from one point in all directions with equal probability. BS power for each user depends on his distance from BS and on environment propagation coefficient γ, as is usual for mobile telephony systems. At the BS cell rim handover to neighbouring BS is implemented. The probability of handover in our model is significant and it may be proved by several examples from practice. According to [6], in digital mobile systems of 2nd and, even more, 3rd generation handovers are very frequent, especially in urban areas, where multiple handovers are possible during one call duration. The probability of handovers may be estimated from graphs in [8]: depending on the value of parameters, which are important for handover, it is between 1/3 and 1/9 of total number of connections. When considering one travelling trace in urban area, [9], there were even three handovers per one kilometre of trace.

It is proved that total BS power is increased as the result of user moving until they do not reach the BS rim, i.e. until handover is not necessary. In the model is supposed that users, who are leaving considered BS cell as the result of handover, are replaced by the same number of users from neighbouring BSs, who are entering the considered BS cell. This part of BS power for users with implemented handover is decreasing as the result of user mobility. Thus total BS power is not increased when users are uniformly distributed in the beginning.

At the end of the paper several examples are analysed. They consider big business centres and big factories in the moment when working time finishes and when employs start their way home. Separately are analysed situations for various positions of business centres or factories in BS cell area and for various street configurations.

These examples from practice show that in some situations is very important to properly choose the moment for BS power measurement. The situation of total BS power increase in the considered examples usually does not last long – until users on their way home reach the considered cell rim (or finish their calls).

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