TSG-RAN Working Group 1 meeting #4
Shin-Yokohama, Japan
April 18-20, 1999

TSGR1#4(99)346

Agenda item:

Source: Ericsson

Title: Recapitulation of the IPDL positioning method

Document for:

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1 Introduction

The Idle Period DownLink (IPDL) positioning method has previously been presented in both ETSI and ARIB. In ARIB the method was referred to as IS-FL. In ARIB SWG2 there was a special group, SG9, assigned to study positioning. The aim of this paper is to recapitulate the IPDL concept and bringing this concept into RAN WG1. The material presented in this document is mainly based on the work performed in SWG2/SG9.

In ARIB the method was described in e.g. AIF/SWG2-30-25.

In ETSI the method was described in e.g. Tdoc SMG2 UMTS-L1 327/98.

2 The IPDL positioning method

The basic principle of downlink positioning is that the UE detects the Time-Of-Arrival (TOA) of signals from different BSs and reports the results. When three or more sites have been detected the position can be calculated.

In CDMA the fundamental problem is that because of the near-far problem it is difficult to hear other BSs when the UE is close to the serving BS. The idea behind IPDL is to cease transmission in the serving BS during short intervals, in order to improve the UEs chances of detecting other BSs. These intervals are called *idle periods.* Please note that these idle periods have nothing to do with compressed mode or slotted mode used for inter-frequency measurements. The idle periods are placed in time by e.g. a pseudo random pattern, made known to all UEs in advance. The pseudo randomness assures that the effect of simultaneous idle periods in adjacent BSs is minimized. The frequency of the idle periods is a parameter, which the operator can change to trade off positioning response time and accuracy against capacity loss in the DL. The frequency is given by $1/T_p$ where T_p is the *average* period between idle periods.

The length of the idle period, herein denoted by T_s, should be as short as possible to ensure that the FL capacity loss is minimized. There is however a trade-off since each idle period has a guard time, which is independent of T_s. In this paper we have assumed that the length of the idle period is equal to one normal slot, plus a guard period of 256 chips, which can be made much smaller. Note however that the period can be made shorter than one slot.

There will be a capacity loss because of the idle periods. This is studied by simulation examples later on in this document.

During the idle period the UE can record and save the received data for subsequent processing. In order to further improve the positioning performance and ease of UE implementation, the UEs is informed in advance about the approximate timing of other BSs, preferably by the neighbouring cell lists transmitted via the BCCH or DCCH. Then the UE can correlate with the BCH. The choice of BCH as the channel to search for is motivated by the following reasons

- The BCH should be decodable by all UE in the cell and thus it has a high power level.
- The BCH is spread by a code that should be unique in the vicinity of the corresponding BS.

- The BCH contains four pilot symbols, thus allowing partly coherent combining.

Of course the UE can, and should, utilize also parts of the BCH that is not pilot data, but in that case the combining has to be performed non-coherently. In has been proposed to also use traffic channels from the neighboring BSs. This does however need some further study to determine the actual gain and compare it with the additional UE and signalling complexity.

The approximate timings of the other BSs that are reported to the UE are associated with a certain uncertainty, which depends on the cell-size. Figure 1 below illustrates the uncertainty. The relative timing of BS0 (the serving BS) is reported to the UE. This relative timing depends on the position at which it is considered. The timing is reported as the relative timing difference at the central location of the cell (or any other reference point that can be compensated for in the position calculation). Since the UE position is unknown there is a certain uncertainty associated with the relative timing. The uncertainty should be given to cover all possible positions of the UE. The uncertainty is the same for all UEs in the cell. If however there is a prior estimate of the UE position, the uncertainty can be considerably reduced. For example if the uncertainty of the UE is about 2.3 km, the timing uncertainty in the UE will be smaller than 64 chips.

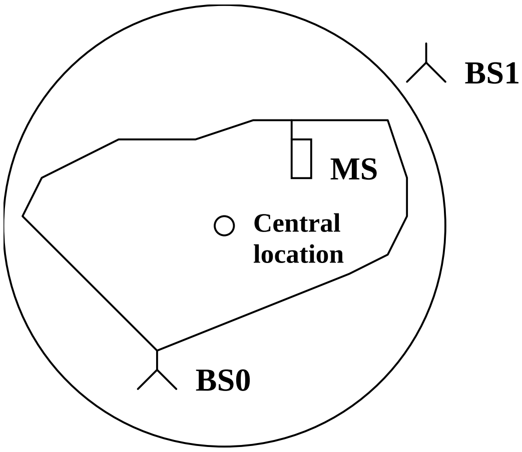

Figure 1 Illustration of the uncertainty. The timing of the other BS (e.g. BS1) is given in a central location of the cell. Due to the unknown position of the UE and propagation delays, there is an uncertainty in the arrival time of the signal from BS1. The uncertainty is given to cover all possible UE positions, illustrated by the large circle.

The UE performs correlations at the time-offsets given by the uncertainty mentioned above and the approximate timing. The timing and uncertainty is illustrated in Figure 2 below.

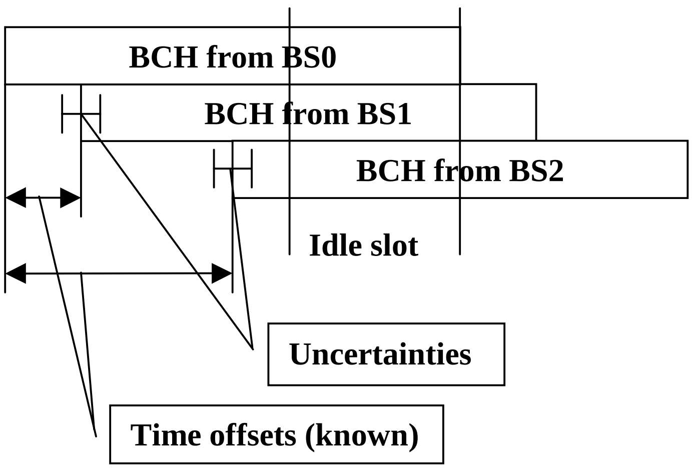

Figure 2 Illustration of time offsets and uncertainties, as seen in the UE.

The correlation results obtained from several idle periods can be non-coherently combined in order to improve the hearability and mitigate effects of multipath propagation. Since the correlation is performed off-line the UE can search for several BSs at the same time. Later in this paper there is a section addressing UE implementation complexity. Figure 3 below outlines the UE functionality.

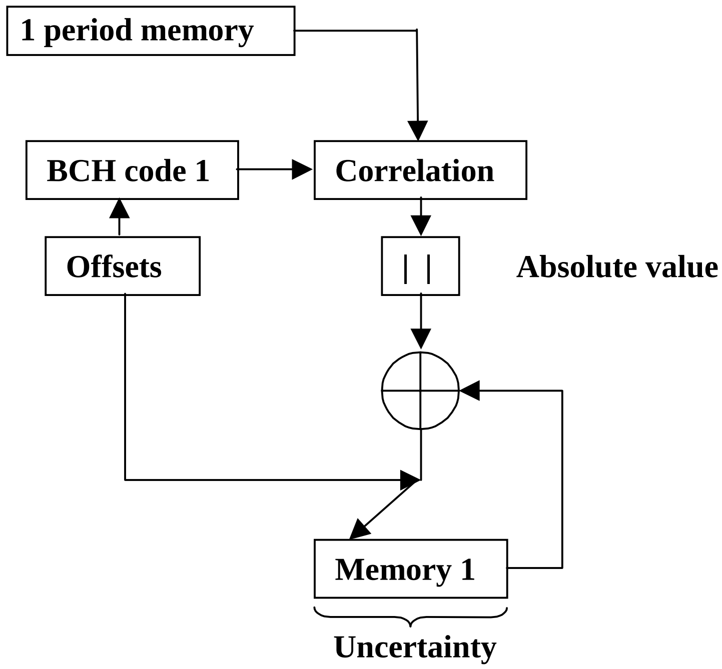

Figure 3 Outline of the UE functionality, for the first BCH correlations. During the idle period the received data is stored in the "1 period memory". Off line correlations are made between the memory contents and the BCH code at the different offsets. The offset and its number depend on the reported timing and corresponding uncertainty.

The non-coherently combined correlation function will have peaks corresponding to the delays of the different multipaths. The leftmost one of these peaks that is above a certain threshold is taken as the time of arrival of the signal. The time can be measured e.g. relative to the offset time reported in the BCCH/DCCH.

When the timing of a certain BS is found the UE reports the timing and quality along with the BS identification back to the serving cell BS (and further on into the network).

When three or more BSs are found the position can be calculated. The more BSs found the better the position estimate will be.

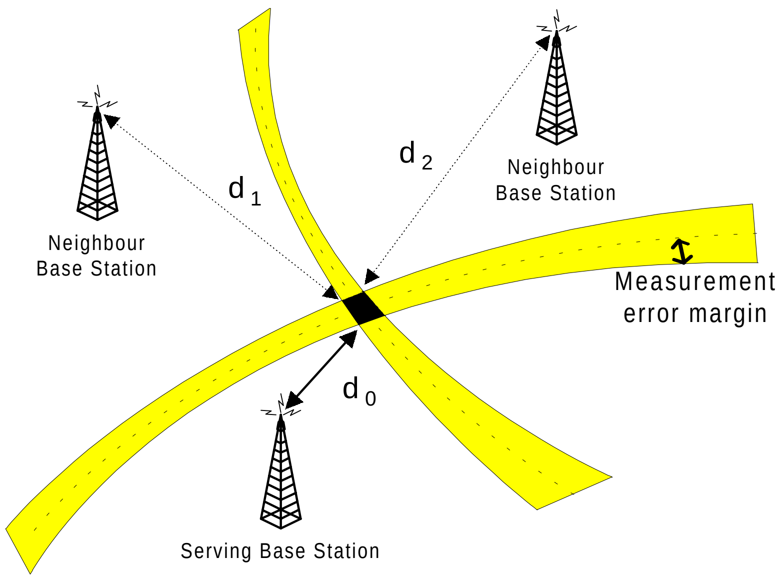

Figure 4 Position estimation with TDOA methods.

The different parts of the IPDL positioning scheme is summarized in the following:

- The pseudo random slotting pattern is known a priori or broadcast
- The UEs are informed of the approximate frame timing of adjacent BSs (and the corresponding code number) through BCCH or DCCH (or by some other means)
- The BS ceases all transmission during the idle periods
- The UE records data during the idle periods and correlates with the BCH (for example)
- If the UE searches even when not ordered, the positioning response time can be significantly reduced
- The timing, quality and BS ID of detected BSs are reported back to UTRAN. Alternatively, if the UE knows the BS coordinates, position is calculated directly in the UE.
- The position is calculated

3 UE implementation and hardware complexity

The UE implementation does not have to be standardized and hence this section is just an example to get some rough estimate of the computational complexity and hardware requirements of IPDL. The computational complexity is mainly handled by correlators and the additional hardware is primarily memory, in which to store the intermediate results. In order to get expressions of the number of required correlators and memory we introduce the following notation, and also list exemplary numbers.

Number neighboring of BSs to correlate with	n_{BS}	5
Oversampling rate	P	2
Uncertainty in chips	u	64
Length of idle period in chip intervals	T_s	2816
Spacing of idle periods (in slots)	T_p	160
Bits per correlation offset when combining non-coherently	b_c	16
Bits per sample	b_s	1

With this notation the memory requirement can be calculated to be

$$2T_s b_s P + uPn_{BS} b_c$$

where the first term is due to the sampled data saved during the idle period and the second term is the memory required for the intermediate (non-coherent) correlation results. With the exemplary numbers listed above the required memory is 2.6 Kbytes.

Between the idle periods the UE must make $n_{BS} Pu$ correlation computations, each of length less than or equal to T_s. Assuming that each (complex) correlator can be used to make close to T_p such correlations between two idle periods, approximately

$$\frac{n_{BS} Pu}{T_p}$$

correlators are required to perform all correlations between two idle periods. With the exemplary number this evaluates to approximately 4 correlators (run at chip-rate). Furthermore, since the computations can be made faster than at chip-rate (since the correlations are performed off-line) the number of correlators required can be significantly decreased. The computational complexity is directly related to the slotting frequency. In Section 0 it is shown that sufficient accuracy is obtained e.g. when the idle period frequency is one fourth of the example used above.

It should be noted that both the required memory and number of correlators can be reduced by not correlating with all BSs at the same time. If correlation with the strongest BSs from the neighbor list is performed first, these are likely to be found quite fast, and then these correlators and memory locations can be used to search for other BSs.

It should further be noted that the hardware similar to what was discussed above is required also for normal cell-search. Hence we can conclude that the additional hardware required for IPDL is very small or non-existent.

4 Inter-BS timing and synchronization

Unidirectional time-based positioning methods need to know the relative timing of the BSs involved in the positioning. One attractive alternative to obtain inter-BS relative timing, which is possible when using IPDL, is to have reference UEs in some of the BSs. These reference UEs can detect other BSs during the idle periods, and thus relative timing is obtained. The relative timings can be stored in a central node, e.g. the RNC. Note that in the case with reference UEs there is no need to have equipment in all BSs, since one reference UE can obtain relative timings of several BSs.

The frequency at which the relative timings will be updated depends on the time-accuracy and drift of the BSs. It is specified that the time-accuracy should be at least 0.05 ppm. This means that in the worst case, assuming that we want updates as soon as the relative timing has drifted one chip, there would be only a few seconds between the updates. It should be noted however that 0.05 ppm is a *worst case* offset in the frequency. The frequency is never allowed to deviate with more than 0.05 ppm. In general the accuracy is much better. Furthermore, a distinction has to be made between long term time drift and short term. Even if the time drift is allowed to be 0.05 ppm momentarily any reasonable BS design will have a time-accuracy that is much more accurate on a long term. With a good network it is for instance possible to obtain stratum one, which is in the order of 10^{-11}. Thus it is likely that the relative timing measurements reports will be very infrequent. Even if the network is very unstable it is possible to obtain stable timing in the BS, e.g. by advanced filtering or having dedicated clock-sources.

Another issue is the frequency stability of the UE. The question in this case is whether the UE is stable enough in order to perform non-coherent combining throughout the time of the positioning. Similar arguments as in the previous paragraph hold in this case. When the UE is locked to one BS it will not drift, on a long-term basis, compared to that BS. The only case when it will drift is when it moves sufficiently long during the time of positioning. Assuming the worst case that the UE is moving towards a BS and away from another, a one-chip offset would correspond to a movement of about 40 meters. Assuming the positioning takes one second this corresponds to a speed of about 140 km/h. Of course a UE that moves rapidly will always be more difficult to position. This holds for any positioning method.

5 Impact on standard

The reoccurring total BS power shut-off can be done with very small physical layer impacts. The shut-off function can e.g. be placed within the power amplifier of the BS, and the base-band processing part does not even have to know that idle periods exist. The shut-off function however needs to have a time-reference in order to do the shutting down at the correct periods. The actual implementation is up to the BS manufacturer.

The UE has to know the pattern of the reoccurring idle periods, so that it can record those portions of the received signal at a chip-level or higher, for subsequent processing.

The UE needs to know the approximate frame timing of the BSs involved in the positioning.

The IPDL positioning method should be optional for the BS, but mandatory for those UEs that support positioning. This would give the control of IPDL positioning to UTRAN.

6 Performance and capacity impact

6.1 Positioning accuracy

In this section we present some simulations carried out to illustrate the performance of the IPDL method in realistic environments. Much attention has been focused on the channel model. Important factors to consider when selecting a channel model for positioning include the following:

- The channel model should be based on physical, measurable parameters. Such parameters include e.g. delay spread, angle of arrival, fading statistics and power delay profile shape.

- Delay spread is important, due to the fact that many positioning techniques use time estimations to position the mobile. The accuracy of these estimates depends on the delay spread of the channel impulse response. Therefore the delay spreads generated by the model should conform to measurements.

- The model should represent the general channel behavior in a range of typical environments, corresponding to geographically diverse conditions.

The channel model used is a version of the CODIT model, slightly modified to conform to empirical channel measurements. The CODIT model is a measurement based wideband channel model, defined for different environments such as urban, suburban, rural etc. The ITU model used for UTRA link simulations is not used due to the constant nature of that model. It would be an over-simplistic assumption that the propagation characteristics are the same from all BSs.

The simulation setup is described in the following. The algorithms are tested in two environments, urban and suburban. The BSs have three sectors and are located in a hexagonal pattern and the closest inter-BS distance is 1.5 km for urban and 4.5km for suburban. Mobiles are randomly placed until full system load is achieved (normally more than 90 voice UEs per cell). Each mobile has a speed of 50 km/h. The carrier frequency is 1.9 GHz and the bandwidth 5 MHz. All transmitted signals are QPSK modulated chip-sequences filtered through raised cosine filters with a roll-off factor of 0.22. The so-obtained signal is fed through the channel model. The received signals (transmitted signal plus interference) are filtered and sampled with a 4-bit A/D converter. The length of each idle period is equal to the length of one slot. The slotting frequency is 10 Hz (one idle period every tenth frame).

The UEs try to detect the five strongest cells from the neighbor list. The results from 300 randomly selected UEs is shown below. The upper part of the figures show the circular probability, i.e. the probability that the UE's estimated position is closer to the true position than a certain distance (shown on the x-axis). The lower part of the figures show how many BS sites the UE detected, including the serving BS. The UE can often hear more cells than sites, but since cells belonging to the same BS have the same geographical origin they provide little extra information in the position calculation. In the two first figures the UE uses 16 idle periods, and in Figure 7 only 4 idle periods are used. Figure 8 is included to illustrate the performance that would be obtained without idle periods.

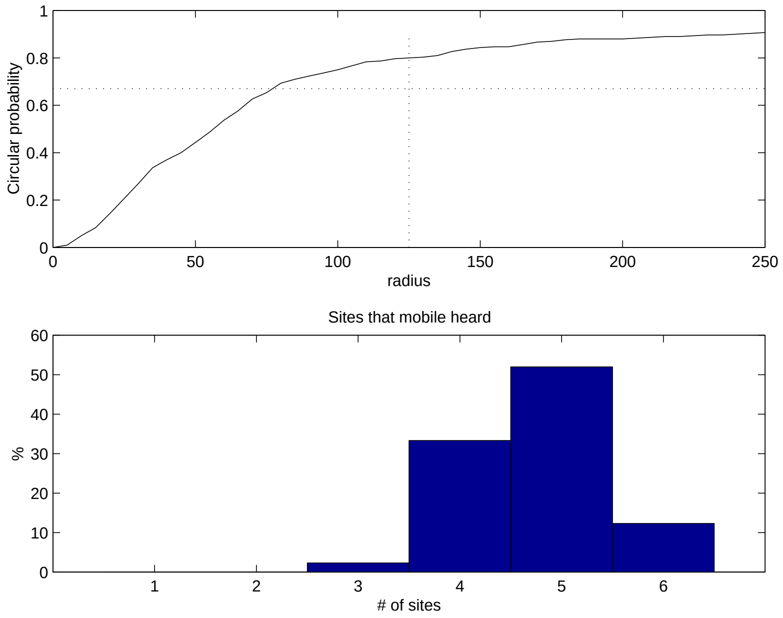

Figure 5 Results obtained in the urban case with 16 idle periods. Circular probabilities and a histogram of the number of detected sites are shown.

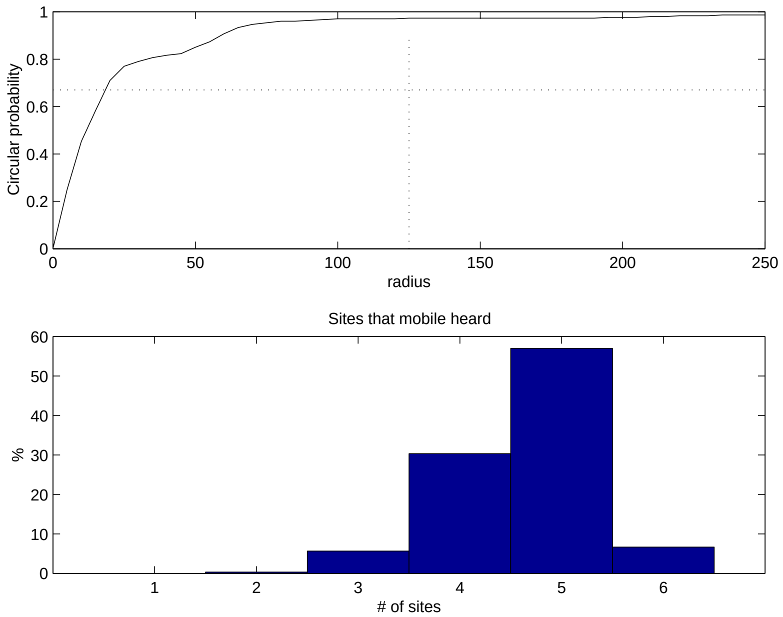

Figure 6 Results obtained in the suburban case with 16 idle periods. Circular probabilities and a histogram of the number of detected sites are shown.

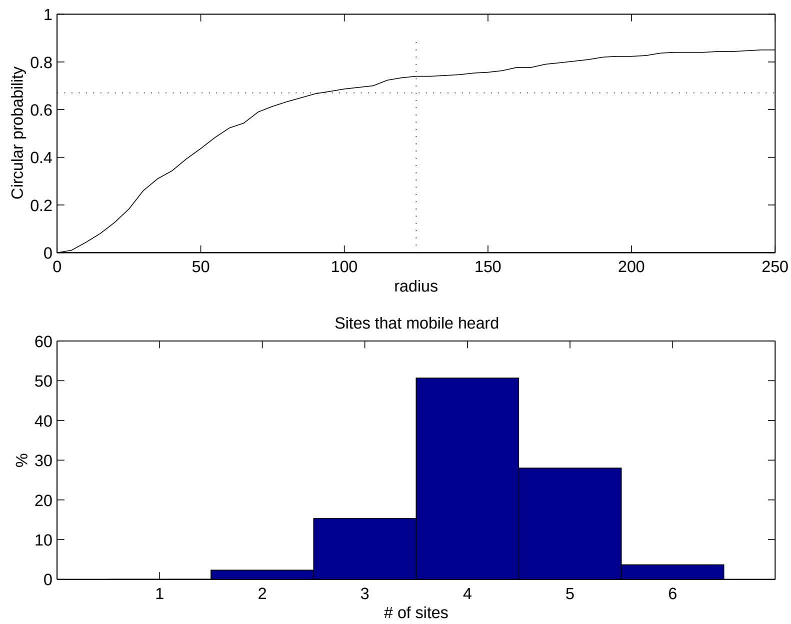

Figure 7 Results obtained in the urban case with four idle periods. Circular probabilities and a histogram of the number of detected sites are shown.

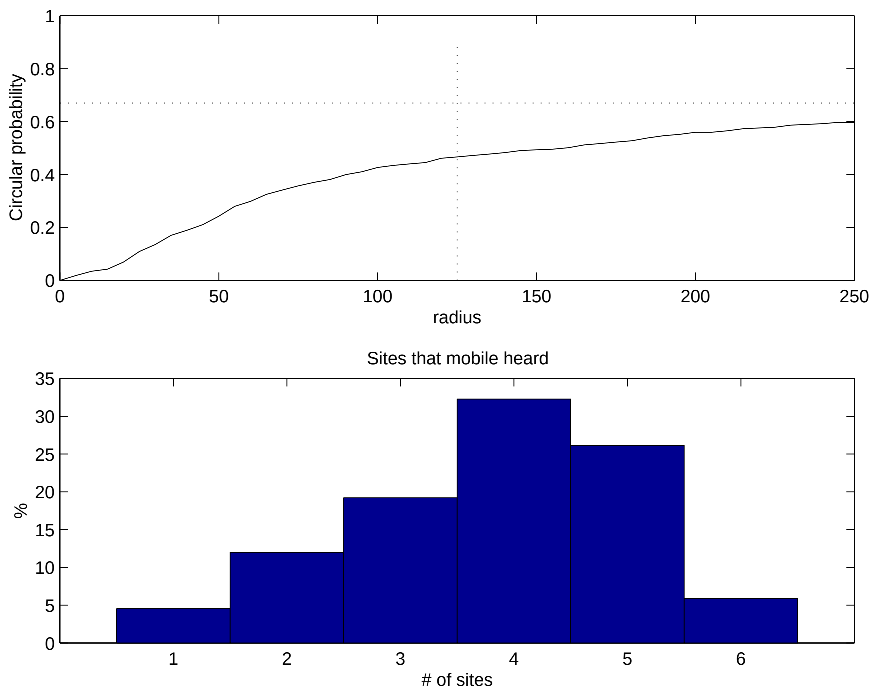

Figure 8 Results obtained in the urban case with 16 periods that are not idle. Circular probabilities and a histogram of the number of detected sites are shown.

6.2 Capacity impact

Link simulations have been carried out to investigate the capacity impact of the idle periods. In the figures below the BER/FER is shown for different lengths of the idle periods. The length of the idle periods are given in symbols, including one guard symbol. The idle period reoccurence is 10 Hz in Figure 9. In other words, for the idle length of 11 there will be one 11 symbols long idle period every 10^{th} frame. The environment is Vehicular A and the service is 8 kbps data, using 10 ms interleaving. In the simulation the UE does not know that there is an idle period. By utilising this knowledge the performance could be slightly improved. In Figure 10 the loss in BER and FER are shown for a varying slotting frequency. The required Eb/N0 is evaluated at a BER of 10^{-3} and a FER of 10^{-2}.

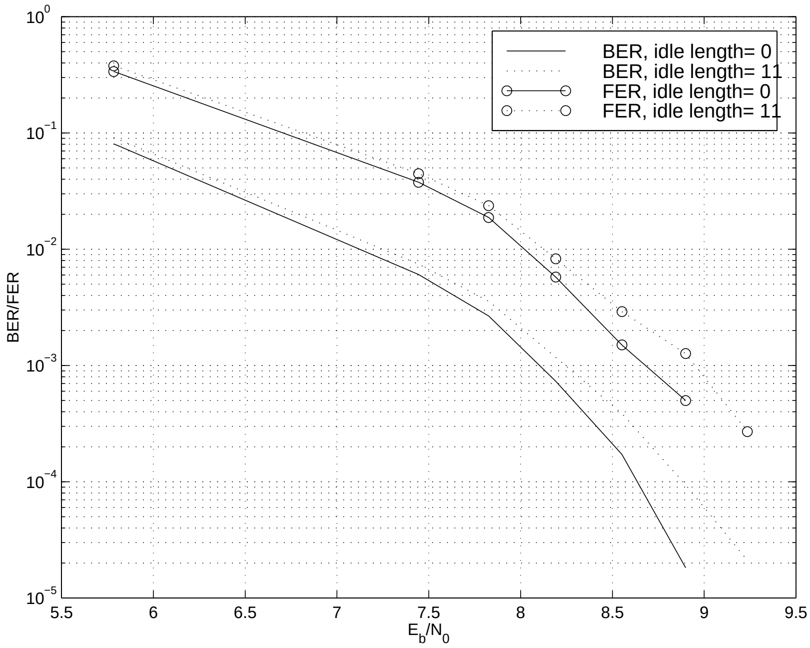

Figure 9 Effect of introducing idle periods with a frequency of 10 Hz.

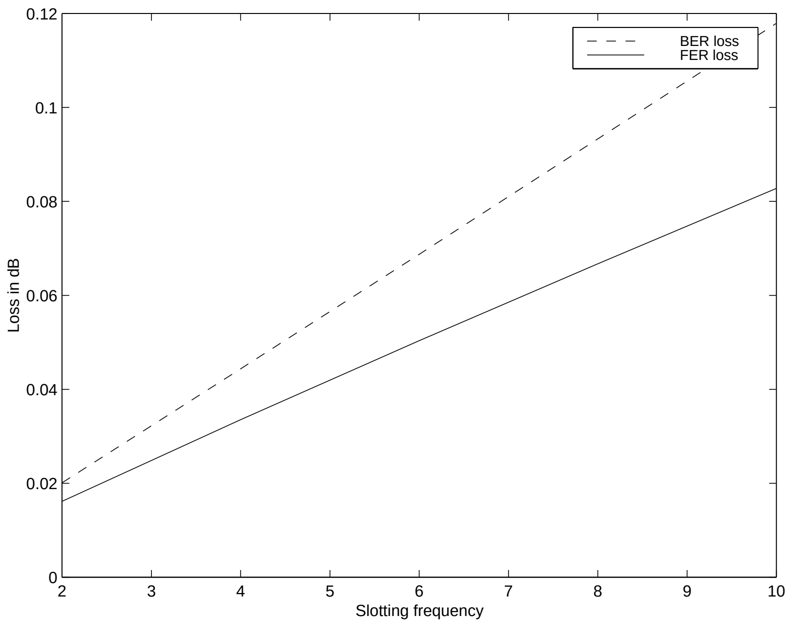

Figure 10 The loss in Eb/N0 as a function of idle period reoccurence frequency (in Hz).

7 Conclusions

To conclude the proposal we list a number of characteristics of IPDL:

- All UEs can be positioned simultaneously, including idle ones. This can be done at a constant capacity loss, neglecting signaling
- Inter-BS timing, necessary for positioning, can be obtained by having simple reference UEs located at the BS sites
- The performance is adjustable by varying time between idle periods, T_p
- The timing information can be utilized when performing SOHO searches
- Little or no additional hardware is required in the UE