Simulation Analysis on the Efficiency of STAMP Method

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***Abstract*— STAMP is a positioning method that relies on the exploitation of historical location related measurements captured and stored by mobile terminals. This paper presents a simulation analysis regarding the various parameters of the proposed method for the CGI++ mobile positioning technique and reveals its efficiency. Furthermore, the paper investigates two pre-filtering techniques with respect to the estimation accuracy of the positioning algorithm. The application of STAMP method in the CGI++ technique requires only minor software updates on the terminal and network side, thus reducing the deployment time and cost.**

I. Introduction

Location Based Services (LBS) enable the provision of enhanced personalized services to the mobile user through the identification of the user current position. In a period of growing competition, LBS open new opportunities for mobile operators as well as application and content providers for the provision of innovative value added services. So far, a wide variety of location techniques has been proposed, each one of them presenting certain advantages as well as drawbacks.

To deal with the issue of required investment on the network side and the modernization of terminals, all LBS technology roadmaps begin with low cost and low accuracy techniques (e.g. Cell Identity based) and evolve in the long term towards the Assisted Global Positioning System (A-GPS), the best performing mobile positioning technique in terms of the resulting accuracy and reliability [1]. However, A-GPS terminals are still expensive and there will be a relatively long period of time for which legacy 2G or 2G/3G mobile terminals will not be equipped with GPS receivers. Therefore, other mobile positioning solutions with very high degree of applicability are in demand. Moreover, due to the limited indoor applicability of GPS, hybrid techniques are often considered combining A-GPS with a network-based positioning method. Apparently, the crucial requirement for a cellular-based location method refers to the ability of direct deployment in commercially available mobile networks, without the need for mobile terminal replacement and with low network investments required for the network operator.

A well studied positioning method, that meets the above criteria of fast and low-cost deployment and presents moderate accuracy, is CGI++. This method is based on the Cell IDs and the Received Signal Strength (RSS) at the terminal side from the serving and neighboring Base Transceiver Stations (BTS). Based on these RSS levels an estimation of the distance between the terminal and each BTS is feasible by using a propagation model. The Location Server employs these distances in the trilateration technique, using the Least Square Optimization algorithm in order to calculate the most probable location of the terminal. The optimum location is the point where the squared difference between the distance computed by the RSS measurements and the distance of the current estimation $\widehat{(x,y)}$ from each BTS is minimized for all BTSs.

Statistical Terminal Assisted Mobile Positioning (STAMP) is an innovative method which is generic and applicable to legacy networks as well as in Beyond 3G (B3G) heterogeneous radio access environments, were multiple networks coexist (e.g., GSM/GPRS, 3G, WLAN, etc.). The basic principle of STAMP is the exploitation of measurements from all available networks, that the mobile terminal performs periodically while in idle mode. These measurements are exploited through standard positioning techniques to provide estimations of the history of the terminal motion and then through statistical filtering provide a better estimation of the current terminal position. It should be noted that STAMP is applicable even when just a single access technology is present.

The current paper considers the application of STAMP method for the CGI++ positioning technique in a GSM network. The main objective of STAMP is to increase the estimation accuracy of the current terminal position, when an LBS application is initiated. The efficiency of STAMP concept was illustrated in [2] by using actual field measurements collected during a survey in a single route. In that case up to 65% improvement on accuracy was achieved over the CGI++ method. Our main contribution in this paper is the investigation of various parameters that affect the performance of the STAMP method in a GSM environment when CGI++ is used. This promising positioning scheme is evaluated through extensive simulation with respect to the following parameters: measurement storage requirements, number of BTSs employed in the position estimation and measurement sampling period.

An assessment of how STAMP can be applied in this case in an operational network is also presented. Pre-filtering techniques that lead to significant performance increase (improved accuracy) are also described and evaluated within the STAMP context.

The rest of the paper is structured as follows. Section II describes the STAMP positioning method. Section III provides the details of the simulation model and presents the results obtained with the application of STAMP in the CGI++ technique concerning different parameters. Section IV describes a pre-processing technique in order to enhance the positioning accuracy of STAMP. Section V discusses the tracking and speed estimation capabilities of STAMP. Finally, section VI provides some concluding remarks and discusses the future work related to STAMP.

II. The STAMP method

The STAMP method employs sequential location estimations, derived from the CGI++ technique and then calculates the terminal position with certain accuracy. For GSM networks the basic principle of STAMP is the exploitation of Network Measurement Reports (NMR), that the Mobile Station (MS) performs periodically while in idle mode. The Received Signal Strength (RSS) measurements included in these reports are stored locally in a list. Each entry in the list is a vector containing the RSS measurements from the respective BTSs. These vectors are then uploaded to the Location Server at the beginning of an LBS session and employed in the CGI++ positioning technique to provide coarse estimations of the past MS locations; then through statistical filtering a better estimation of the current MS position is achieved. Figure 1 depicts the STAMP concept for an MS moving through a GSM network.

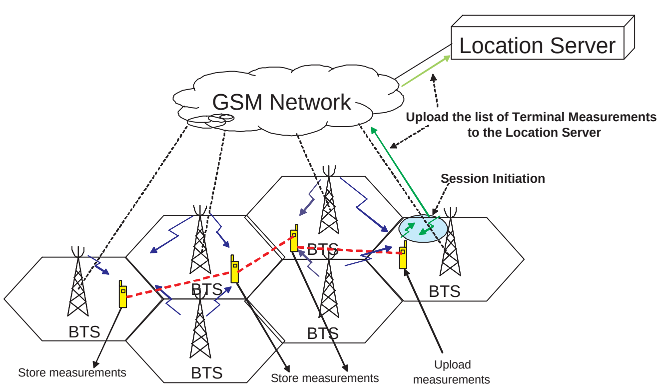


Fig. 1: Representation of the STAMP concept.

At the initiation of an LBS application, such as locating the nearest restaurant or pharmacy, the following actions take place:

- **Current Position:** The CGI++ technique is employed to provide an estimation of the current MS position.
- **Previous Positions:** The CGI++ technique is also employed for each vector in the list to calculate estimations of the MS positions at previous time instances.
- **Statistical Processing:** The previous steps have resulted in a set of coarse MS position estimations corresponding to the history of the MS motion. These estimations can be exploited in standard statistical methods in order to improve the accuracy of the current MS position estimations.

The most common statistical method applied in modern navigation systems is Kalman Filtering [3]. In STAMP we rely on Kalman Filtering for smoothing the initial position estimations and achieve higher accuracy for the current MS location. These estimations, provided by CGI++ method, are treated as measurements

$$Y(k) = \begin{bmatrix} Y_1(k) \\ Y_2(k) \end{bmatrix}$$

where $Y_1(k)$, $Y_2(k)$ denote the x and y coordinates of the calculated MS position and k represents time instance t_k. These measurements are taken at discrete time points $t_k = t_0 + k\Delta t$, $k \in N_0$. We define a four dimensional stochastic process

$$X(k) = \begin{bmatrix} X_1(k) \\ X_2(k) \\ V_1(k) \\ V_2(k) \end{bmatrix}$$

where $X_1(k)$, $X_2(k)$ denote the x and y coordinates of the MS position and $V_1(k)$, $V_2(k)$ denote the x and y coordinates of the velocity vector at time instance t_k. Process $X(k)$ is assumed to satisfy the discrete linear recursion

$$X(k) = \Phi \cdot X(k-1) + \Gamma \cdot W(k) \quad (1)$$

where Φ and Γ are the following matrices:

$$\Phi = \begin{bmatrix} 1 & 0 & \Delta t & 0 \\ 0 & 1 & 0 & \Delta t \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \Gamma = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ \Delta t & 0 \\ 0 & \Delta t \end{bmatrix}$$

$W(k)$ is two dimensional stochastically independent random error following a Gaussian distribution with expectation $\mathbf{0}$ and covariance matrix

$$Q = \begin{bmatrix} \sigma_Q^2 & 0 \\ 0 & \sigma_Q^2 \end{bmatrix}$$

The parameter σ_Q^2 can be estimated by the proposed approach in [4] or by using a more sophisticated mobility model of the MS motion in the area.

The interpretation of (1) is that if the MS is located at $[X_1(k), X_2(k)]^T$ having velocity vector $[V_1(k), V_2(k)]^T$ at time t_k, then after time Δt it has moved to position

$$\begin{bmatrix} X_1(k) \\ X_2(k) \end{bmatrix}' = \begin{bmatrix} X_1(k) \\ X_2(k) \end{bmatrix} + \Delta t \cdot \begin{bmatrix} V_1(k) \\ V_2(k) \end{bmatrix}$$

and the components of the actual velocity vector are changed by a random amount

$$\Delta t \cdot \begin{bmatrix} W_1(k) \\ W_2(k) \end{bmatrix}$$

The initial estimations $Y(k)$ are modeled by independent additive random errors, in order to take into account the effect of shadow fading, as

$$Y(k) = M \cdot X(k) + U(k) \tag{2}$$

where

$$M = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

$U(k)$ is two dimensional stochastically independent random error following a Gaussian distribution with expectation **0** and covariance matrix

$$R = \begin{bmatrix} \sigma_R^2 & 0 \\ 0 & \sigma_R^2 \end{bmatrix}$$

R reflects the positioning error introduced in the initial position estimations when the CGI++ method is used. In that sense standard deviation σ_R can be easily obtained by performing real measurements in the area of interest and calculate the average positioning error when CGI++ is applied.

Equations (1) and (2) form a discrete linear difference equation with white Gaussian noise and the optimal recursive estimator of minimum variance for the process $X(k)$ is obtained by Kalman Filter according to [4].

In order to facilitate the collection of measurements on the MS side a software mechanism is employed based on some important parameters that affect the overall performance of STAMP. The $STAMPList$, implemented as an embedded memory, stores N RSS measurement vectors, corresponding to the N most recent MS locations. The $STAMPSamplingPeriod$ defines the frequency at which these vectors are stored, which reflects on their temporal as well as spatial, in case of a moving MS, diversity. The $AdoptionCondition$ is a condition according to which the MS decides whether a specific measurement or a whole vector is adopted or rejected. This is necessary in order to deal with corrupted and incomplete measurements or RSS values that fall below a certain threshold. The $TimeStamp$ is a parameter that indicates the absolute or relative time instance that a vector was collected and stored. It can be either a real time reference or a counter since the difference of time is always a multiple of $STAMPSamplingPeriod$. $TimeStamp$ parameter is used to associate vectors with time, creating in that way historical data for the MS.

All the required information for STAMP is available in GSM networks. The NMRs contain the Cell IDs and the RSS levels (RxLEV) from the serving and six neighboring cells used in the Cell Selection and Cell re-selection functions according to GSM specifications. The implementation of STAMP can take place either at the terminal or at the network side. In the first case new terminals are required with high processing power and new software installed. In the latter case though, the terminal needs only a small amount of memory and minor software updates in order to store and eventually upload the measurements to the Location Server. This makes STAMP a network-based-terminal-assisted positioning method, that can be easily integrated into current GSM networks and terminals.

III. Application of STAMP

In order to prove the accuracy of STAMP method, several simulation tests were performed. The simulated service area consists of 37 GSM cells, placed over a uniform hexagonal pattern. The cell radius is considered 500m and BTSs are placed in the center of the cells and equipped with omnidirectional antennas. MSs are located randomly all over the service area, while the number of simulated users is 500. Users are assumed to follow a single moving pattern: static, walking, city driving or fast city driving with an average speed of 0, 4, 20 or 40km/h, respectively. For simplicity reasons and without loss of generality steady speed is assumed, while directionality remains the same for all three moving scenarios. The Hata propagation model [5] is adopted to express the Path Loss as a function of distance between the MS and each BTS, and is applied with typical values $f = 900MHz$, $h_{MS} = 1.5m$ and $h_{BTS} = 20m$. Path Loss is calculated as the difference between the RSS and the Transmitted Signal Strength (TSS) of each BTS. Each NMR is available every 5 seconds while in idle mode, which is sufficient to smooth out the fast fading effect [6]. Zero-mean white Gaussian Noise with standard deviation $\sigma = 8$db is added to the RSS measurements in order to represent shadow fading [7]. The MS is able to store a maximum of 50 vectors with RSS measurements in the $STAMPList$ corresponding to the serving and up to six neighboring cells. Figure 2 illustrates STAMP method for the position estimation of an MS moving with 20km/h compared to the CGI++ technique. The $STAMPList$ is assumed to contain 40 vectors corresponding to the MS location in the recent past, while the $STAMPSamplingPeriod$ is 5 seconds. The *Distance Error*, defined as the geometrical distance between the actual and the estimated through STAMP final position of the MS, is 89m. The estimated speed at the final position is 26km/h. Apparently, the coarse estimates obtained by the application of the CGI++ technique are smoothed effectively by the Kalman Filter resulting in increased positioning accuracy.

A. STAMP List Size

In this section the effect of STAMP List Size N on the accuracy of the final position estimation is investigated. The $STAMPList$ should be long enough in order to store all vectors, corresponding to recent terminal positions and thus achieve better accuracy with the use of statistical processing. On the other hand, N should be kept as low as possible in order to avoid excessive storing requirements at the terminal side. In this way, the STAMP method can be applicable, not only to high-end terminals, but also to legacy ones with low memory capabilities. Figure 3 presents STAMP efficiency with varied N, in terms of the 67% and 95% cumulative distribution function (cdf) for all mobility scenarios. In the case of static MSs, the positioning accuracy of STAMP increases significantly with the number of samples exploited until the

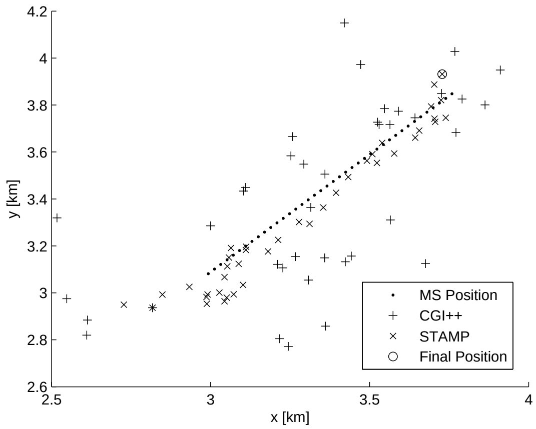


Fig. 2: Application of STAMP in driving scenario.

value $N = 30$, however the additional gain achieved by storing more vectors in the $STAMPList$ (i.e. $N = 40$) is marginal. Extending N to 50 only adds unnecessary storage overheads. For $N = 40$, simulation results present accuracy of 86m for 67% cdf and 141m for 95% cdf, while mean positioning error and standard deviation (σ_p) is 72m and 39m, respectively (Fig. 3a,e). In the case of a walking scenario (Fig. 3b,f), the same conclusion as in the previous case holds. For $N = 40$, simulation results present 113m, 196m for 67% and 95% cdf, respectively and a mean positioning error of 95m ($\sigma_p = 53m$). However, in the case of an MS following the driving pattern (Fig. 3c,g), a 12% improvement in accuracy is achieved when N is increased from 30 to 40 samples. For $N = 40$, simulations result in positioning accuracy of 143m, 236m for 67% cdf, 95% cdf respectively, and a mean positioning error of 119m ($\sigma_p = 63m$). When driving speed is increased to 40km/h for the same value of N, positioning accuracy of 185m and 346m can be achieved for 67% and 95% cdf respectively, with an 161m ($\sigma_p = 100m$) mean positioning error (Fig. 3d,h). This corresponds to a 30% improvement on accuracy over the value $N = 30$. Results obtained for all three moving scenarios do not satisfy the FCC 911 directives, as far as the 67^{th} percentile is concerned, while the 95^{th} percentile constraint is also violated in the fast city driving scenario. In Section III-C it is shown that shorter sampling period improves accuracy significantly and the FCC mandate for network-based solutions is met. The preferred value for all three moving scenarios is $N = 40$[1], in order to keep storage requirements as low as possible and provide acceptable accuracy at the same time. This value of N is kept constant in the simulations conducted in the subsequent sections.

[1]Memory size of less than 2K bytes is adequate to store 40 measurements of Rx levels from the primary and the neighboring cells plus the primary cell ID. The amount of memory is much less than the one a picture occupies in high-end camera equipped terminals.

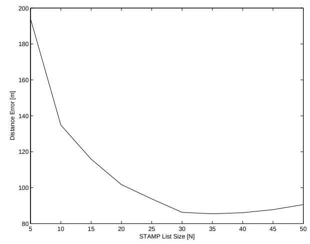
B. Number of BTSs

Instead of employing only three BTSs in STAMP, power measurements from all seven cells (serving + six strongest) could be exploited to minimize the *Distance Error*. The main problem however is the quantization and truncation of power measurements according to GSM specifications [8]. Power measurements are mapped to an RxLEV value between 0 and 63, over the full range of -110dBm to -48dBm, with measurements above (below) the upper (lower) limit being truncated to upper (lower) RxLEV boundary value. This can lead to erroneous distance calculation according to Hata propagation model, resulting in accuracy degradation of STAMP. A remedy is feasible by using the power measurements of cells with value well inside the measured range and/or by requesting the MS to send Enhanced Measurement Reports (EnMR), that scale power measurements accordingly [9]. Figure 4 depicts the accuracy achieved versus the number of BTSs employed in STAMP in terms of the 67^{th} (Fig. 4a) and 95^{th} (Fig. 4b) percentile, respectively. It is observed that accuracy is improved as more BTSs are incorporated, especially in the static and walking scenario. Additional improvement on the accuracy is feasible by using EnMRs, since the maximum number of reported neighboring BTSs is not limited to six. In a commercial deployment of STAMP a threshold value for RSS (e.g. -90dBm) should be chosen as the $AdoptionCondition$ to ensure that only BTSs with strong enough signal contribute to the position estimation. This is essential especially in higher mobility scenarios where a performance degradation is observed when 7, instead of 6 BTSs are employed.

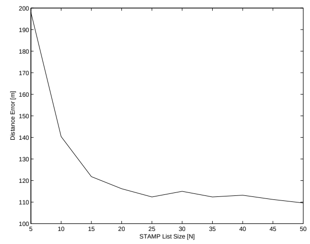
C. STAMP Sampling Period

In this Section the effect of $STAMPSamplingPeriod\ T$, on the accuracy of the final position estimation, is evaluated. In a GSM network the MS is in *active mode* i.e. connected, when it is communicating with the serving BTS using a dedicated channel. On the other hand, the MS is in *idle mode*, when it is turned on but no two-way communication takes place. In the latter case, the serving BTS is considered the one accessed by the MS if a two-way communication had to be initiated [10]. The basic sampling period, during idle mode denoted as T_0, is assumed to be 5 seconds and $T = k \times T_0, k = 1, 2, ...$ The value of T should be small enough to allow for accurate positioning in the recent past, especially when moving on walking pace or driving in the city, while longer T is desirable in order to keep battery consumption low. Figure 5 shows the accuracy obtained with increasing T for an MS following a stationary or walking pattern. The respective plots for both driving scenarios are not included as it is intuitive to use the minimum available sampling period when higher mobility is considered to ensure both accurate MS tracking and speed estimation.

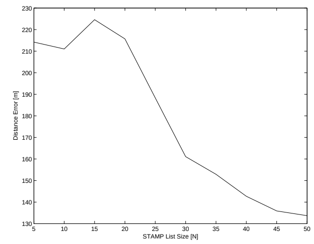
Estimation error increases if longer T is employed, even in the case of non moving MSs. Changing the value of this parameter is not an option in cases where high accuracy is demanded. For LBS with not so strict accuracy requirements T could be extended in order to minimize power consumption.



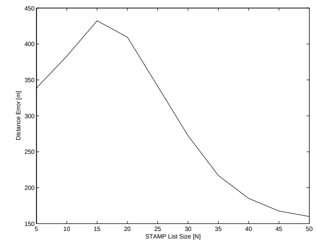
(a) 67% cdf (static)



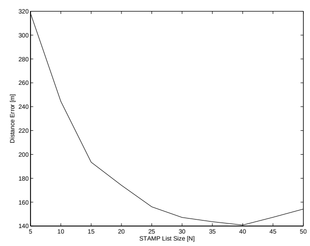
(b) 67% cdf (walk)



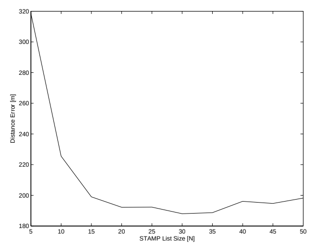
(c) 67% cdf (drive)



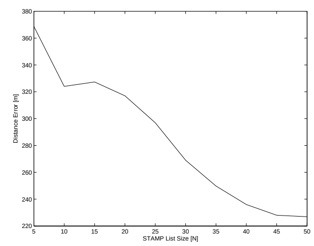
(d) 67% cdf (fast drive)



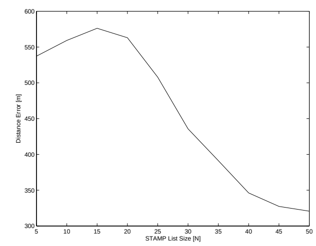
(e) 95% cdf (static)



(f) 95% cdf (walk)

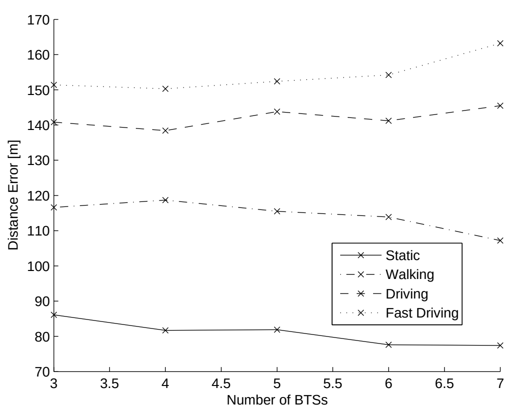


(g) 95% cdf (drive)

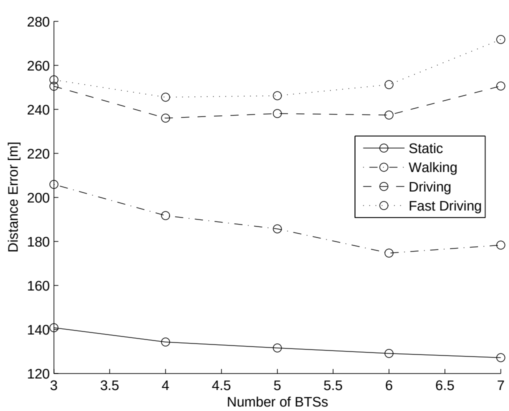


(h) 95% cdf (fast drive)

Fig. 3: The effect of List Size N on STAMP efficiency



(a) 67% cdf



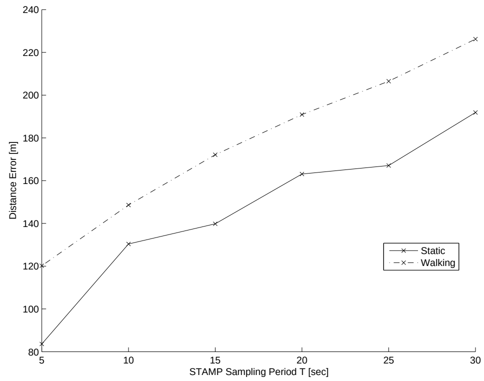
(b) 95% cdf

Fig. 4: STAMP accuracy for 3 to 7 BTSs.

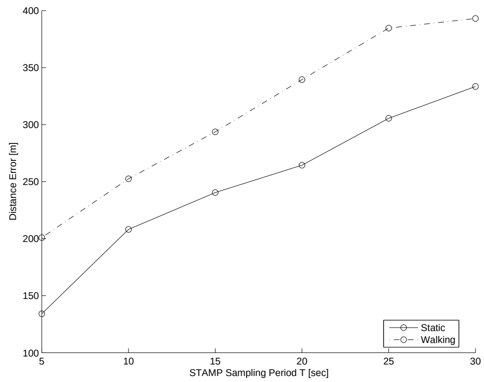
It is interesting to evaluate the effect of T when the MS is in active mode. In this case NMRs are available every 480msec and T_0 can be set to this value. Figure 6 illustrates the improvement on STAMP performance in every case. When $T = T_0$ is selected, the 67^{th} percentile FCC constraint is met for all except for the fast driving scenario, where accuracy is still satisfactory. Simulation results reveal that employing shorter sampling period, which is applicable only during active mode, provides better accuracy especially when the speed of the MS is increased. On the other hand, it leads to higher processing rate, which directly affects the battery consumption on the MS.

IV. Enhancing STAMP Accuracy

In order to improve STAMP performance, the shadowing component, which is incorporated in the measurements, must be reduced by means of averaging applied on vectors, in the $STAMPList$. This is a pre-processing step employed just before the application of Kalman Filter. Different filters can be used for this purpose. In this section we present two distinct pre-filtering techniques and evaluate their trade-offs and improvements on the effectiveness of the original STAMP scheme. The averaging filter reduces the shadow fading component considerably, without modifying the actual path loss. Subsequently, uploading of the pre-filtered samples to the Location Server takes place which are used to generate coarse estimates of the MS location. The notion here is that Kalman Filter will perform better since these coarse estimates are more accurate. It is evident that averaging pre-filter will be mostly beneficial when combined with short sampling period. This stems from the fact that averaging samples, which in the fast moving MS case correspond to distant successive locations leads to erroneous position estimations. In this section the

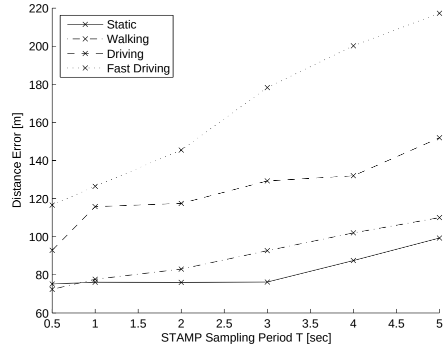


(a) 67% cdf

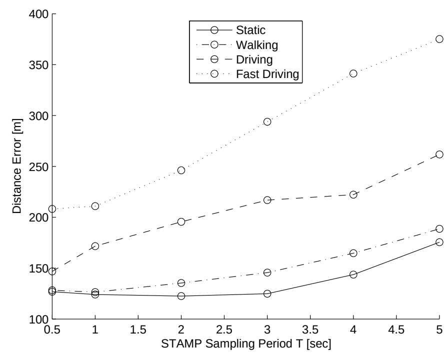


(b) 95% cdf

Fig. 5: STAMP efficiency with increasing T in idle mode.



(a) 67% cdf



(b) 95% cdf

Fig. 6: STAMP efficiency with increasing T in active mode.

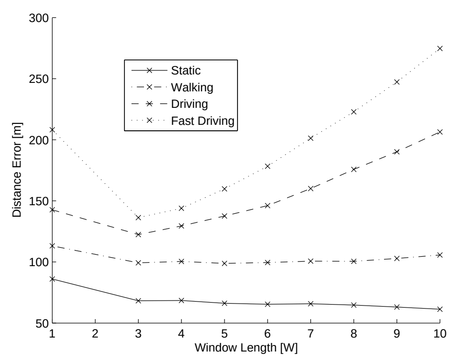
concept of pre-filtering is illustrated during *idle mode*, proving that significant improvement is feasible.

A. SW Pre-filter

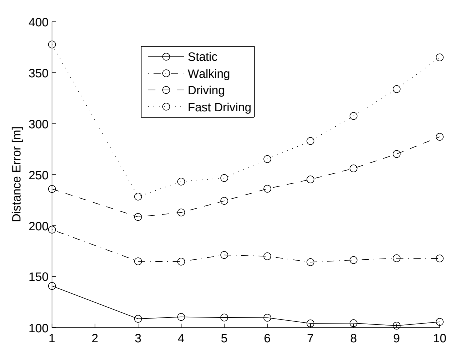
Each vector S in $STAMPList$ consists of the RSS values from all seven cells. Applying a rectangular Sliding Window (SW), the output of averaging pre-filter is given as:

$$\widetilde{S}_n = \frac{1}{W} \sum_{i=n-W+1}^{n} S_i$$

where W is the length of the window. Figure 7 shows the effectiveness of this pre-filtering scheme on the accuracy of the final position estimations for different values of W. For small values of W the shadowing component is not filtered out completely and significant error is still introduced in the final position estimations; however, as W is increased averaging is performed over a larger time frame and differences in RSS values due to the MS motion are masked, leading to higher error estimations especially when moving fast. A solution to this problem could be the use of an averaging filter bank [11], each with small length W. Simulations show that there is a 12% - 29% (11% - 26%) improvement on STAMP accuracy considering the 67^{th} (95^{th}) percentile depending on the mobility scenario, by selecting the appropriate value of W.

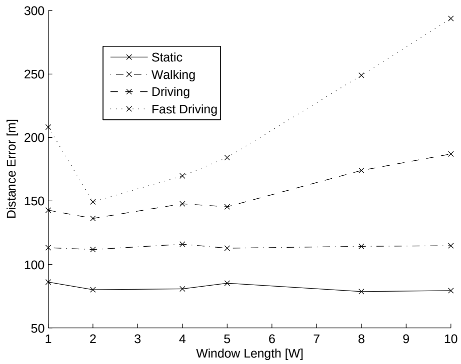


(a) 67% cdf

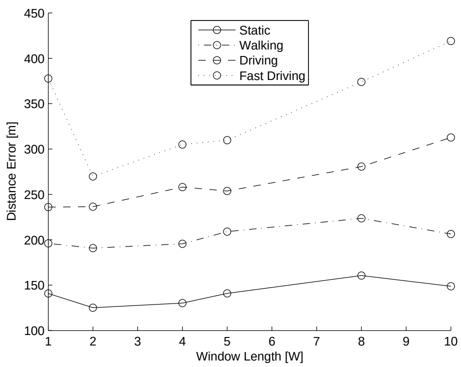


(b) 95% cdf

Fig. 7: Effectiveness of Sliding Window pre-filter.

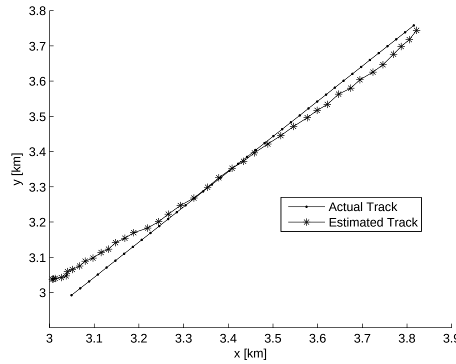


(a) 67% cdf

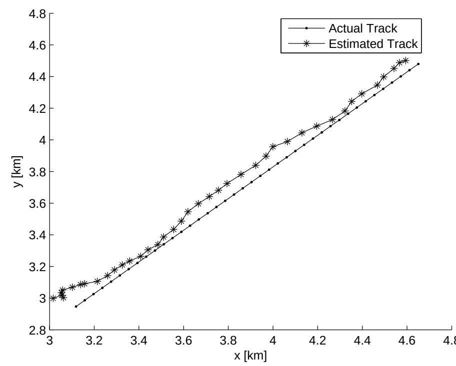


(b) 95% cdf

Fig. 8: Effectiveness of Moving Average pre-filter.



(a) Driving speed 20km/h



(b) Driving speed 40km/h

Fig. 9: STAMP estimated track in driving scenarios.

B. *MA Pre-filter*

Another possible pre-filter is the Moving Average (MA) which could be preferable in terms of lower storing requirements and less time for uploading the pre-processed samples, if pre-filtering is performed on the MS side. Applying an MA Window, the output of averaging pre-filter is given as:

$$\widetilde{S}_n = \frac{1}{W} \sum_{i=nW-W+1}^{nW} S_i$$

where W is the length of the window. Thus, vectors in the $STAMPList$ are reduced to N/W. Figure 8 shows the effectiveness of MA pre-filtering on the accuracy of the final position estimation for different values of W. It is observed that the MA scheme retains the effectiveness of STAMP only for small values of W when the MS is assumed to be static. Based on simulations, selecting $W = 2$ leads to a 2%-7% (2%-11%) improvement considering the 67^{th} (95^{th}) percentile depending on the mobility scenario. This is due to the fact that MA pre-filter reduces the number of vectors employed in the smoothing step with the aid of Kalman Filter. For larger W STAMP fails to keep track of the MS dynamics even when walking speed is considered. MA pre-filter does not require high processing capabilities from the MS and is suitable in cases where the uploading overhead and consequently the system response time need to be the lowest possible.

V. TRACKING AND SPEED ESTIMATION CAPABILITIES

Figure 9 depicts the tracking capabilities of STAMP, in two driving scenarios. The estimated track is formed by connecting the estimated MS location coordinates with straight lines. At 20km/h speed the mean positioning error during MS tracking is 106m ($\sigma_p = 41m$), while at 40km/h it is 183m ($\sigma_p = 104m$). MS speed estimation at the final position has a mean value of 21km/h ($\sigma_v = 4km/h$) and 42km/h ($\sigma_v = 5km/h$), respectively. STAMP provides acceptable tracking accuracy, which makes it applicable on LBS that require tracking capabilities.

VI. CONCLUSIONS - FUTURE WORK

STAMP is a powerful and robust position estimation method that exploits RSS measurements collected by terminals during idle mode, as part of their standard functionality. The current paper presented the simulation results obtained from the application of STAMP in the CGI++ positioning technique for a GSM network. Several mobility scenarios for the MS were taken into account. Two pre-filtering techniques that improve the efficiency of the method were also introduced. Additional improvement is feasible if shorter sampling periods are selected and/or measurements from more BTSs are employed in the positioning algorithm. The deployment of the proposed technique requires only additional software at the terminal and network side and therefore the initial investment on behalf of network operators is considered reasonable. The $TimeStamp$ parameter was included in a Change Request for the Secure User Plane Location Protocol (SUPL) submitted to Open Mobile Alliance (OMA) [12] and was accepted. Time-stamping of RSS measurements will be standardized, supporting in that way easier deployment of STAMP method.

Future work includes using actual field measurements in order to prove the efficiency of STAMP in real life conditions. The applicability of STAMP concept in a B3G network environment is another challenging research issue. Next steps involve employment of various propagation models and investigation on how (and if) measurements from various access technologies (GSM, UMTS, WLAN) can be combined in order to improve the estimated accuracy.

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