OPTIMIZING CELLULAR WIRELESS NETWORKS WITH HYPERBOLIC COMPENSATION TECHNIQUES

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ABSTRACT

Being applicable for almost every scenario, a mobile localization of the cellular network has gained increasing interest in recent years. Since Received Signal Strength (RSS) information is available in all mobile phones, RSS-based techniques have become the preferred method for a localization of Global System for Mobile (GSM) communications. We use a COST 231-Hata propagation model with directional and omnidirectional antennas to determine a position of the target. To compare the performance of accurate mobile location, we consider both a classical hyperbolic technique, based on time difference of arrival (TDOA) using metric RSS measurements extracted from at least four base stations, and a hyperbolic compensation technique (HCT). The simulation results show that the HCT has a better and stable positioning performance on cellular networks. In addition, the frequency dependence of a surface localization is also studied.

KEYWORDS: Hyperbolic technique, Cellular network, COST 231–Hata, HCT, Received signal strength.

1. INTRODUCTION

In wireless communication systems or cellular networks, the location service is predicted as an important value which must be provided in near future [1-3]. Mobile stations that have global positioning system (GPS) component can generally provide accurate location information under good environmental conditions. But in current market, most of the mobile stations do not have GPS receiver because of cost reduction. Furthermore, GPS has poor positioning performance and even cannot work in urban or indoor areas.

The wireless geolocation is an operation that measures the radio signal traveling between a mobile station and a set of fixed stations. Such a schematic setting can also be adopted to a smaller volume, for example, ad hoc wireless sensor network. On a two-dimensional plane, the line of sight (LOS) distances between a mobile and at least three participating base stations can be used to locate the mobile terminal [4, 5].

Different wireless networks can benefit from location information such as cellular networks [6] and wireless sensor networks [6, 7]. Due to expanding demand and applications of wireless geolocation such as location-based services, wireless emergency services [6], intelligent transportation systems, and military applications [6, 9], the wireless geolocation has received considerable attention over the past two decades. This continuous growth and reliance on wireless geolocation will make the fifth-generation (5G) networks the first generation to benefit from location information that is sufficiently precised to be leveraged in its design and optimization at the various network layers [8, 9].

Cellular location technologies, which are designed to estimate the position of a mobile station or user equipment, have received much of attention over the past few decades. The quality of service of positioning accuracy of such systems has been driven by the requirements on subscriber safety service and the continuously growing interest in location-based services applications [6]. In this article, we only concentrate on a feasible and simple mobile stations location method by exploiting previously available resources or location measurements in cellular networks. Generally, mobile stations location methods are based on measurement technologies like time of arrival (TOA), time difference of arrival (TDOA), angle of arrival (AOA) or received signal strength. [1, 10]. The measurements can be acquired from base station or mobile stations, regardless of 2G (IS95, GSM), 3G (CDMA EVDO, WCDMA) or 4G (LTE) technologies.

The main purpose of this paper is to improve the precision of the hyperbolic technique using metric RSS based on an existing network. We use a hyperbolic compensation technique and determine the mobile position location estimation on cellular networks by employing the COST 231-Hata propagation model in GSM with directional and omnidirectional antennas.

The remainder of this paper is organized as follows. In Section 2, we describe the problem. COST 231 -Hata propagation model is described in Section 3. Classical hyperbolic technique and the proposed hyperbolic compensation technique are presented in section 4.Section 5 presents a discussion of the simulations. Finally, we present our conclusion in Section 6.

2. PROBLEM DESCRIPTION

The determination of a target position in the urban environments is an important problem especially when the used parameter is the received power of the signal. The complexity of this parameter, which is also related to the environmental conditions, is how best to minimize the losses. These losses are generally caused by the phenomena such as the diffraction, reflection, and scattering. Figure 1 presents a case of diffraction. In this situation, we can see that the expression of the separation distance between the transmitter and the receiver would generate enormous errors based on the empirical model. This is why in radiolocation we always find the expression of a propagation channel model which takes into account all environmental risks. Therefore, we use a COST 231-Hata model in order to test various types of antennas and carry out a static radiolocation in a reliable way with a hyperbolic technique.

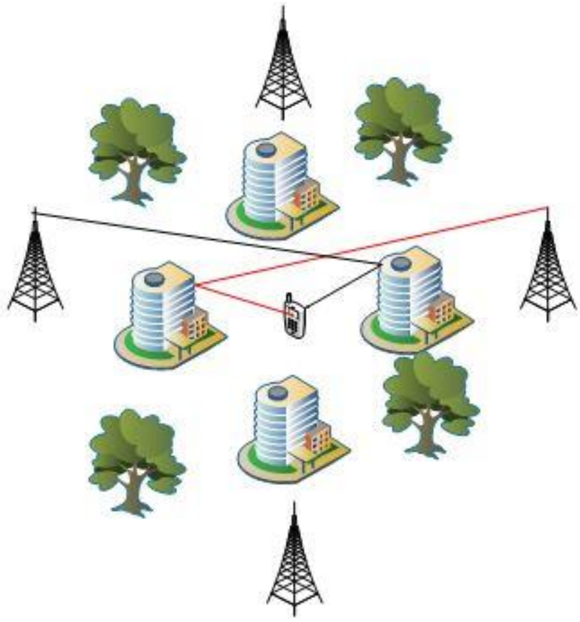

Figure 1: Problem Description.

3. COST 231–HATA PROPAGATION MODEL

The COST 231-Hata model is a widely used in the radio propagation as shown in Fig. 2. This model was established in Europe for coverage prediction across various European terrains. COST is an acronym for European Cooperative for Scientific and Technical research. The COST 231-Hata model is an extension of the Okumura-Hata model and covers a wider range of frequencies. Moreover, its simplicity and availability of correction factors make it applicable to urban, suburban, and rural areas [11]. This empirical model is designed to be used in the frequency range of 1500 MHz to 2000 MHz, where the loss of way is negligible. The COST-231 model is an improved version of the Hata model which is restricted to the following range of parameters [12]:the carrier frequency f_c=1500 - 2000 MHz, the base station antenna height h_b =30 - 200 m, the transmission distance d=1 - 20 km ,and the mobile antenna height h_m=1 - 10 m.

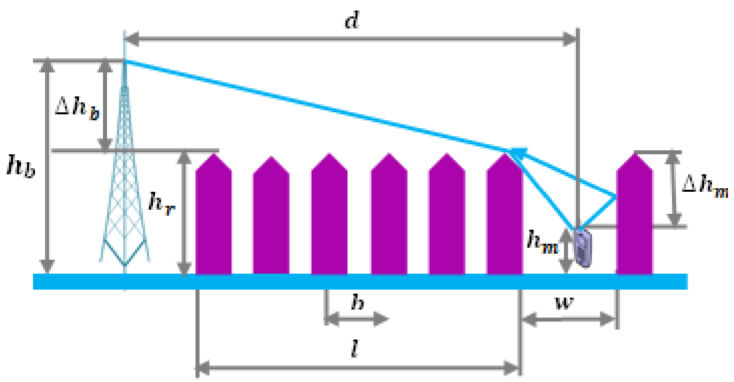

Figure 2: Geometry of the Cost 231 – Hata radio propagation model.

The mathematical formulation of the path loss, L_P, according to the COST 231-Hata model is expressed as [13-14]:

$$L_P = A + B\,log_{10}(d) + C,$$

where $A = 46.3 + 33.9\,log_{10}(f_c) - 13.28\,log_{10}(h_b) - a(h_m)$ with a correction factor for the mobile station $a(h_m) = [1.1\,log_{10}(f_c) - 0.7]h_m - [1.56\,log_{10}(f_c) - 0.8]$, and $B = (44.9 - 6.55\,log_{10}(h_b))$, $C = 0$ for medium city and suburban areas and $C = 3$ for metropolitan centers.

4. HYPERBOLIC TECHNIQUE

4.1 Classical hyperbolic technique

Figure 3 presents the geometry of the hyperbolic technique. This technique in radiolocation often uses the TDOA as a parameter for estimating the target coordinates [15-17]. It stipulates that by knowing the TDOA of a signal, it is possible to obtain a separation distance between the transmitter and the receiver. This distance represents the focal distance and the foci of the hyperbolas which are the receivers. The targeted zone is the surface delimited by the intersection of the hyperbolas. The use of the RSS in the hyperbolic technique is based on probabilistic assumptions which allow the results of the technique to improve. This probabilistic approach consists in giving a rate of the reception signal describing the distribution of the power of the received signal [18].

The idea of the traditional hyperbolic technique is to estimate the minimal and maximum distances compared to a reader i according to the confidence interval which allows us to obtain an interval of the power of transmission. To express them, we use the path losses formula of COST-Hata. It is defined as follows:

$$\boldsymbol{R_i = R_{0i} * 10^{\frac{P_{tm}-P_{Ri}+G_{tm}+G_{Ri}+L_P}{44.9-6.55*\log_{10}(h_b)}}}, \tag{1}$$

where R_{0i} is the distance reference, P_{tm} is the power of transmission, P_{Ri} is the received power, G_{tm} is the gain of the transmitting antenna, G_{Ri} is the gain of the receiving antenna, L_P is the whole losses.

To obtain the distances min (R_i^-) and max (R_i^+), we must vary $P_{tm} = [P_{tm}^-; P_{tm}^+]$. We thus have: $\boldsymbol{R_i^- = R_{0i} * 10^{\frac{P_{tm}^- -P_{Ri}+G_{tm}+G_{Ri}+L_P}{44.9-6.55*\log_{10}(h_b)}}}$ and $\boldsymbol{R_i^+ = R_{0i} * 10^{\frac{P_{tm}^+ -P_{Ri}+G_{tm}+G_{Ri}+L_P}{44.9-6.55*\log_{10}(h_b)}}}$. Then, we evaluate the range of variance ($\Delta R_{i,j}^-$ and $\Delta R_{i,j}^+$) of the distances between a pair of readers i and j limited by the minimum and maximum data values by:

$$\Delta R_{i,j}^- = R_i^- - R_j^- \text{ and } \Delta R_{i,j}^+ = R_i^+ - R_j^+. \tag{2}$$

By combining a pair of readers, we estimate the difference in distance between these two readers. Then, we build the hyperbolas limited by the minimum and maximum values given above. Hence, we obtain an equation of a pair of hyperbolas $H_{i,j}^-$ and $H_{i,j}^+$ which represent, respectively, the lower and higher limit. This makes the targeted surface to restrict as

$$\Delta R_{i,j}^- \le \sqrt{(x-x_i)^2+(y-y_i)^2} + \sqrt{(x-x_j)^2+(y-y_j)^2} \le \Delta R_{i,j}^+\,, \tag{3}$$

where x and y are the coordinates of the sought target, $x_{i,j}$and $y_{i,j}$ are the coordinates of the receivers forming a pair of hyperbolas.

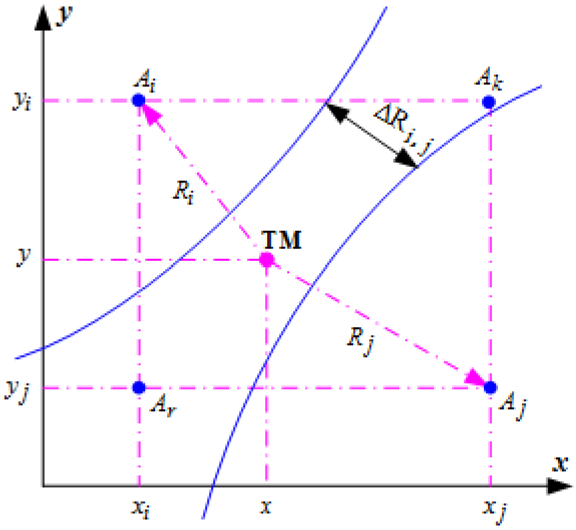

Figure 3: Geometry of the traditional hyperbolic technique.

4.2 Hyperbolic compensation technique

The proposed hyperbolic compensation technique has the same assumptions as that of the traditional hyperbolic technique. However, it utilizes a factor of adjustment which is the distance of the receivers forming a pair of hyperboles. In this case, we do not vary either the transmission power of the target or the height of the transmitting antenna. The hyperbolic compensation technique is carried out in two stages:

Step1. Calculation of the adjustment factor $k$which is a ratio of the receiver's distances.

This adjustment factor is a ratio of the receiver's distances forming a pair of hyperbolas. It is calculated from the type of the reception antenna such as directional or omnidirectional ones. In the case where the reception antenna is directional and the transmitting one is omnidirectional, the reception antenna receives a signal emitted by the target in a precise direction. The advantage of such an antenna in radiolocation is that it has the capacity to collect a transmitter in the direction of radiation even if the severe conditions of propagation exist.

We note here that, in a mobile network, the assessment of connection is a function of the ray of cover of the network. According to the formula for the assessment of connection, we can write the distance between the transmitter and the receiver:

$$\boldsymbol{R_i} = \boldsymbol{R_{0i}} * \boldsymbol{10}^{\frac{P_{tm}-P_{Ri}+G_{tm}+G_{Ri}+L_P}{44.9-6.55*\log_{10}(h_b)}} \text{ and } \boldsymbol{R_j} = \boldsymbol{R_{0j}} * \boldsymbol{10}^{\frac{P_{tm}-P_{Rj}+G_{tm}+G_{Rj}+L_P}{44.9-6.55*\log_{10}(h_b)}}. \quad (4)$$

We assume that the receivers are identical and are subjected to the same environmental conditions. Defining $k = \frac{R_i}{R_j}$, we obtain:

$$k = 10^{\left(\frac{P_{tm}-P_{Ri}+G_{tm}+G_{Ri}+L_P}{44.9-6.55*\log_{10}(h_b)}\right)-\left(\frac{P_{tm}-P_{Rj}+G_{tm}+G_{Rj}+L_P}{44.9-6.55*\log_{10}(h_b)}\right)} = 10^{\frac{P_{Rj}-P_{Ri}}{44.9-6.55*\log_{10}(h_b)}}. \quad (5)$$

In the case of omnidirectional receiver and transmitting antennas, we use the algorithm of compensation of the received power. We assume that the transmitter and the receiver are identical, and two receivers i and$j$ receive the powers of the signal, P_{Ri} and P_{Rj}, emitted by the target, respectively [4]. Then we have:

$$\{44.9 - 6.55\log_{10}(h_b)\}\log_{10}\left(\frac{R_i}{R_{0i}}\right) + 10\log_{10}(P_{Ri}) = \{44.9 - 6.55\log_{10}(h_b)\}\log_{10}\left(\frac{R_j}{R_{0j}}\right) + 10\log_{10}(P_{Rj}). \quad (6)$$

By simplifying Eq. (6), we obtain:

$$\frac{R_i}{R_j} = \left(\frac{P_{Rj}}{P_{Ri}}\right)^{\frac{10}{(44.9-6.55*\log_{10}(h_b))}}.$$

Therefore, Eq. (5) becomes: $k = \left(\frac{P_{Rj}}{P_{Ri}}\right)^{\frac{10}{(44.9-6.55*\log_{10}(h_b))}}$.

Step 2. Calculation of the distance difference in the transmitter-receiver of the pair.
$\Delta R^{-}_{i,j}$ and $\Delta R^{+}_{i,j}$ can be writtenfrom Eq. (2) as:

$$\Delta R^{-}_{i,j} = R_i - R_j \text{ and } \Delta R^{+}_{i,j} = R_j - R_i. \quad (7)$$

By inserting $R_i = k * R_j$, using an adjustment factor $k = \frac{R_i}{R_j}$, into Eq. (7), we obtain:

$$\Delta R^{-}_{i,j} = R_j(k-1) \text{and } \ \Delta R^{+}_{i,j} = R_j(1-k). \quad (8)$$

Then, Eq. (3) can be expressed as:

$$R_j(k-1) \leq \sqrt{(x-x_i)^2+(y-y_i)^2} + \sqrt{(x-x_j)^2+(y-y_j)^2} \leq R_j(1-k), \quad (9)$$

This algorithm allows us to generalize an estimation of the distance between transmitter and receiver, regardless of the path loss model which is related to the channel and the type of antennas in the static radiolocation.

5. RESULTS AND DISCUSSION

The use of metric RSS in radiolocation assumes that the effective isotropic radiated power (EIRP) of the transmitter is known and that the receiver is able to measure the power of the received signal with an adequate precision. Knowing that the power of the signal attenuates proportionally at the distance covered, it is best to use the model of propagation which gives the behaviour of the signal propagation in the medium of localization. This deduces the distance covered between the transmitter and the receiver with a certain degree of confidence. An accurate measurement of the RSS is crucial when the estimation of the position is based on a geometrical interpolation, jointly with a model of propagation, to find the distance. In this case, the value of the RSS constitutes a single indicator on the distance, where it provides the relation between the accurate measurement of RSS and that of the estimated distance.

In this calculation, we used four receivers of GSM, A_1, A_2, A_3, and A_4which have the following Cartesian coordinates (5, 5), (10, 5), (5, 10) and (10, 10) in unit of km, respectively. These receivers are directional and omnidirectional antennas and have a gain of directivity of 10 dB and a height of 68 m. Two cases for the target, which have an omnidirectional antenna of power 20 dB and 42.3 dB, are considered. The height of the target is 3 m and the frequencies used here are:915 MHz, 1800 MHz and 2100 MHz. The urban environment in our simulations is considered.

Figure 4 presents the results of the localization using the traditional hyperbolic technique. This shows that a surface localization increases about 1.6832 km^2.On the other hand, Fig. 5 shows that the HCT allows the surface of localization to reduce up to 1.2363 km^2, which corresponds to a 95.05% reduction. This clearly indicates that the HCT in urban environment is more effective than the traditional hyperbolic technique. Simulations also showed that the HCT using the RSS gives a better result for estimating a parameter of target coordinates than the traditional technique using the TDOA. However, we must emphasize that the formation of a pair of hyperbolas requires a larger numerator than the denominator in the adjustment factor, k. Nevertheless, it is worth to note that the COST 231-Hata model is more favourable in radiolocation than the empirical model worked out by FRIIS.

Finally, we study the frequency dependence of a surface localization. The surface areas with directional antenna are calculated for three different frequencies in Table 1, in which the localized surface area increases as the frequency increases. We note that, regardless of the frequency values, the area of the localized surface using HCT is smaller than the one obtained from the traditional hyperbolic technique. This clearly indicates that the HCT is robust for the variation of the frequency and has a better positioning performance than a classical hyperbolic technique. However, the surface area with omnidirectional antenna is reduced as the frequency increases, shown in Table 2.

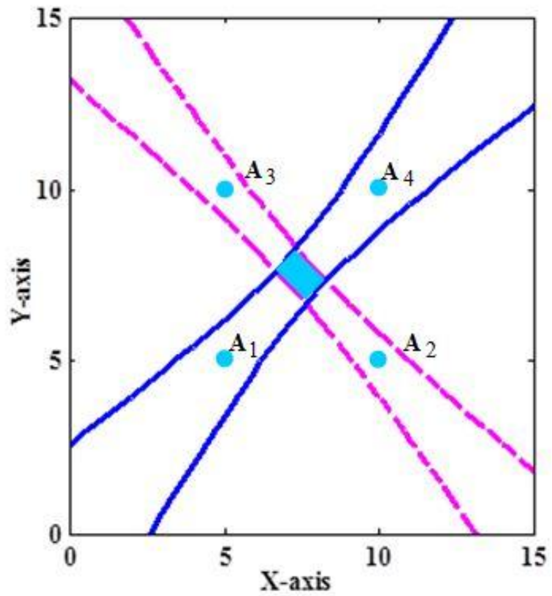

Figure 4: Classical hyperbolic technique using directional antenna with $f = 915\ MHz$.

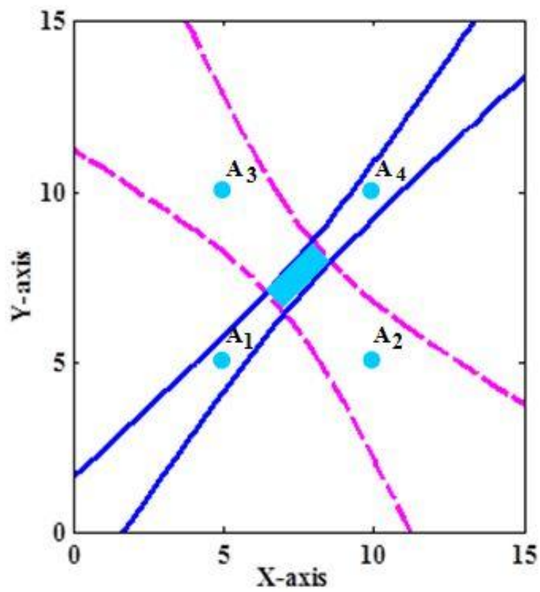

Figure 5: Hyperbolic compensation technique using directional antenna with $f = 915\ MHz$.

Table 1. Frequency dependence on surface area withdirectional antenna

Frequencies (MHz)	**915**	**1800**	**2100**
Surface (km^2)	1.2363	1.3277	1.3674

Table 2. Frequency dependence on surface area withomnidirectional antenna

Frequencies (MHz)	**915**	**1800**	**2100**
Surface (m^2)	4476.06	4219.5	4104.1

6. CONCLUSION

In summary, we have applied a hyperbolic compensation technique to estimate the mobile position location on cellular networks using the COST 231-Hata propagation model. It is shown that this technique has a better and stable positioning performance than a classical hyperbolic technique in urban environment. In addition, the frequency dependence of a surface localization is investigated using the HCT. The localized surface area with directional antenna increases as the frequency increases. On the other hand, the surface area with omnidirectional antenna is more localized with an increase of the frequency. Finally, we note that the proposed technique can be used regardless of the propagation model. The future research will consist of an experimental study of the two metric TDOA and RSS by applying the proposed algorithm in order to validate our numerical data.

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