4th URSI AT-RASC, Gran Canaria, 19-24 May 2024

Experimental Analysis of 5G-NR Based Positioning in Outdoor and Indoor Environments

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Abstract

In this paper, an experimental analysis of the localization accuracy in a 5G-NR network operating in various urban environments is presented. Measurements of 5G-NR downlink signals were performed in several environments to investigate the user terminal localization process. The main goal is to analyze the differences in the estimated positions accuracy in three different environments, i.e., outdoor, light-indoor and deep-indoor, when the terminal uses signals from the same gNodeBs and is in the same test area. Results show that the localization accuracy may degrade by 146 m to 273 m when the localization process is performed just by moving the terminal from outside a building to its inside.

1. Introduction

Localization services are nowadays one of the most demanded ones in the set of additional services in radiocommunication networks. Knowledge about the position of a user terminal, the UE (User Equipment), may be crucial, e.g., for providing a non-telecommunications service tailored to the user's needs. Moreover, in 5G-NR networks it has been assumed that the estimated position of the UE is used to adjust parameters of the radio interface, which will help, among others, in minimizing radio interferences.

The growth of 5G-NR standalone (SA) networks, enabling private ones, gives a flexible possibility to carry out experiments representing realistic scenarios. In works related to the problem of estimating the UE position various environments and use cases are widely analyzed. Nevertheless, there is still the need to investigate localization performance not only via simulation studies but also by measurements carried out in actual propagation environments, with a noticeable influence of the radio channel. In some works, the authors investigate the ability of UE localization using only one base station (gNodeB), which involves a complex analysis of the channel impulse response, being sensitive to changes in the environment state and multipath propagation. As a consequence, in most cases it is assumed that the UE will detect dedicated positional signals from at least three gNodeBs to perform a two-dimensional localization [1-4].

In this paper, results from trials of 5G-NR based positioning in various urban environments (outdoor, light-indoor and deep-indoor) are presented. In Section 2, the general principle of UE localization in a 5G-NR network is described, and in Section 3 the methodology used for measurements and obtaining location is presented. Section 4 addresses the analysis of results, and conclusions are drawn in Section 5.

2. Localization in the 5G Network

UE position estimation in cellular networks can be realized by using dedicated positioning signals, e.g., the PRS (Position Reference Signal) proposed for 4G-LTE networks, as well as in a modified form for 5G-NR ones.

Currently, in the majority of commercial 5G-NR networks PRS signals are not transmitted due to business reasons, which can be also observed in 4G-LTE ones [5,6]. This eliminates the possibility of estimating the position of a UE with the accuracy assumed in the standard in various use cases. Nevertheless, in the DL (Downlink) of the 5G-NR radio interface other signals are available that can be processed by the terminal as signals of opportunity. In this paper, the authors assumed the use of PSS (Primary Synchronization Signal) to estimate the position of the UE, which is a signal that is periodically transmitted in DL radio frames, configured by the network operator. The PSS is transmitted in coexistence with SSS (Secondary Synchronization Signal) and PBCH (Physical Broadcast Channel) resource elements in the form of an SS/PBCH block. Its bandwidth is higher and transmission time shorter with respect to the PSS in the 4G-LTE radio interface, thus, it can increase localization accuracy, but also reduce the signal detection probability with respect to a 4G-LTE network [5,6].

3. The Methodology of Experimental Studies

In this section, the designed and used testbed is described, as well as the methodology used for analyzing the user terminal position estimation accuracy.

3.1 The Measurement Testbed

In order to obtain the localization of a UE involving signals from a commercial network, a flexible testbed was designed and used. An SDR (Software Defined Radio) platform, based on the USRP (Universal Software Radio Peripheral) X310 [7], along with a PC-class computer was used to obtain samples of the radio signals, and further process them using the developed software. The signal was sampled at 30.72 MHz, i.e., four times higher than the required minimum to analyze the 5G-NR synchronization block. The block diagram of the testbed is presented in Figure 1.

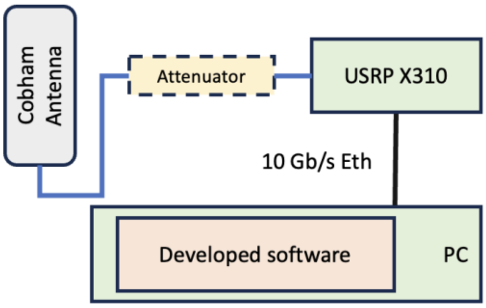

Figure 1. Block diagram of the testbed used for 5G-NR signal registration.

The omnidirectional Cobham AO2-0.3-10.0V/1667 [8] antenna was used, with low-loss Huber-Suhner Sucoflex [9] cables. In the outdoor scenario, an attenuator was used, due to the high level of the signal resulting from the very close proximity of eNodeBs. The carrier frequency of the 5G-NR channel was 2.59455 GHz, corresponding to the current deployment in Poland of the 5G-NR standalone commercial network (with a 50 MHz bandwidth). Before the actual registration of signals, care was taken in identifying the frequency where the synchronization block was located, to record only the relevant part of the system bandwidth, and in checking that PRS signals were not transmitted [5,6].

The 5G-NR DL signal was recorded stationary in three locations corresponding to different types of environments, as typical localization of users, i.e., outdoor, light-indoor and deep-indoor. The metrics taken for differentiating these environments were the ratio between the LoS (Line-of-Sight) and the NLoS (non-LoS) components of the signal, represented by the Rice K-factor, and the RMS (Root Mean Square) Delay Spread, expressing how much delayed NLoS components exist relative to LoS or low delay NLoS ones [10-12]. The values of these parameters for the measured environments are shown in Table 1.

Table 1. Statistical parameters of the analyzed environments.

Environment	Rice K-factor [dB]	RMS delay spread [ns]
Outdoor	14.0	41.2
Light-Indoor	-0.7	102.6
Deep-Indoor	-13.2	60.5

3.2 Methodology of the User Terminal Localization

The localization of the user terminal was obtained by using the TDOA (Time Difference of Arrival) approach, along with the Foy algorithm [13,14]. The major goal was to investigate the influence of the environment type on the accuracy of position estimation (i.e., not the influence of the measurement location or of the gNodeB geometry). The registered signals from different gNodeBs were processed by adding delaying samples [14]. This operation emulated the location of the UE on the test area with an optimum, triangular gNodeB geometry. Therefore, it was possible to investigate the accuracy of position estimation influenced by non-ideal signal detection caused by the influence of the environment type.

A square test area was emulated, with dimensions of 700×700 m^2, in which 400 test points were placed, with 35 m spacing along the axes. This area was located inside an equilateral triangle created by the gNodeBs deployment. The overview of the test area is presented in Figure 2, where the blue + signs represent the emulated test points and the red ones the UE estimated positions. The gNodeBs are marked with square blue points.

The accuracy of position estimates was evaluated by calculating the RMSE (Root Mean Square Error) between the estimated positions and the reference ones, and by the corresponding standard deviation. Moreover, it was checked for how many test points the Foy algorithm did not converge, or RMSE exceeded 2 000 m, i.e., the percentage of points for which the estimation was not properly achieved.

4. Analysis of Results

The results for the estimation of the user terminal position are presented in Figures 2, 3 and 4, respectively for the outdoor, light-indoor and deep-indoor environments, where the actual position of the reference points is shown together with their estimation. Furthermore, the statistics of RMSE for the three environments are shown in Figure 5, and Table 2 presents the overview of the values for the evaluation metrics.

The outdoor environment is depicted in Figure 2, which shows an almost total superposition of the estimated locations with the reference ones, being the one that presents the best results: the RMSE with a median of 28 m and the 90% percentile of 39 m, together with a standard deviation of 11 m, enables a good use of the approach, since locations are separated 35 m in either vertical or horizontal directions. Moreover, it can be observed that the shape of the test area is maintained, with no significant deformations caused, e.g., by improper detection of the PSS signals, enabling the Foy algorithm to converge in all cases. This is the environment with a strong LoS and a relatively low delay spread.

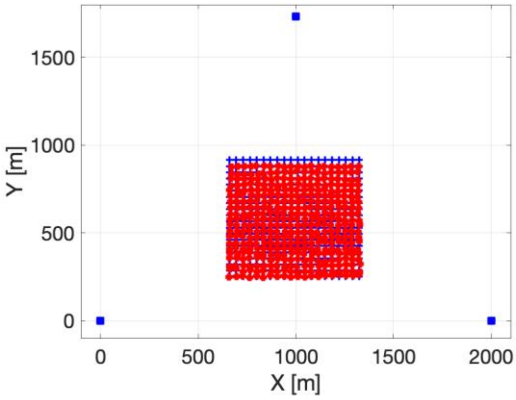

Figure 2. Reference user terminal positions (blue) and their estimates (red) in the outdoor environment.

For the light-indoor environment, Figure 3, a noticeable increase in the position estimation error can be observed. RMSE is 640 m for the 90% percentile and 322 m for median, with a standard deviation of 165 m, which are much higher than the grid resolution of 35 m, hence, not enabling the use of the approach.

The analysis of the calculation process shows that this phenomenon for the light-indoor case is caused by the improper detection of the PSS signal: when the LoS component is not dominant, one of the multipath components is selected as the dominant one during the PSS signal detection, which ends up not being a continuous and uniform process across all positions, hence, the high estimation error and the large variation. The estimated signal detection time is influenced by the propagation delay for this dominant component. In many cases, it causes an alternate selection of different multipath components, which is also observed in the CDF presented in Figure 5. It is worthwhile mentioning that a low delay spread does not cause unrealistic input data for the TDOA method and Foy algorithm; the algorithm converges for a very large percentage of cases. The estimated positions must be further analyzed so that they can be discarded if, e.g., there is large displacement between nearby test points.

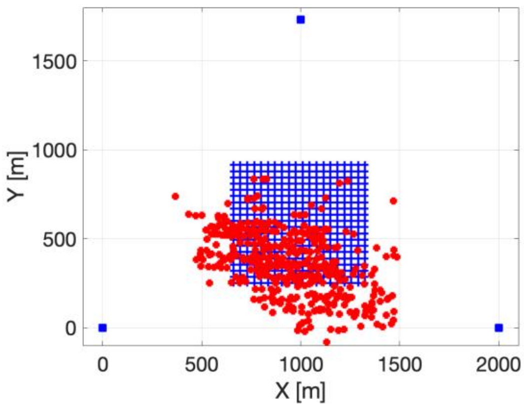

Figure 3. Reference user terminal positions (blue) and their estimates (red) in the light-indoor environment.

The results for the deep-indoor environment are presented in Figure 4, where one can observe intermediate values for RMSE compared to the two previous ones: 342 m and 229 m for the 90% and 50% percentiles, and a standard deviation of 102 m. However, there is a strong increase in the number of test points where the Foy algorithm did not converge, up to almost 33%. The main cause for these results is the additional propagation loss observed in this environment, since all signal components were in NLoS, which significantly disturbs the PSS signal detection [14]. Nevertheless, most of the multipath components were attenuated, which eliminates the problem of detecting reflected signals as the dominant ones (as in the light-indoor case). Still, a significant influence of the propagation delay can be observed.

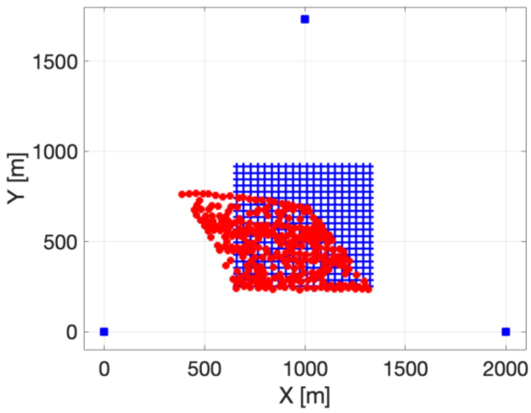

Figure 4. Reference user terminal positions (blue) and their estimates (red) in the deep-indoor environment.

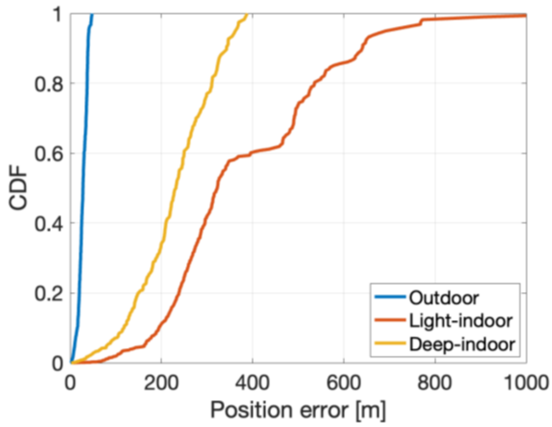

Figure 5. Cumulative distribution functions of RMSE for the three environments.

Table 2. Statistical parameters for the position estimation in the three environments.

Scenario / Environment	**Mean RMSE [m]**	**Standard deviation [m]**	**Missed estimations [%]**
Outdoor	22	11	0
Light-indoor	295	165	< 2
Deep-indoor	168	102	< 33

The shape of the CDF in Figure 5 for the three environments clearly shows the difference among them, and the problem arising for light-indoor.

5. Conclusions

In this paper, an experimental analysis of the localization accuracy in a 5G-NR network operating in various urban environments is presented. Measurements of 5G-NR downlink PSS signals were performed in three different environments (outdoor, light-indoor and deep-indoor) from a commercial standalone network in an urban area to investigate the user terminal localization process.

The presented results show that even if the user changes its position within a range up to 30 m, getting into the building, the localization conditions and achieved position estimation accuracy vary significantly. The environmental change causes a significant degradation of position estimation accuracy, from 146 m to 273 m of RMSE difference between the outdoor to light-indoor and deep-indoor environments respectively. This may result in an unrealistic relocation of the user on the test area, i.e., to a different, nearby building.

In future work, the authors will propose a method for extending the DL signal detection process to increase the accuracy of position estimation by compensating the negative influence of the multipath radio channel.

6. Acknowledgements

Financial support of these studies from Gdansk University of Technology by the DEC-03/2023/IDUB/II.1/AMERICIUM grant under the AMERICIUM - 'Excellence Initiative - Research University' program is gratefully acknowledged.

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